UNIVERSITY FOR DEVELOPMENT STUDIES

FACULTY OF AGRICULTURE

DEPARTMENT OF AGRONOMY

RESPONSE OF ONION (*Allium cepa* L.) CULTIVARS TO SPACING AND STORABILITY IN THE SUDAN SAVANNAH AGRO-ECOLOGICAL ZONE OF GHANA

BY

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(UDS/MCS/0012/14)

THESIS SUBMITTED TO THE UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

2016

DECLARATION

I, Abugri Razak Abangiba hereby declare that apart from references to other people's work which have been duly cited, this thesis is the result of my own research under the supervision of Dr. Isaac K. Addai and Dr. Benjamin K. Badii. I also declare that the work has never in whole or part been submitted for another degree elsewhere.

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ACKNOWLEDGEMENTS

I express my profound gratitude to the Almighty ALLAH, for the power and knowledge he has provided me to make this research project possible. My sincere gratitude goes to my supervisors, Dr. Isaac K. Addai and Dr. Benjamin K. Badii for their guidance and constructive criticisms towards the successful completion of this work. May Almighty ALLAH bless them in all their endeavors. I am also very grateful to my entire family for their support.

I would like to express my appreciation and thanks to my friends, Abugri Amadu, Anane Sadique, Zakaria Mohammed and Gali Nuru Mohammed for their help.

I am thankful to all my brothers, Awini Isaac Nderago, Abugri Atirago Listowel, Issifu Tanimu and Issifu Awal for their special assistance.

I am very grateful to my uncles, Mr. Abanga Joeseph and Mr. Abanga Shaiba for their help. The project work would not have been possible without their support.

Finally, my deepest gratitude goes to my family for their prayers, support and encouragement.

DEDICATION

I dedicate this research to my uncles, brothers, cousins and friends, for their patience and support throughout this project work.

TITLE **TABLE OF CONTENTS** **PAGE**

LIST OF TABLES

Table **Title** **Page**

LIST OF FIGURES

Figure **Title** **Page**

LIST OF PLATES

Plate **Title** **Page**

LIST OF APPENDICES

LIST OF ACRONYMS

WAT: Weeks after transplanting

DAT: Days after transplanting

SARI: Savannah Agriculture Research Institute

CSIR: Council for Scientific and Industrial Research Institute

MoFA: Ministry of Food and Agriculture

NPK: Nitrogen Phosphorus Potassium

GMT: Greenwich Mean Time

CRD: Completely Randomized Design

RCBD: Randomized Complete Block Design

AR: Ares

BR: Bawku Red

RC: Red Creole

TH: Top-Harvest

pH: Potential of hydrogen

DAH: Days after harvest

GSS: Ghana Statistical Service

ABSTRACT

Low yield and poor quality of onions produced from the Sudan Savannah Agro-ecological Zone of Ghana among other factors attributed to lack of appropriate cultivars for cultivation, poor knowledge of plant spacing and storability. These factors have the potential of lowering income levels of farmers and wasting of precious agriculture land. Field and storage experiments were conducted at Bawku in the Upper East Region of Ghana from 2015 to 2016 to investigate the response of cultivar and spacing on growth as well as yield and shelf-life of onions. Four cultivars namely; Ares, Bawku Red, Red Creole and Top-Harvest and spacings namely; 8 cm x 10 cm, 10 cm x 10 cm, 12 cm x 10 cm and 14 cm x 10 cm were used for the field studies. Levels of the two factors were factorially combined and replicated three times using Randomized Complete Block Design (RCBD). Results showed that Ares was superior to the other cultivars in terms of bulb yield. The order of superiority among cultivars in terms of bulb yield was as follows: Ares > Red Creole > Top-Harvest > Bawku Red. Plant height, leaf length, leaf number, chlorophyll content, girth of bulb neck, root number per plant, root biomass per plant, average bulb weight, bulb diameter, percentage of bulbs with girth of 10-19 cm and percentage of bulbs with girth ≥ 20 cm increased with increasing plant spacing. However, leaf area index, days to hundred percent bulb initiation, biomass accumulation, days to maturity, total bulb yield and percentage of bulbs with girth < 10 cm increased with decreasing plant spacing. In general the results from the 2015 cropping season were lower in magnitude values as compared to those of the 2016 cropping season. After harvest, bulbs were stored in building with thatch roof and building with corrugated iron sheet roof. Results from the storability showed that the thatch roofed storage structure was superior to the corrugated iron sheet

roofed structure. Bulb rot, bulb sprout, and total bulb weight loss were lower with the thatch roofed structure as compared with the corrugated iron sheet roofed structure. Cultivars such as Ares and Red Creole having large bulbs size recorded the highest losses in terms of rot, sprout, and total bulb weight loss as compared with Top-Harvest and Bawku Red that had smaller onion bulbs. Percentage bulb rot, bulb sprout and total bulb weight loss increased with increasing spacing. Bulbs harvested from 8 cm x 10 cm spacing stored better probably because these were those with high percentage of bulbs of smaller sizes.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Onion (*Allium cepa* L.) belongs to the family *Amaryllidaceae* (*Amaryllis*) or *Liliaceae* and is one of the most important monocotyledonous, cross-pollinated and cool season vegetable crops (Zurihun, 2013). Onion is widely grown as herbaceous biennial vegetable crop. It has diploid chromosomes number (2n=16) (Bassett, 1986). The bulb varies in size (small, medium and large), colour (yellow, white and red), and shape (flattened, round and globular) (Dawar *et al*., 2007).

In Ghana, onion cultivation is mostly carried out in the dry season under irrigation, especially in the northern parts of the country in areas such as Bawku in the Upper East Region. Onions are also cultivated in some parts of southern Ghana such as Ashiaman, Dawhenya, Akatsi, Nsawam, Prestea and Koforidua. The commonest cultivar often grown on large scale in the locality is the Bawku Red but other exotic cultivars such as Red Creole, Top-harvest, Texas Granos, Dramani, Safari and Ares are also grown on small scale.

The usefulness of onion bulbs cannot be over emphasized. Onion is grown as cash crop and serves as livelihood for resource poor farmers in the study area. The crop makes an important contribution to human diet, having vitamins, flavonoids as well as macro and micro elements (Jurgiel *et al*., 2008). Since ancient time, it has been of great economic importance for its medicinal and dietetic values (Mollah *et al*., 2015). According to Raemaekers (2001), onion forms an indispensable part of the human diet and it is a rich source of several minerals and vitamins. As food, onion can be eaten raw, boiled, baked, fried, dried or roasted. It is commonly used in salads, soups, spreads, curries and other dishes (Chaudhary, 1979). It has been reported that onion extract can be a potent cardiovascular and anticancer agent with hypocholesterolemia thrombolytic and antioxidant effect (Block, 1985). Several antioxidant compounds, mainly polyphenols and sulphur containing compounds have been found in onion (Nuutila *et al*., 2003).

Variations in plant density resulting from spacing have produced diverse results from different experiments according to Vishnu and Parabhaka (1989). These authors obtained higher yield with close spacing (10 x 15 cm) while Bhaitia and Pandy (1991) harvested better yield with wider 45 x 15 cm plant spacing. Increased number of rows/bed that is, decreasing row spacing linearly is known to increase onion yield (Stoffela, 1996). Dawar *et al*. (2007) reported that interaction between plant density and varietal difference was significant only for bulb yield, and that planting density greatly influenced the quality, texture, taste and yield of onion even within a particular variety. In addition, same cultivars grown with different densities in the same environment often responded differently (Dawar *et al*., 2007).

1.2 Problem Statement and Justification

Onion cultivation is the livelihood for most farmers having access to irrigation facilities in the Sudan Savannah Agro-ecological Zone of Ghana. Approximately 15,000 farming families were active in onion production during the year 2010 at Bawku West and Garu Tempane districts (Trias, 2010). Yield and quality of the bulbs in these areas have been low and this has necessitated the research. The low yield and poor quality of onion bulbs in the study area has resulted in mass influx of quality onions from the Sahel regions such as Niger, Nigeria, Mali and Burkina Faso into Ghana. In 1992, Ghana imported 1100 tons of dry onion bulbs (FAO, 1992), and 11,341 tons in 1996 (Vordzorgbe, 1997). Large sums of money are spent each year importing onions into Ghana from other West Africa countries. For instance, about 120 tons/annum of onion was imported from Burkina Faso (MoFA/PPRSD, 2012). If this trend of event is not checked, it could lay Ghanaian onion farmers off from the farming business.

The low yield and poor quality of onion bulbs produced from the Sudan Savannah Agro-ecological Zone of Ghana could be attributed to a number of factors such as lack of appropriate cultivars for cultivation, poor knowledge of plant spacing and poor storability. Although there have been a lot of work done on spacing of onions, there has not been any significant change in yield. Using inappropriate agronomic practices coupled with the use of local cultivar by farmers may be the core factors causing the low yield of onions in northern Ghana. This has resulted in low income levels of farmers and waste of precious agriculture lands. The erratic nature of rainfall as a result of global warming has compounded the problem by having effect on water bodies and consequently affecting onion production.

1.3 Objectives

The main objective of the study seeks to investigate growth, yield and shelf-life of bulbs of onion in storage as influenced by cultivars and spacings in the Sudan savannah zone of Ghana.

Specific objectives of the study were to determine;

(i) the best onion cultivar among the four with the highest bulb yield and shelf-life at storage in Bawku.

(ii) the best spacing for optimum bulb yield of the cultivars.

(iii) the best storage structure for better bulb quality and shelf life.

(iv) the cultivar that is early maturing.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Taxonomy and systematics of onion

Onion (*Allium cepa* L.) belongs to the family *Amaryllidaceae* (amaryllis) or *Liliaceae* (Zurihun, 2013). The Allium family has over 700 members; each with different tastes, forms and colours; they are close in biochemical, phytochemical, and neutraceutical contents (Tepe *et al.*, 2005). Members belonging to the same family as onion include shallot (*A. cepa* L. *var*. *aggregatum* G. Don.), common garlic (*A. sativum* L.), leek (*A. ampeloprasum* L. *va*r. *porrum* L.) and chive (*A. schoenoprasum* L.) (Griffiths *et al*., 2002). The following hierarchy has been adopted according to Takhtajan (1997); Class *Liliopsida*, Subclass *Liliidae*, Superorder *Liliianae*, Order *Amaryllidales*, Family *Allieae*, Subfamily *Allioideae*, Tribe *Allieae* and Genus *Allium*. Onion is the most common member of the family *Amaryllidaceae* (*Alliaceae*) and the widely grown herbaceous biennial vegetable crop (Bassett, 1986).

Onion has monocotyledonous behavior having diploid chromosomes number (2n=16) (Bassett, 1986). Onion has a bulb, hollow tubular leaves with greenish to whitish flowers. Onions form a single bulb and are mostly grown from seed. The plant is grown for production of green or bulb onions and it is treated as an annual which rarely gets more than 31cm tall (Zurihun, 2013). The bulb varies in size (small, medium and large), colour (yellow, white and red), and shape (flattened, round and globular) (Dawar *et al*., 2007).

2.2 Origin and distribution of onion

Onions originated in Iran and Pakistan and were established staple foods of Egypt and India around 1500 B.C. By the Middle Ages, they were already in Europe and brought to North America by Spanish settlers (Zurihun, 2013). Onion is produced in almost 170 countries of the world and Pakistan has been on the list of the leading onion producers of the world (Nisar *et al*., 2011). China ranks first in the world with respect to onion production followed by India, USA, Turkey, Pakistan, Iran, Indonesia, Vietnam and Myanmar in that order (Kabir, 2007). The *Allium* is widely distributed over the holarctic region from the dry subtropics to the boreal zone. One or two of the species even occur in the subarctic belt and few *Alliums* are scattered in mountains or high lands within the subtropics and the tropics (Fritsch and Friesen, 2002). Onions can be grown on varied topographies of land. They are typically plants of open, sunny, dry sites in fairly arid climates, however, many species are also found in the steppes, dry mountain slopes, rocky or stony open sites, or summer dry, open, scrubby vegetation (Hanelt, 1990).

In West Africa, onion production is concentrated in Nigeria, Niger, Ghana, Burkina Faso and Senegal (Norman, 1992). The crop was introduced into West Africa by the early Europeans (Judith, 2012). Sinnadurai (1992) reported that Bawku Red onion was brought to Ghana from Burkina Faso around 1930, and was first grown at Bugri near Bawku in the Kusasi District of the Upper East Region.

2.3 Economic importance of onion

There are historic evidences of onion and garlic usage as food and medicine. Garlic has been used as both food and medicine in many cultures for thousands of years, dating as far back as the time that the Egyptian pyramids were built (Garcia, 2007). Since ancient time, it has been of great economic importance for its medicinal and dietetic values (Mollah *et al*, 2015).

Although Onion is mainly used as seasoning vegetable, the bulbs make an important contribution to human diet, having vitamins, flavonoids as well as macro and micro elements (Jurgiel and Suchorska, 2008). The unique flavour of onions have made it an excellent food source that provides zest to many dishes (Zurihun, 2013). The numerous ways in which onions are prepared from boiling, frying, stewing, baking and pickling to eating raw make them a versatile food source (Zurihun, 2013). Onion is considered it as an indispensable part of human diet and are commonly used both by rich and poor (Tindal, 1983). It is widely used as a condiment all over Latin America, Africa and Asia (Zurihun, 2013). Nutritionally, onions are low in calories (about 40 calories for an average size onion) and high in ascorbic acid (Jones and Man, 1963). Onion also contains Vitamin B, Vitamin C, carbohydrate and small percentage of proteins (Lemma *et al*., 1994). An average onion consumption is approximately 6.5 kg per capita each year across the world (Nisar *et al*., 2011).

Onion and its relatives in the *Amaryllidaceae* family have long been used by many cultures for the treatment of various ailments, and modern science is beginning to reveal more potential health and medicinal benefits of these plants (Randall *et al.*, 1999). During both World Wars I and II, soldiers were given garlic to prevent gangrene, and today people use garlic to help prevent atherosclerosis and treat ailments such as high blood pressure, colds, coughs, and bronchitis (UMM, 2004). Onions contain a variety of other naturally occurring chemicals known as organosulfur compounds that aid in lowering blood pressure and cholesterol levels (Nisar *et al*., 2011). Hussain (2001) reported that, it is free of fats and cholesterol and contains numerous amount of vitamins and chemicals which help figure the free radicals in human body. It is one of the richest sources of flavonoids in the human diet (Yemane *et al*., 2013). Flavonoid consumption has been associated with a reduced risk of cancer, heart disease and diabetes (Yemane *et al*., 2013). In addition it is known for anti-bacterial, antiviral, anti-allergenic and anti-inflammatory potential. It also contains the vitamins thiamine, riboflavin and niacin (Mettananda and Fordham, 2001).

Generally, onions supply in Ghana do not meet national demand due to their small acreage of production, low yields and seasonal production (Abbey *et al*., 1997). As a result, dry onion bulbs are imported annually, thus reducing its contribution to national earning (Abbey *et al*., 1997). Onion contributes substantially to the national economy apart from overcoming local demand (Geremew *et al*., 2010). In terms of income, onions are the second most important vegetable crop after tomatoes in the world (Griffiths *et al*., 2002; Mallor *et al*., 2011). Among the spice crops, onion ranks second in terms of area coverage (37,560 ha) but attains top in production (153,000 mt) covering about 15 percent of total area under spices and condiments (BBS, 2004).

2.4 Cultivar and spacing requirements for onion

In Ghana, Onion is grown extensively as dry season vegetable crop under irrigation. Among the varieties available in Ghana, Bawku Red is the most popular and is grown extensively throughout the country (Abbey, 1997). Other exotic cultivars such as Texas early Grano, Crystal White Wax, Lisbon White, Yellow Flat, Suttons, Australian Brown, Early Cape and Market Winner have been introduced into the country (Kyofa-Boamah *et al*., 2000; Awuah *et al*., 2009). Cultivars that performed best included Texas Early Grano, Red Creole, Market Winner and Australian Brown and have been maintained to date

(Awuah *et al.*, 2009). The exotic cultivars which have proved useful include Texas Early Grano and Crystal White Wax which do well in the south, and Tropical Bombay Red which does well throughout Ghana (Sinnadurai, 1992). Some other exotic cultivars in the Ghanaian market include Prema, Top Harvest, Safari, Ares, Dramani and Red Passion F1. Cultivars differ in their distinguishing features especially of the foliage (leaf length and leaf erectness); shape of the bulbs (globe, a flattened globe, flat top and cylindrical); the uniformity of the bulb shapes; skin color of the bulbs (white, yellow), nature of inflorescence including its fertility, number of flower in the umbel, the petal and anther color in attracting pollinating insects, the presence or absence of bulbils in the inflorescence and whether an inflorescence is indeed produced or if reproduction is normally vegetative. The above features may be heritable and easily seen with the naked eye although many are subject to environmental variability (Astley *et al.*, 1982). The performance of an onion cultivar depends on the interaction between genotype and the environment (Jilani and Ghaffoor, 2003).

The recommendations on plant density of onion varies (Daniela and Maniutiu, 2011). Onions are grown in the dry season at a seeding rate of 2-3 g seeds/m^2 seedbed, transplanted after 5-7 weeks at a spacing of 30 cm x 15 cm, and finally harvested after 14-18 weeks from time of sowing (Abbey, 1997). Plant density plays an important role in onion production. Plant population is important in onion production since it has an influence on growth, yield and quality of bulbs (Brewster, 1994). Similarly, Dawar *et al*. (2007) reported that interaction between planting densities and variety was significant only for bulb yield and that planting density greatly influenced the quality, texture, taste and yield of onion even within a particular variety.

Spacing has effect on varieties as their root and leaf growth habits differ. Higher yield and better control over bulb size could be obtained if plants are grown at optimum density (Yemane *et al*., 2013). Additionally, total bulb yield increases significantly as population density increases and number of marketable bulbs increases significantly with higher planting density. Pakyurek *et al*. (1994), Rizk (1997) and Dawar *et al*. (2007) observed that the highest sowing rate (planting density) produced a noticeably higher yield of good quality bulbs than the lower sowing rate. Farrag (1995) emphasized that high planting density significantly increased single-bulb, double-bulb and total yields, as well as reducing bulb weight and diameter. Coleo *et al.* (1996) reported that highest commercial bulb yield was recorded at higher planting density, while the highest proportion of large bulbs and average bulb weight were obtained at lower planting density. Similarly, Stoffella (1996) observed that percentage of small and medium-sized bulbs increased and percentage of large bulbs decreased as in-row spacing decreased. The optimum use of spacing or plant population has dual advantages. It avoids strong competition between plants for growth factors such as water, nutrient and light (Geremew *et al*., 2010). In addition, optimum plant population enables efficient use of available crop land without wastage.

Different cultural practices and growing environments are known to influence growth and yield of onion (Yemane *et al*., 2014). Geremew *et al*. (2010) recommended intra row spacing of 4 cm for 'Nasik' Red and 'Adama' Red varieties, and 6 cm for 'Bombay' Red variety, both of which gave highest marketable yield and reduced unmarketable bulb yield in central rift valley areas of Ethiopia. Twenty years ago it was recommended that a distance of 10 cm should be allowed between two consecutive plants (FAO, 1995). Krug *et al*. (1986) recommended a density of up to 150 plants/m^2 for varieties and 80-100 plants/m^2 for hybrids. Recent research conducted for directly sown onions, have shown that by increasing the density of plants harvested at 80-90 plants/m^2, productions can be achieved between 54 t/ha and 80-82 t/ha (Popandron *et al*., 2009). Kanton *et al.* (2003) concluded that varieties as well as planting densities significantly affect onion bulb yield. In addition, number of marketable bulbs increases significantly with higher planting density.

2.5 Onion production areas in Ghana

Generally, onions are grown extensively throughout Ghana with commercial production occurring in the Northern, Upper East and Upper West Regions (Abbey, 1997). In the Upper East region of Ghana, approximately 15,000 farming families were active in onion production in year 2010 at Bawku West and Garu Tempane districts (Trias, 2010). Seed production is concentrated in the Upper Regions of Ghana (Norman, 1992). Onion producing areas in southern Ghana include Sogakokpe and Akatsi in the Volta Region, Ashaiman and Dawhenya in the Greater Accra, Nsawam in the Eastern region and Prestea in the Western Region (Awuah *et al.*, 2009).

2.6 Climatic requirements and ecology of onion

Onions are photoperiod sensitive and are classified as short day, intermediate day or long day varieties, depending upon the day length which will trigger bulb formation (USAID, 2012). The short-day onion varieties form bulbs when the day length is between 10 and 12 hours. Intermediate-day varieties form bulbs at 12 to 14 hour day length and the long-day onions on the other hand begin to form bulbs when the day length is between 14 and 16 hours (USAID, 2012). Onion completes its life cycle from seed to seed in two growing seasons (biennial) whereas seed to bulb takes one growing season (annual). Onions can be grown under a wide range of climatic conditions but are more successful under mild season without extremes of heat or cold and excessive rainfall (Jilani and Ghaffoor, 2003). The seeds will germinate at temperatures as low as 2^{o}C. A temperature of at least 13^{o}C is required for 70 percent seedling emergence within two weeks of planting, whiles the optimum temperature range for germination, emergence, and plant growth is 20^{o}C to 25^{o}C (Ronald *et al*., 2013). The optimum temperature for rapid growth is about 16-20°C (Abbey, 1997). However, tropical varieties grow between temperatures of 22°C and 30°C, with night temperatures not exceeding 22^{o}C for irrigated crops (Messiaen, 1994). Night temperatures below 10^{o}C for a 2-3 week period will induce bolting (seed stalk formation) after 7-10 leaf stage. Little bolting occurs if temperatures are around 21^{o}C. High temperatures during early growth also induce bolting. Light intensity, light quality, and other factors interact with temperature and day length to influence bulbing response whiles excessive nitrogen applications near this time may delay bulbing even if the critical day length period occurs at the right stage of crop growth (Randall *et al.*, 1999).

A region of especially high species diversity stretches from the Mediterranean basin to Central Asia and Pakistan. A second pronounced centre of species diversity occurs in Western North America (Fritsch and Friesen, 2002). Onions exhibit particular diversity in the eastern Mediterranean countries which are most important sources of genetic diversity and are believed to be center of origin of onion (Brewster, 2008). Evolution of the genus has been accompanied by ecological diversification and the majority of species grow in open, sunny and rather dry sites in arid and moderately humid climates. A good array of genetic variation in the crop can be found in the West African sub-region, in countries such as Mali, Burkina Faso, Niger, Nigeria, Chad and Cameroun, which can be harnessed to produce better-quality cultivars for local production (Abbey, 1997). Onion varieties are mainly described on the basis of bulb quality characteristics such as colour, size, shape, neck thickness, dry matter content, splitting tendency, bolting and pungency (Abbey, 1997). Both genetic and environmental influences can determine bulb shape. Genetic variation for onion bulb shape ranges from extremely flat to oblong or torpedo types (Grant and Carter, 1990).

2.7 Production estimates

Onion yields in the northern and southern regions of Ghana are 15-25 t/ha and 5-15 t/ha, respectively (Norman, 1992). While the local Bawku Red onion yields about 7 t/ha (below the average world yield of 12.4 t/ha), yields of 10-20 t/ha of the exotic Early Texas Grano have been obtained in Ghana (NARSP, 1994; Sinnadurai, 1992). In 1995, shallots and onion production in the country was 29,000 tons covering an area of 1,970 ha (Vordzorgbe, 1997). Up to 36 t/ha onion bulb yield has been reported in Botswana (Madisa, 1994) and 25-35 t/ha from improved composite varieties in Nigeria (Denton and Ojeifo, 1990). The variety 'Red Creole' is popularly grown by farmers, both for home use and source of income (Ijioyah *et al*., 2008). Currently, it is the only variety available with an average yield of 22 t/ha (Ado, 2001). This was considered low especially when compared to the yield produced by other varieties grown elsewhere (Lao, 2002).

2.8 Agronomic practices

Onions like any other crop has agronomic and management practices to be observed. Various crop management practices such as mulching, shelters and raised beds help to conserve soil moisture, prevent soil degradation, and protect vegetables from heavy rains, high temperatures, and flooding (Hughes, 2007). The nursery beds should be well tilled to enhance proper seed germination. For good germination in the nursery a well-tilled seed bed with a loose surface is necessary (Sani and Jaliya, 2012). The seed bed should be moist and fowl dropping or compost worked into the seedbed before sowing (Sani and Jaliya, 2012). Drills are created, seeds are evenly spread in the drills and covered with thin layer of soil. The nursery bed is then covered with light mulch. Fields for transplants should have good drainage and excellent soil texture and must be free of roots or clods (Randall *et al.*, 1999). To establish seedlings in a field nursery for 1 acre of bulb onions, one needs to sow 907.18g of seed in a 418.22 m^2 seedbed at a per-acre rate of 9.06-13.59 kg. Earlier seeding may result in transplants that are too large and prone to bolting (forming seed stems) during the onset of rains. Earlier seeding is done for onions destined for salad production and later seeding may result in plants too weak to survive cold (Boyhan, 2002). Onion seeds are nursed by broadcasting or by drilling. Seeds can be broadcast, but they usually are planted in rows 15.24-20.32 cm apart and 0.64-1.91 cm deep at a rate of 60-70 seeds per linear foot (Randall *et al.*, 1999).

Onions produced under irrigated facilities during dry season are transplanted in November and December for dry bulb production. In Ghana, onions may be transplanted up to the end of January and still produce good quality bulbs (Boyhan, 2002). Depending on the time of the year, seedlings will be ready for transplanting 4–10 weeks after sowing, when seedling necks have pencil size diameter (0.25-0.79 cm) and (17.78-30.48 cm) tall, and have three to five leaves (Randall *et al.*, 1999). At nursery the seedlings are often hardened-up for quicker establishment in the field after transplanting. Water supply should be reduced about 7-10 days before transplanting takes place to harden the seedlings (Randall *et al.*, 1999). Water transplanted onions soon establish good contact between the soil and roots, and assure a good stand (Boyhan and Kelley, 2007). Onions can also be planted using the bulbs. The bulb-to-seed method may be preferable, however, bulb quality is more variable in open-pollinated onions, and the bulb-to-seed method allows seed producers to select high-quality bulbs for seed production (Ronald *et al*., 2013). Bulb-to-seed may also be used in hybrid seed production to stagger planting dates and manipulate the flowering times of male and female lines. Sown onion seed must not be allowed to crush during the pre-emergence periods which can last 10-20 days after the initial irrigation. Because they have a shallow root system, onions require frequent irrigation or rainfall throughout the season. Onions extract very little water from depths beyond 60cm of soil (Ronald *et al*., 2013). The peak water demand for onions can be as high as 3.81-5.06 cm per week. Peak water use generally occurs during the latter stages of bulb enlargement especially during periods of warm weather (Boyhan and Kelley, 2008).

The required amount and frequency of irrigation will depend on the irrigation method, soil type and conditions, and weather. Additionally the optimal time for irrigation is when 25% of the available moisture in the 60cm has been depleted (Ronald *et al*., 2013). Also, an onion seed crop will use 65 to 90 cm of water, with 70 to 80 percent efficiency. Water applications of 90 to 115 cm may be required. At an optimal regime of water supply at the increasing plant density from 50-80 plants/m^2 led to production increases of 13.3% in Wolski variety and of 24.0% in the variety Red of Turda (Apahaidean, 1996).

Controlling weeds during onion cultivation is very important as weeds can cause considerable yield loss. Onions are poor weed competitors because of the long period they take to achieve ground cover and because the long growing season permits the emergence of successive flushes of weeds. One or two cycles of hand hoeing are required in many cases to ensure low weed populations (Ronald *et al*., 2013). Cultivation and hand weeding should be done 10 days after transplanting to be followed two to three times more to make sure that the weeds are checked. Other methods of weed control include the use of herbicides, site selection and other cultural practices. The commonest weed control in onion production in Ghana is by hand weeding and herbicide application.

The method of fertilizer application is very important in obtaining maximum yield. Multiple applications ensure good yields (Boyhan and Kelley, 2008). Because onions are shallow rooted and are generally grown on cool soils, they are quite responsive to fertilization. The optimal fertility programme will provide nutrients to the upper 15 to 40 cm of the soil over the entire growing season. Typically, no more than one-third of the nitrogen (N) should be available at planting, one-third at early season (3 to 4 leaf stage), and one-third at midseason or when seed stalks are available (Ronald *et al*., 20013). Additionally, total supplemental nitrogen needs may vary from 110 to 450 kg/ha of N per acre, depending on soil, cropping history and irrigation efficiency.

Onions require more fertilizer than most vegetable crops because fertilization of both plant beds and dry bulb onions must be considered (Boyhan and Kelley, 2008). An amount of 11 to 22 t/ha of composted manure are sometimes used to meet planting and early season N requirements and other nutrient needs (Ronald *et al*., 2013). Fertilizer rates range from 60-120 kg N/ha, 60-70 kg P/ha and 110-135 kg K/ha depending on the inherent soil nutrient status, and about 90 m^3/ha of cattle manure could also be worked into the soil to substitute inorganic fertilizer (Abbey, 1997). Organic soil amendments such as manure and compost can improve soil structure, moisture-holding capacity, and fertility (Randall *et al.*, 1999).

At maturity, onion does not produce new roots and leaves. As onions reach maturity, they cease to produce new leaves and roots with reserved food still present in the leaves and moving into the bulbs (Sani and Jaliya, 2012). Physiological maturity is reached when 20-50 percent of the onion tops are down. In most seasons onion neck tissue breaks down when the plant is mature (Boyhan and Kelley, 2008). Although this is a good rule-of-thumb for determining onions maturity period, the tops may not go down as readily in some years or for some varieties. Bulb ripening, indicated by the neck drying and the tops falling over generally requires the same day length or longer than that for bulb initiation, as well as temperatures in the range of 21.1°C-26.7°C (Randall *et al.*, 1999). Matured onions are harvested either by using mechanical harvester or manually by hand. Manual harvesting of onions by hands are very common among small scale onion producers. The process involves gently pulling the onion leaves to remove the bulbs or unearthing of bulbs from the ground with the aid of a hoe, and the tops are cut at the neck side of the onion with a knife. Bulbs that are harvested when they are too immature may take longer time to dry properly for storage and if the necks are not yet soft, the inner leaves may still be growing and will continue to elongate from the topped bulbs, yielding an unsightly product (Sani and Jaliya, 2012).

2.9 Storage and shelf life of onion

Storage condition, type of storage structure, type of cultivar and cultural practices play vital roles in the shelf-life of onions. Many factors, such as cultivar, bulb maturity, moisture content of the bulb, temperature and relative humidity are associated with spoilage of onion during storage (Biswas *et al*., 2010). Onions are semi-perishable commodity and like most fresh vegetables, long term conservation often requires cold storage or well ventilated rooms (Windpouire *et al*., 2011). Stow and Ward (1978) reported that the major causes of bulb deterioration during storage are rotting, dehydration and sprouting. Rabbani *et al.* (1986) reported that storage losses in onion could be as high as 66%. High temperatures such as 30-35°C encouraged bulb rot caused by *Aspergillus niger* while low temperatures favored bulb rot caused by *Botrytis alli* (Tucker *et al*., 1977; Stow and Ward, 1978). Brewster (1994) explained that bulb storage at warm temperature such as 25-30°C reduces cytokinin activity that would otherwise increase the activities of gibberellin and auxin as sprouting progresses. Different cultivars of onions shelf-life exhibit variations even under the same structure, and the ability to store for long duration is a varietal characteristic of onions (Brewster, 1994). Cultural practices such as early or late harvesting of onions also affects the shelf-life of onions at storage. Tucker and Drew (1982) have shown that sprouting is earlier in bulbs harvested late and that the rate of bulb rots in storage increases with the lateness of harvesting. Wall and Corgan (1994) also found that when the harvesting of bulbs was delayed to the time 80% of the leaves 'tops down,' there was an increase in the rate of storage rot. Storage studies have indicated that shelf life is the same for machine and hand harvested mature onion bulbs (Boyhan and Kelley, 2008).

Irrigation has an effect on onion storability. Irrigation may have some effects on storability of onion as it helps increase moisture content of the bulb (Chung, 1989). Soujala *et al.* (1998), however, reported that irrigation had only a minor effect on the storage performance and shelf life of onion. On the contrary, a substantial increase of rotting in onion bulbs during storage with increasing irrigation was reported by Shock *et al.* (1998). Regarding the influence of bulb size, it has long been known to seed producers that small or medium sized bulbs store better in storage than larger bulbs (Ward, 1979; Peters, 1990).

Cho *et al.* (2010) stated that larger onion bulbs are more susceptible to bruising, disease and other damage than smaller bulbs. Ward (1976) explained that respiration was responsible for less than 20% of physiological weight loss in onion. Carbon dioxide levels above 8 percent also increased the chance of translucent scale (Boyhan and Kelley, 2008).Translucent scale is a post-harvest phenomenon caused by high carbon dioxide in storage facilities.

2.10 Biochemistry of onion bulbs during storage

Many biochemical changes take place during storage, and some of them are linked to bulb's respiration (Abrameto *et al*., 2010). Depending on genotype and storage conditions, sprout growth is initiated after a certain period of storage (Komochi, 1990). These changes can be in carbohydrate content, flavor compound concentration, and plant growth regulators (Chope *et al*., 2006). The phenolic content in onion increased during sprouting (Asterisk *et al*., 2014). Hormonal control involving a gradual increase of the ratio of sprouting promoters to inhibitors may underlie the loss of dormancy with time (Gubb and MacTavish, 2002). According to Gebhard (2008), the specific roles of different hormones, and especially of ethylene, in the regulation of dormancy and sprouting of onion bulbs are not known. Johnson (2006) reported commercial onion stores that continuous application of ethylene retards sprout growth during cold storage. Dry onion bulbs treated with the ethylene-action inhibitor 1-methylcyclopropene (1-MCP) reduced sprout growth in bulbs stored at 4^{o}C or 12^{o}C, but not when stored at 20^{o}C (Chope *et al*., 2007). According to Abrameto *et al*. (2010) change in the bulb biochemistry that modifies its quality in storage is the softening of tissues. This is produced by the hydrolysis of the pectin portion of the bulb cell walls through pectolitic enzymes. Pectins are sources of dietary fiber and are basically galacturonic acid polymers (Ridley *et al*., 2001). Immediately after harvest, the bulbs are in a natural state of rest that is controlled by endogenous hormone levels and varies with genetic makeup of the particular cultivar (Salamal *et al*., 1990). Cultivar specific weight losses between 2-5% of fresh weight/month have been recorded during the first month of storage (Koopsell and Randle, 1997; Gubb and MacTavish, 2002). There are relatively low initial rate of weight loss and this represents loss of water through the skin, and low-level respiration rates of dormant bulbs.

2.11 Carbohydrate metabolism

Carbohydrates in onion bulbs account for a major portion of their dry weight and include fructose, glucose, sucrose, a series of oligosaccharides, and possibly arabinose and ribose (Rutherford and Whittle, 1982). Plants store sugars usually as large molecules of starch which are required to produce energy, plants are required to break them into smaller molecules (Hapkins, 1999). During cold storage, due to hydrolysis of starch, carbohydrates in onion tissues acquire mobility (Fulton *et al*., 2001). Carbohydrate macromolecules such as starch are converted into simple sugars such as sucrose, glucose, and fructose, making this process possible. Transport and accumulation of these substances (sugars) that are source of energy are used in cellular metabolism, and produce the energy needed for plant growth (Langens-Gerrits *et al*., 2003). In addition to energy transfer in plants, carbohydrates are also involved in the regulation of gene expression (Gupta and Kaur, 2005; Iraqi *et al*., 2005). Organic acids that have been identified include pyruvic, malic, citric, fumaric, and α-ketoglutaric (Masters *et al*., 1984). According to Salama *et al*. (1990) adequate metabolic substrate levels (primarily carbohydrate but may also include organic acid) are essential for storage of any crop. In onions, fructose level at harvest has been suggested as an indicator of storage potential (Rutherford and Whittle, 1982, 1984). Gorin and Borcsok (1980) considered total sugar content during storage to be an index of keeping quality. Sugar metabolism is linked to bulb dormancy and the state of sprouting (Kato, 1966). There are variations in monosaccharide and disaccharide levels in onion bulbs during storage (Suzuki and Cutcliffe, 1989; Benkeblia *et al*., 2002; Benkeblia *et al.*, 2004). However, the relationship between variation in sugar levels and physiological factors is not clearly understood. Fructans are accumulated during the bulb developmental stage. Then, they are metabolized during regrowth and sprout of the bulbs. However, the enzymatic processes involved, or the mechanisms by which they contribute to long bulb maintenance are still poorly understood (Shiomi *et al*., 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The experiments were in two forms; field experiment and room storage experiment. The field trials were conducted during the 2015 and 2016 cropping seasons at the Kpalugu-Kpalwega irrigation dam in Bawku. The storage experiment was conducted in 2015 and 2016 at Kpalwega-Bawku. The two storage structures used were room with thatch roof and room with corrugated iron sheets roof (Plate 7 and 8). Kpalugu-Kpalwega Irrigation Dam lies on 11^{o} 02' 12.0"N, 000^{o} 16'37.4"W and at an altitude of 214 m above sea level. The study area is located in the Sudan-savannah agro-ecological zone of Ghana. The area has a single rainfall pattern. During the 2015 cropping season, there was rainfall in April (9.4 mm), whereas the 2016 cropping season recorded a total rainfall of 56.3 mm in March (Table 1). The first six weeks of the first quarter of 2015 cropping season (1st January, 2015 to 14th February, 2015) were characterized with harmattan windy weather whereas the remaining six weeks of the same quarter (15th February, 2015 to 31st March, 2015) were very sunny with high temperatures (Table 1).

The average minimum and maximum monthly relative humidity for 2015 and 2016 cropping seasons are also in Table 1. Soils in Bawku are generally Savannah ochrosol (GSS, 2014). Detailed soil classification reveals four different soil series and the study site falls under the Varempare series (GSS, 2014). These soils are mainly sandy loam and are associated with hornblende and granites. They are quite permeable with moderately good water retention capacity and are suitable for the cultivation of vegetables, cereals and legumes. The soils in Bawku show low nutrient properties and often require soil amendment to boost crop production (GSS, 2014).

3.2 Field experiments

The field studies consisted of two experiments conducted in 2015 and 2016 cropping season respectively. Both field experiments were conducted at Kpalugu-Kpalwega irrigation dam site at Bawku in the Upper East Region. The plate below shows an experimental field with transplanted onion seedlings.

Plate 1: Experimental field at Kpalugu-Kpalwega dam site used for the studies

3.3 Experimental design and treatments

A 4 x 4 factorial experiments in Randomized Complete Block Design (RCBD) with three replications was used in the field experiments. The factors and their levels were as follows:

Cultivars (Bawku Red, Ares, Red Creole and Top-harvest) and spacing (8 cm x 10 cm, 10 cm x 10 cm, 12 cm x 10 cm and 14 cm x 10 cm). A plot size of 1.5 m x 3.4 m was used and the total land area was 259.08 m^2.

3.4 Cultural practices

The seeds of Ares, Red Creole and Top-harvest cultivars were purchased from Agriseed Limited, a registered Agro-Inputs dealer in Kumasi whereas those of Bawku Red cultivar were bought from local Seed Producers at Bawku in the Upper East Region of Ghana. Nursery beds were prepared with a hoe to a fine tilth and the seeds were then nursed on the prepared nursery beds in drills of 1-2 cm deep a month prior to transplanting the seedlings. In the 2015 cropping season, the seeds were nursed on 6th December 2014 whereas the 2016 cropping season seeds were nursed in 6th November 2015.The seeds in the drills were covered with humus soil liaised with well decomposed organic matter to boost vigorous seedling growth after emergence. The nursery beds were mulched with rice straw and watered twice daily (32 litres). The mulched materials were removed on the 8th day after germination (Plate 2).

The experimental field was ploughed and harrowed to break large soil clods into fine soil tilth. A hoe was used for the preparation of the beds (Plate 5).

Plate 2: Nursery beds covered with rice straw and early millet stocks

Plate 3: Onion seedlings emerging from nursery bed

Plate 4: Onion seedlings in nursery beds

Plate 5: Land preparation for transplanting

Transplanting of seedlings from the nursery beds to prepared beds on the field were carried out 30 days after nursery. Transplanting of crops in 2015 cropping season was on 5th January, 2015 and the 2016 cropping season was on 6th December, 2015 as shown in Plate 6.

Plate 6: Transplanting of onion seedlings

Water supply to crops was mainly by irrigation with the aid of water pumping machine. An amount of 64 litres of water was used for watering the crops once every two days in the month of February during the 2015 cropping season. Similar quantity of water was used for watering the plants in the first six weeks after transplanting the crops in the 2016 cropping season. The reduction in watering of the crops six weeks after transplanting was due to the cold season of the harmattan. But the subsequent quantity of water used for watering the crops was 64 litres at least. During March in both production seasons, watering was done once daily due to prevailing sunny weather condition in March.

Plate 7: Onion plants being watered in the field

Weed control were by hoeing, hand picking and herbicide application. The herbicide, stomp was applied at 0.25 litre a week after transplanting. Hoeing was carried out once in every three weeks intervals not only to control weeds but to lose the soil for easy water percolation and also to enhance soil aeration. There was no noticeable insect pest problem throughout the production seasons of the crop.

Plate 8: Controlling weeds in onion field 3WAT by hoeing

Both organic and inorganic fertilizers were applied to plants at various stages of growth and development. The organic fertilizer (poultry droppings) was worked into the soil thirty days before seedlings were transplanted. The inorganic fertilizer was first applied to the seedlings at the nursery bed fourteen days after seeds emergence. The second application was carried out twenty one days after transplanting whilst the last application was done in the next twenty one days.

Plate 9: Onion plants having being treated with inorganic fertilizer

3.5 Data collection

3.5.1 Weather parameters

Data on rainfall and general weather conditions during the cropping seasons (2015 and 2016) at the experimental sites were obtained from the CSIR-SARI sub-station at Manga-Bawku.

3.5.2 Soil analysis data

There was soil testing for N.P.K, organic carbon content, soil texture and soil pH before transplanting of seedlings. Soil samples were taken at 30 different points at random at the two diagonals of the experimental field at a depth of 0-20 cm. The soil samples were bulked and thoroughly mixed, air dried under shade and sent to CSIR-SARI for analysis. The results are shown in Table 2.

3.5.3 Vegetative data

3.5.3.1 Germination test

Germination test was conducted on each of the four cultivars ten days prior to nursing of the seeds. Hundred seeds from each of the cultivars were wrapped with moist piece of cloth and put in separate small containers for a period of eight days for germination as indicated in plate 10. Germination test was estimated using the method of Saxena and Cramer (2009) as following;

$$\text{Percentage emergence} = \frac{\text{Number of seedlings emerged}}{\text{Total number of seeds planted}} \times 100.$$

Plate 10: Germination test of seeds prior to nursing

3.5.3.2 Percentage crop establishment

Percentage plant establishment 4 weeks after transplanting (4WAT) was conducted by counting the number of survived plants and dead plants per bed or plot. Based on counting, the percentage of established plants per bed was then determined according to the formula of Saxena and Cramer (2009) as shown below;

$$\text{Percentage crop establishment} = \frac{\text{Number of seedlings survived}}{\text{total number of seedlings emerged}} \text{x}100.$$

3.5.3.3 Plant height, leaf length and leaf number

Plant height was taken weekly from 4 to 11 weeks after transplanting. It was collected from five randomly selected and tagged plants in the middle rows of each plot. The height was measured from ground level closer to the plant to the end of the terminal bud of the plant with the aid of a tape measure.

Leaf length was taken weekly from 4 to 11 weeks after transplanting. The data was collected from five randomly selected and tagged plants in the middle rows of each plot. The length of every green leaf on each of the five plants was measured from ground level to the end of the apex with the aid of a tape measure.

The leaves of five tagged plants were counted weekly from 4 to 11 weeks after transplanting.

3.5.3.4 Leaf area index and days to hundred percent bulb initiation

Leaf area index was determined according to Stenberg *et al.* (1994). Leaf area was obtained by using Scanning Planimeter Device to scan the leaves for the leaf area values. The leaf area values obtained from the Scanning Planimeter device were divided by unit ground surface area covered by the plants. The data was taken every two weeks starting from 4 to 10 weeks after transplanting.

Days to hundred percent Bulb Initiation was estimated by visual observation through monitoring the crops on their respective plots to the day they attained 100% bulb initiation. The bulb initiation was characterized by bulking of the base of the stem region and colouration of the bulb.

3.5.3.5 Chlorophyll content

Data on chlorophyll content of plants were collected fortnightly starting from 4 to 10 weeks after transplanting. One of the middle leaves was measured with the chlorophyll meter and the values recorded.

3.5.3.6 Girth of bulb neck

Data on girth of bulb neck was taken weekly from 4 to 11 weeks after transplanting. The data was collected from five tagged plants in the middle rows of each plot. The neck of each of the plants was measured with a piece of thread and stretched on a meter rule to obtain the measured value.

3.5.3.7 Root number and root biomass

Roots count data were obtained monthly, starting from 4 to 12 weeks after transplanting. The roots of two randomly uprooted plants were countered with the aid of hand held lens. Root biomass of uprooted plants was determined by weighing with electronic top pan balance. Root biomass data was obtained monthly, starting from 4 to 12 weeks after transplanting.

3.5.3.8 Fresh and dry biomass

Two plants were randomly uprooted from each experimental plot and the fresh weight determined by weighing with an electronic top pan balance. Measurements were carried out every four weeks, started from 4 to 12 weeks after transplanting.

The plant dry biomass was determined by oven drying uprooted plants for 48 hours at 80^0C and weighed with electronic top pan balance. Measurement started at 4 to 12 weeks after transplanting.

3.5.3.9 Days to maturity

Days to maturity was estimated by visual observation through monitoring the crops on the field to the time they reached physiological maturity, (Plate 11). Onion maturity is characterized by leaf senescence, cessation of new leaf formation as well as softening and toppling of leaves (Sani and Jaliya, 2012).

Plate 11: Matured onion plants at 12 weeks after transplanting

3.6 Yield and yield components

3.6.1 Yield

Yield was determined by weighing all harvested bulbs of an experimental plot with a weighing scale and converted into t/ha (Plate 12).

Plate 12: Weighing of onion bulbs after harvest

3.6.2 Average bulb weight

Average bulb weight was obtained by weighing bulbs from ten randomly picked plants per an experimental unit at harvest with a weighing scale and dividing by the total number of bulbs weighed.

3.6.3 Grading

Percentage grading was obtained by measuring the girth of 100 randomly picked bulbs harvested from each of the plots with fibre tape measure. The bulbs were grouped as percentage of bulbs with girth ≥ 20 cm as large, percentage of bulbs with girth 10-19 cm as medium, and the percentage of bulbs with girth < 10 cm was designated as small (Plate 13).

Plate 13: Percentage grading of onion bulbs. Bawku Red = BR, TH = Top-harvest, Red Creole = RC and Ares = AR.

3.6.4 Bulb diameter

An average bulb diameter data was obtained at harvest by measuring the diameter of twenty bulbs picked at random from each of the experimental plots with a pair of vernier calipers and averages computed.

3.6.5 Analysis of field data

The collected data were analyzed using analysis of variance (ANOVA), with a computer software Genstat package (Genstat Discovery Edition 4 software package). Treatment means were separated using Least Significant Difference (LSD) at 5% level.

3.7 Storage experiment

The experiments were conducted in two different cropping seasons of 2015 and 2016 in Kpalwega-Bawku. The structure roofed with thatch is designated **a** whiles the structure roofed with corrugated iron sheet designated **b**.

3.7.1 Experiment design and treatment

The storage structures used for the experiments were two; structure roofed with thatch and structure roofed with corrugated iron sheet. The design used was 4 x 4 factorial experiment laid in CRD with three replications for each storage. That is bulbs from the two factors considered in the field. Each of the four cultivars and the four spacing were stored in each storage structure. Each experimental unit contains 1kg weight of onion bulbs. The storage structures described earlier were cleaned and windows opened for ventilation. The bulbs were put in containers. The storage period was three months. Plate 14 and 15 below show storage structures used for the experiment.

Plate 14: Storage structure roofed with thatch for storing onions

Plate 15: Storage structure roofed with corrugated iron sheet for storing onions

Plate 16: Arrangement of onions in storage structure roofed with thatch

Plate 17: Arrangement of onions in storage structure roofed with corrugated iron sheet

3.8 Storage data

3.8.1 Temperature and relative humidity

The ambient temperature and relative humidity of the storage structures were obtained from mounted clinical thermometer and digital hygrometer. Data from each of the devices were recorded twice a day morning (6:00 GMT) and afternoon (15:00GMT).

3.8.2 Weight loss

The stored onion bulbs were weighed every ten days throughout a storage period of ninety days (90 days) with a weighing scale. Weight loss was determined by changes in bulbs weight.

3.8.3 Percentage of rotten bulbs

The stored onion bulbs were monitored every ten days within a period of ninety days and the rotten bulbs were removed from the lot and weighed as percentage rot out of the total bulbs weight.

Plate 18: Samples of rotten onion bulbs from structure roofed with thatch

Plate 19: Samples of rotten onion bulbs from structure roofed with corrugated iron sheet

3.8.4 Percentage of sprouted bulbs

The stored onion bulbs were also monitored every ten days within a period of ninety days and the sprouted bulbs were removed from the lot and weighed as percentage sprout out of the total bulbs weight.

Plate 20: Samples of sprouted onion bulbs

Plate 21: Samples of sprouted onion bulbs that completely exhausted their nutrients due to sprouting

3.9 Analysis of storage data

The collected data were analyzed using analysis of variance (ANOVA), with a computer software Genstat package (Genstat Discovery Edition 4 software package). Treatment means were separated using Least Significant Difference (LSD) at 5% level.

CHAPTER FOUR

4.0 RESULTS

4.1 Field data

4.1.1 Weather parameters

Total rainfall for the first cropping season (2015) was 9.4 mm and it occurred in April (Table 1). The mean minimum monthly temperatures range was 18.4^{o}C-33.7^{o}C, while the mean maximum monthly temperatures range was 34.3^{o}C-40.1^{o}C. The highest mean monthly temperature of 40.1^{o}C was recorded in April, whereas the lowest mean minimum monthly temperature of 18.4^{o}C was recorded in January. The mean monthly relative humidity of the area was between 31% and 51% at 6:00 GMT; and 18% and 64% at 15:00 GMT (Table 1). In the second cropping season (2016) total rainfall was 56.3 mm and it was recorded in March (Table 1). The mean minimum monthly temperature range was 19.4^{o}C-27.0^{o}C, whiles the mean maximum monthly temperature range was 34.7^{o}C-40.2^{o}C. The highest monthly temperature 40.2^{o}C was recorded in April, whilst the lowest temperature of 19.4^{o}C was recorded in January. The mean monthly relative humidity of the area was between 36% and 74% at 6:00 GMT; and 16% and 41% at 15:00 GMT.

Table 1: Weather condition during 2015 and 2016 cropping seasons

Year	Month	Total Monthly rainfall (mm)	Mean Monthly Relative Humidity % (Hours GMT)		Mean Monthly Max. & Min. Temperatures (°C)		
			06:00	15:00	Min	Mean	Max
2015							
	January	0.0	38	18	18.4	26.4	34.3
	February	0.0	51	26	22.3	30.5	38.6
	March	0.0	31	62	25.3	32.0	38.7
	April	9.4	46	64	33.7	36.9	40.1
2016	December	0.0	40	17	19.4	27.1	34.7
	January	0.0	36	16	21.2	29.4	37.6
	February	56.3	50	25	24.6	32.1	39.5
	March	0.0	74	41	27	33.6	40.2

Source: SARI-CSIR substation at Manga-Bawku. 2015 (Period of transplanting to harvesting January-April) and 2016 (Period of transplanting to harvesting December-March).

4.1.2 Soil characteristics

The soil analysis showed that pH was moderately acidic and there was slight increase in soil pH from 2015 to 2016. The organic carbon content, total nitrogen, phosphorus, potassium and soil texture showed a similar pattern (Table 2).

Table 2: Soil chemical properties 2015 and 2016 cropping seasons

Year	pH (1:2.5H_2O)	% OC	Total N (%)	mg/kg P	mg/kg K	Texture % Sand	% Silt	% Clay
2015	6.37	0.858	0.0786	5.25	120	81.76	0.44	17.8
2016	6.4	0.859	0.0790	5.30	121	81.79	0.45	17.9

4.1.3 Germination test

The germination test showed that the seeds used were very viable. The percentage seed germination was slightly higher in 2016 than it was in 2015. The Ares cultivar recorded the highest of 98% and 99% in 2015 and 2016 respectively, followed by Red Creole (96% and 97%), Top- Harvest (95% and 97%) and Bawku Red (90% and 94%).

4.1.4 Plant establishment

There were highly significant differences ($P < 0.003$ and $P < 0.001$) in percentage establishment of seedlings at 4 weeks after transplanting among cultivars in 2015 and 2016 cropping seasons respectively. In both seasons Ares cultivar recorded the highest and its values were significantly higher than those of other cultivars. The next higher plant establishment values were recorded by Red Creole (98.4% and 96.5%), Bawku Red (97.3% and 96.8%) and Top-Harvest (97.8% and 96.0%) in that order (Table 3).

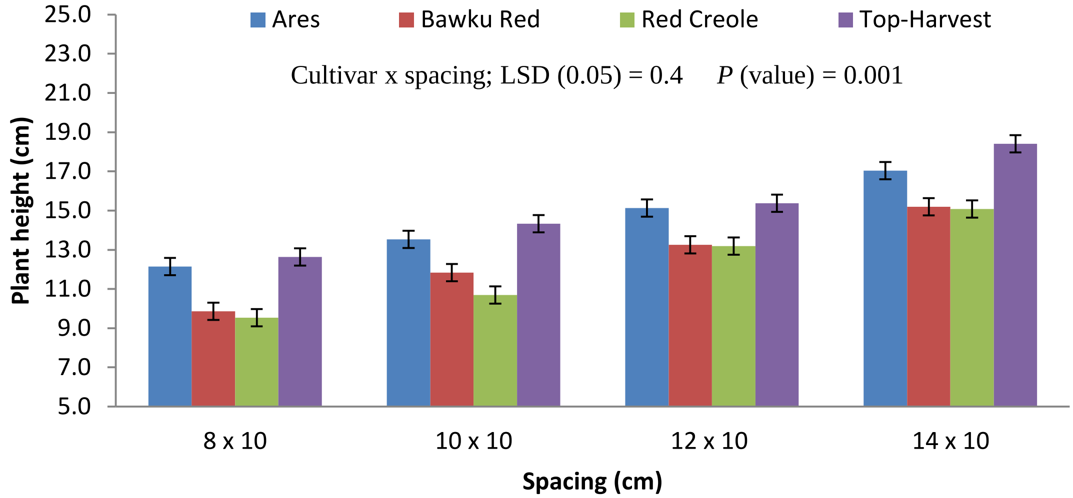
Table 3: Effect of cultivar on percentage plant establishment at 4WAT

Cultivar	**Year**	
	2015	2016
	(%)	(%)
Ares	99.7	98.7
Bawku Red	97.3	96.8
Red Creole	98.4	96.5
Top-Harvest	97.8	96.0
LSD (0.05)	1.2	1.2
P (value)	< 0.003	< 0.001

4.1.5 Plant height

The main effect of spacing shows no significant effect ($P > 0.05$) on plant height in the 2015 and 2016 cropping seasons. However, cultivar and spacing interaction during the 2015 and 2016 cropping seasons showed highly significant ($P < 0.001$ and $P < 0.029$ respectively) difference for plant height (Figure 1b). In the 2015 cropping season, the highest plant height (18.4 cm) was recorded in Top-Harvest at 14 cm x 10 cm spacing whereas the least plant height (9.5 cm) was obtained from Red Creole at the spacing of 8 cm x 10 cm. In the 2016 cropping season, the greatest plant height of 19.4 cm was again obtained from Top-Harvest at a spacing of 14 cm x 10 cm whilst the least plant height of 10.9 cm was observed from Bawku Red at a spacing of 8 cm x 10 cm.

(a)



(b

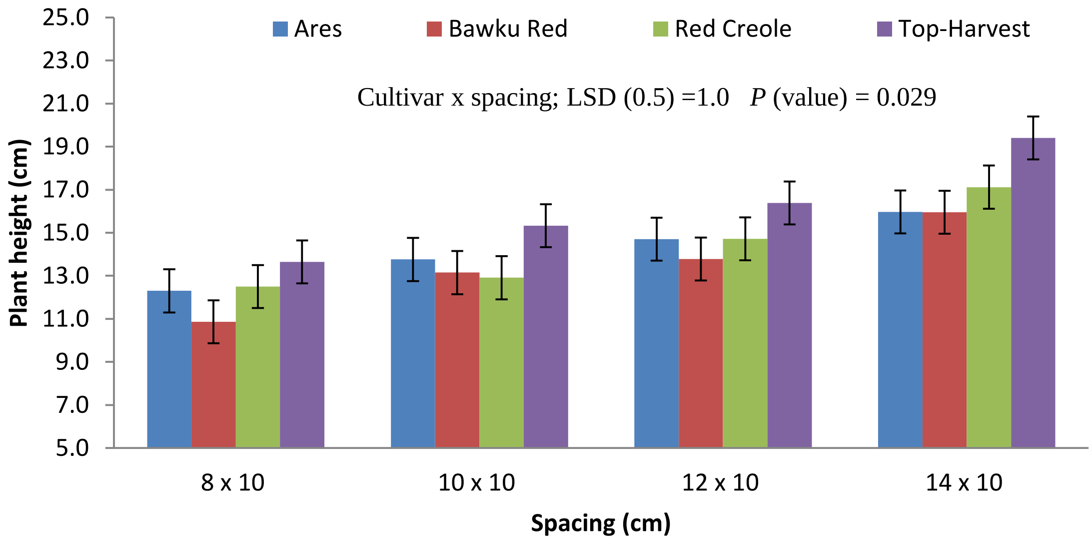
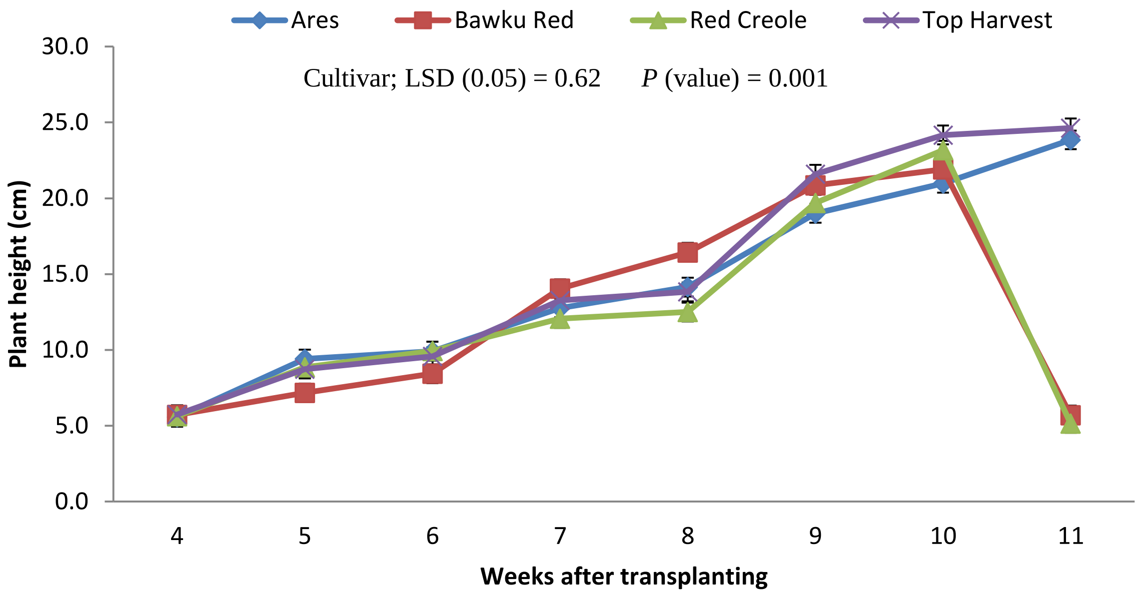


Figure 1: Effects of cultivar x spacing interaction on plant height during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

The main effect of cultivar for plant height in both 2015 and 2016 cropping seasons were highly significant ($P < 0.001$) as shown in Figure 2. Generally plant height increased with increasing weeks after transplanting and dropped at physiological maturity. The highest plant height (24.6 cm) was obtained from Top-Harvest in 2015 season at 11WAT whiles the least plant height (5.2 cm) was obtained from Red Creole at 11WAT. The trend for plant height during the 2016 cropping season was similar to the 2015 season. The highest plant height (25.6cm) was obtained from Top-Harvest at 11WAT, whiles the least was obtained from Red Creole and Ares (6.6 cm) at 4WAT (Figure 1 and Figure 2b).

(a)



(b)

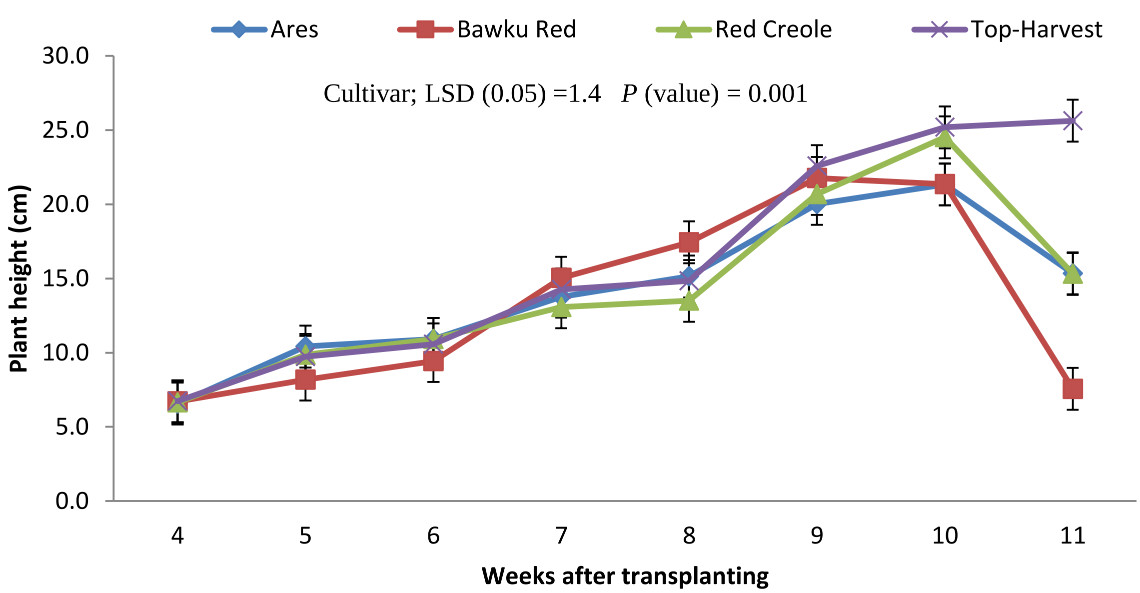
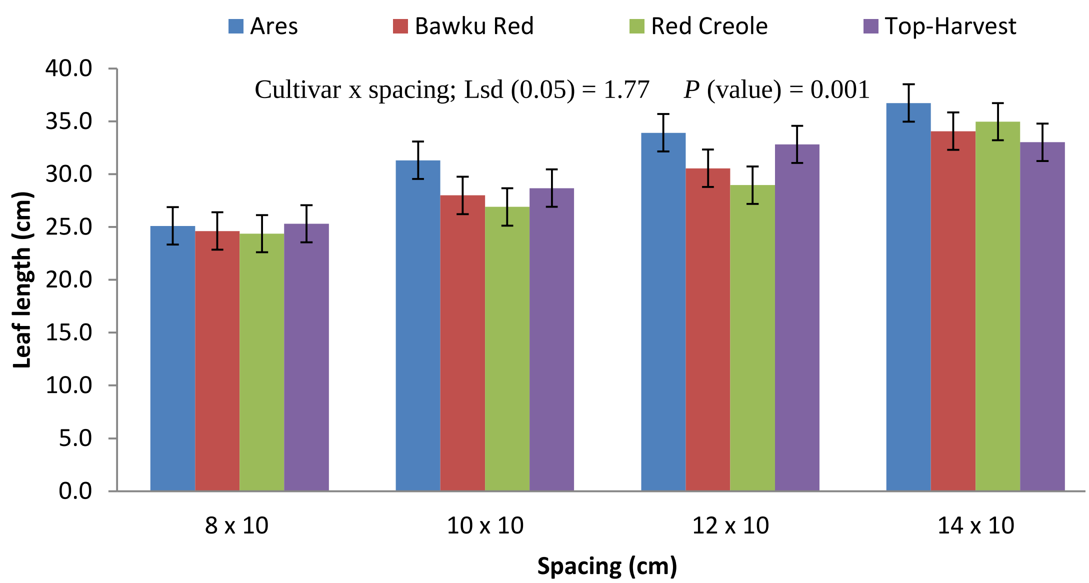


Figure 2: Effects of cultivar on plant height during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

4.1.6 Leaf length

There was no significant difference in leaf length for the main effect of spacing in the two cropping seasons. However, cultivar and spacing interactions were significantly higher ($P < 0.001$ and $P < 0.002$) for leaf length in 2015 and 2016 cropping seasons respectively (Figure 3). In general, leaf length increased with increased spacing. The greatest leaf length (36.7 cm) was obtained from Ares at a spacing of 14 cm x 10 cm spacing in 2015 cropping season, whiles the shortest leaf (24.4 cm) was recorded from Red Creole at a spacing of 8 cm x 10 cm. In the 2016 season, the greatest leaf length (37.9 cm) was also obtained from Ares at the 14 cm x 10 cm spacing, whiles Red Creole had the least leaf length (25.7 cm) at the 8 cm x 10 cm spacing.

(a)



(b)

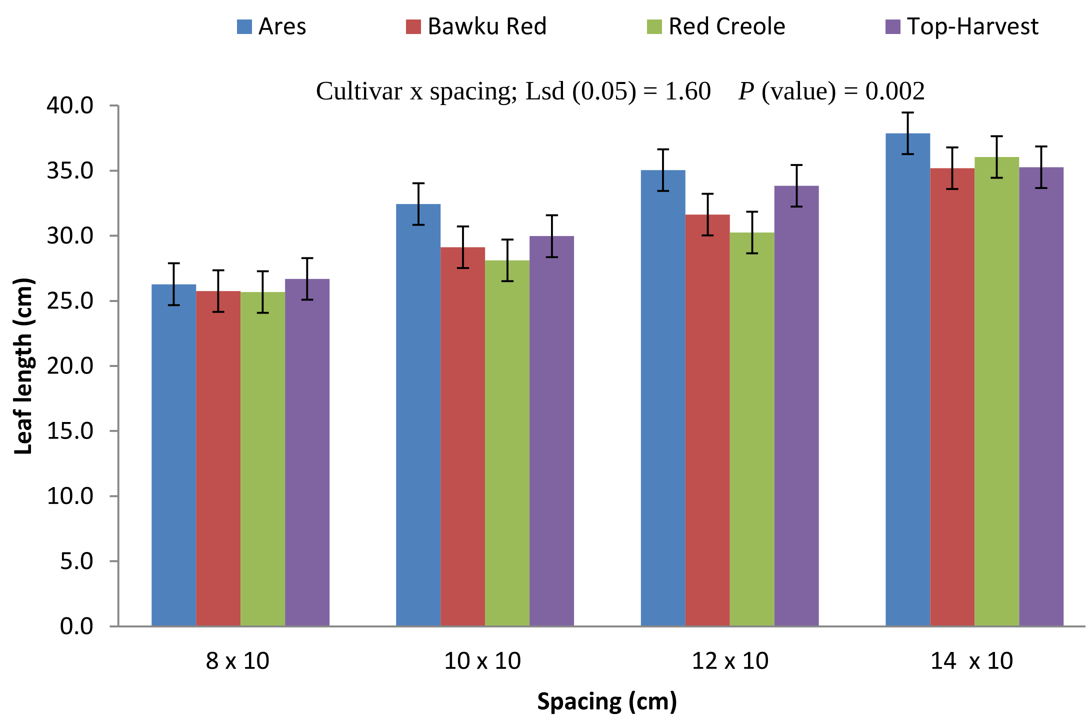
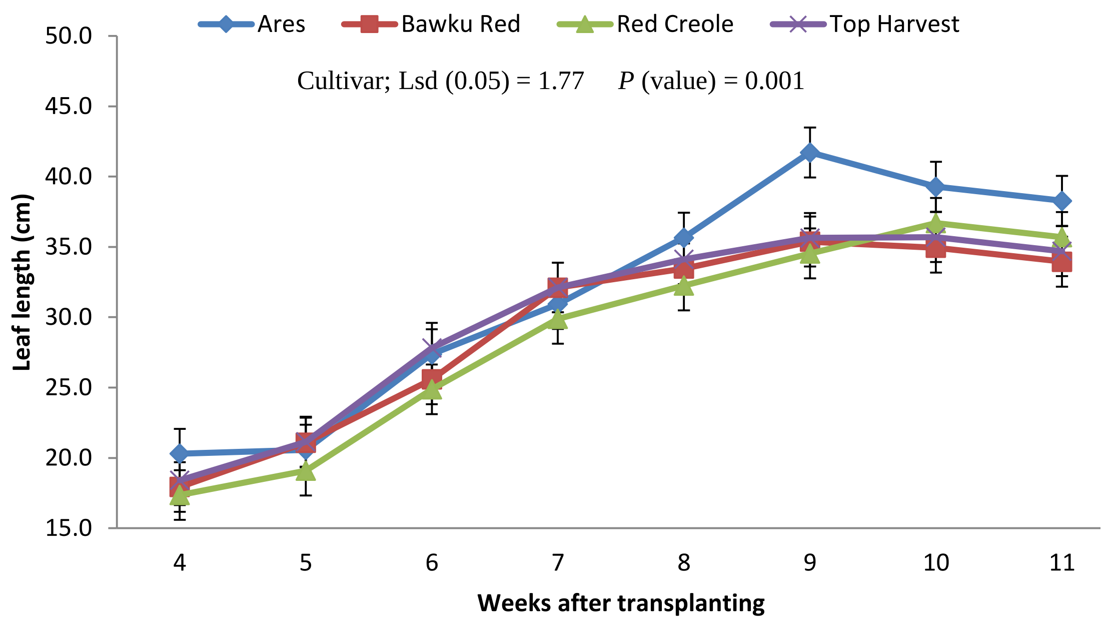


Figure 3: Effects of cultivar x spacing interaction on leaf length during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

Also, the main effect of cultivar varied highly significantly ($P < 0.001$) for leaf length during the two cropping seasons (2015 and 2016) (Figure 4). Cultivar Ares recorded the greatest leaf length (41.7 cm) at 9WAT, whiles the least leaf length (17.4 cm) was recorded from Red Creole at 4WAT. Similar trend was observed in the 2016 cropping season where Ares recorded the greatest leaf length (42.7 cm) at 9WAT whiles the least leaf length of 19.4 cm was recorded by Red Creole at 4WAT (Figure 4). The parameter increased with increasing weeks after transplanting.

(a)



(b)

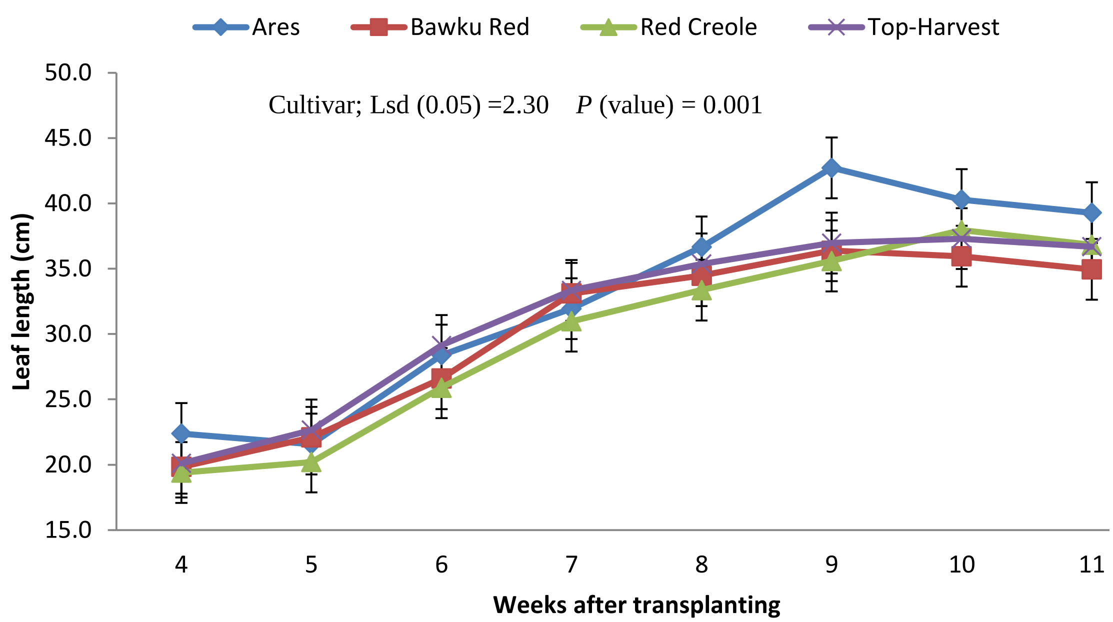
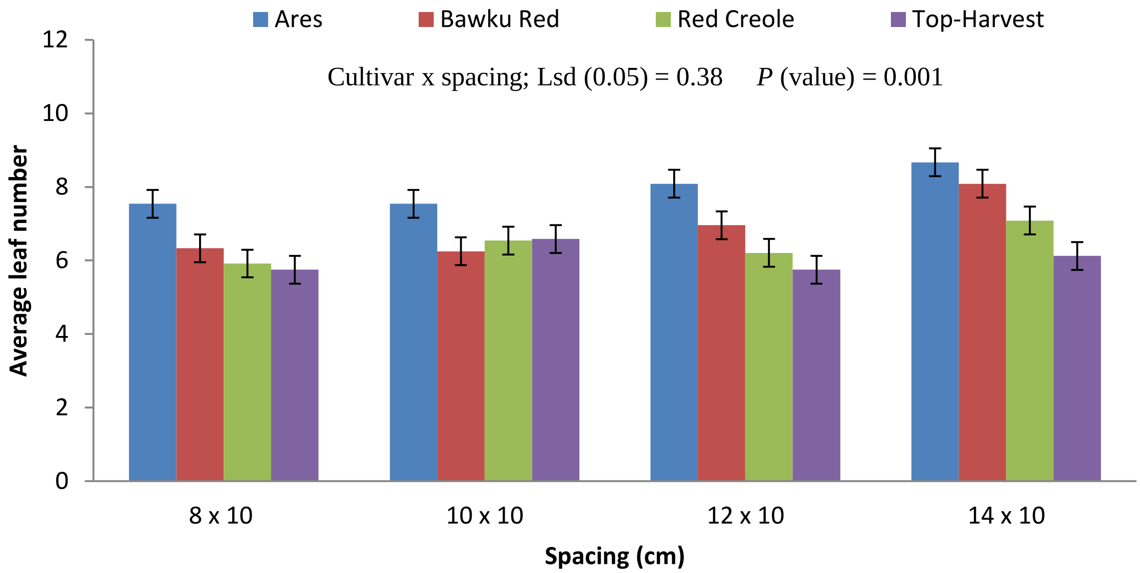


Figure 4: Effects of cultivar on leaf length during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

4.1.7 Leaf number

There was no significant ($P > 0.05$) effect of spacing on leaf number in the two cropping seasons. The results on leaf number were highly ($P < 0.001$) significant for cultivar and spacing interaction during the 2015 and 2016 cropping seasons (Figure 5). The greatest average leaf number (9) was recorded from Ares at a spacing of 14 cm x 10 cm, whiles the cultivar that had the least leaf number (6) was Top-Harvest at a spacing of 8 cm x 10 cm during the 2015 cropping season. Variation in leaf number for the interaction of cultivar and spacing for 2016 cropping season had similar trend as in 2015. Again Ares recorded the greatest leaf number in all spacings. The overall greatest average leaf number (10) was recorded from Ares at the spacing of 14 cm x 10 cm, whiles the cultivar that had the least leaf number (7) was from Top-Harvest at a spacing of 8 cm x 10 cm.

(a)



(b)

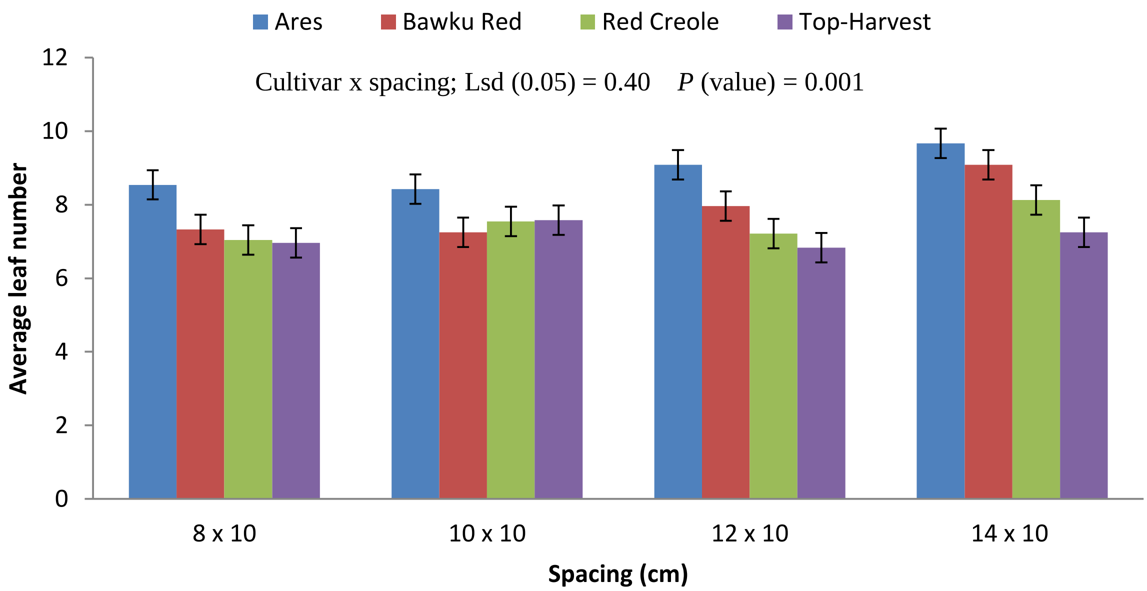
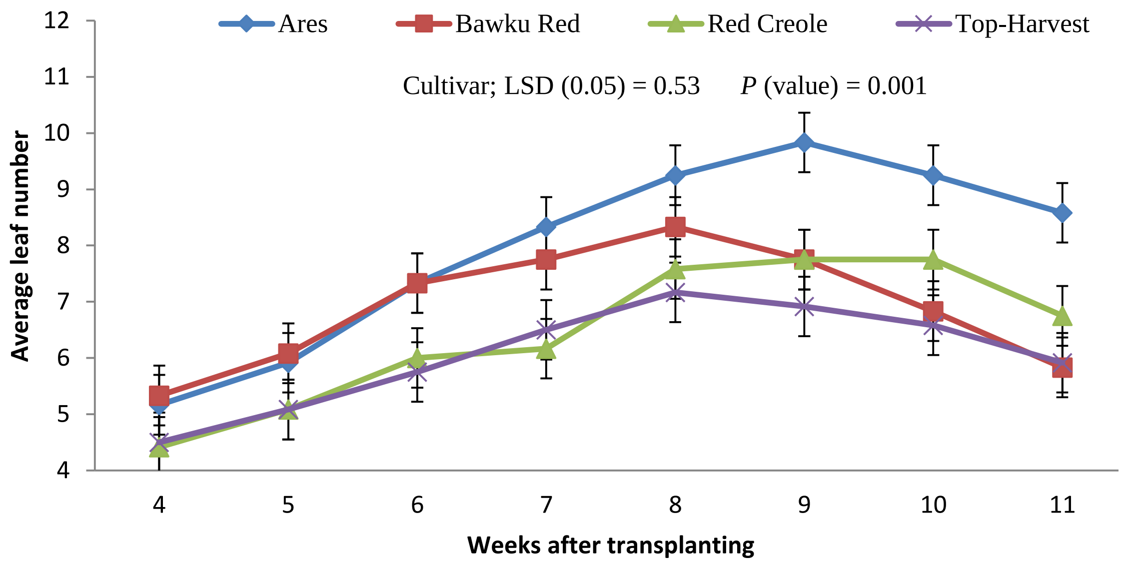


Figure 5: Effects of cultivar x spacing interaction on leaf number during the (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

Leaf number also varied significantly ($P < 0.001$) for the single effect of cultivar in the two cropping seasons (Figure 6). Ares at 9WAT had the greatest leaf number (10) whilst Bawku Red and Top Harvest recorded the least leaf numbers of 4 at 4WAT during the 2015 production season (Figure 6a). In the 2016 production season, Ares again at 9WAT recorded the greatest leaf number (11) and the Red Creole at 4WAT recorded the lowest leaf number (Figure 6).

(a)



(b)

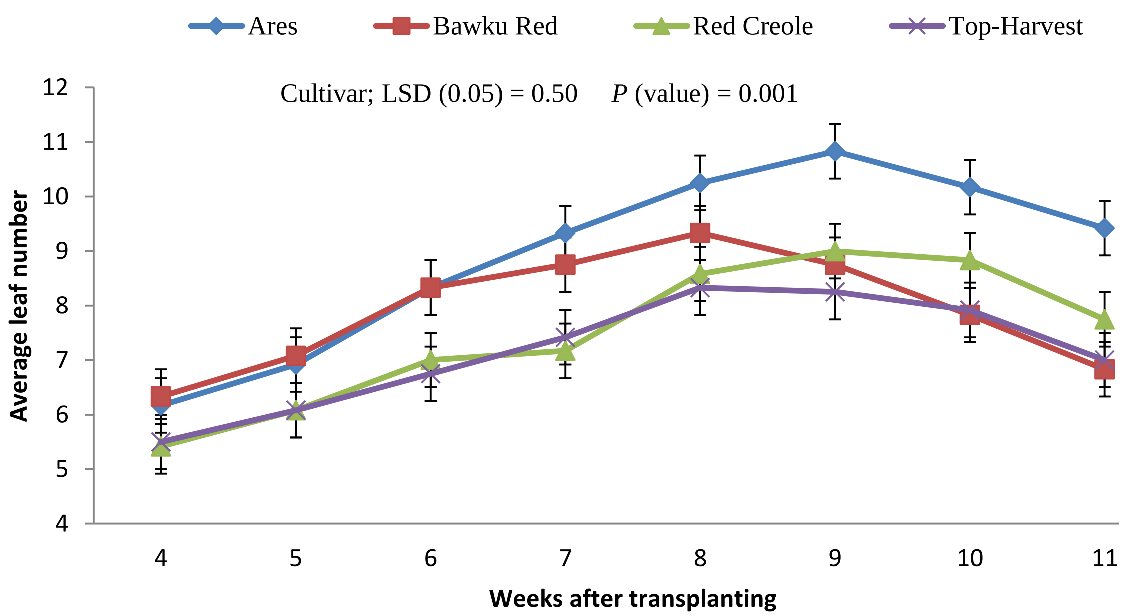


Figure 6: Effects of cultivar on leaf number during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

4.1.8 Chlorophyll content

Cultivar and spacing interaction had no significant effect ($P > 0.05$) on chlorophyll content in both cropping seasons. Cultivar variation (main effect) was highly significant ($P < 0.001$) for leaf chlorophyll content in both cropping seasons. The cultivar with the highest leaf chlorophyll content was Red Creole in both 2015 and 2016, but was significantly higher than that of Bawku Red only (Table 4).

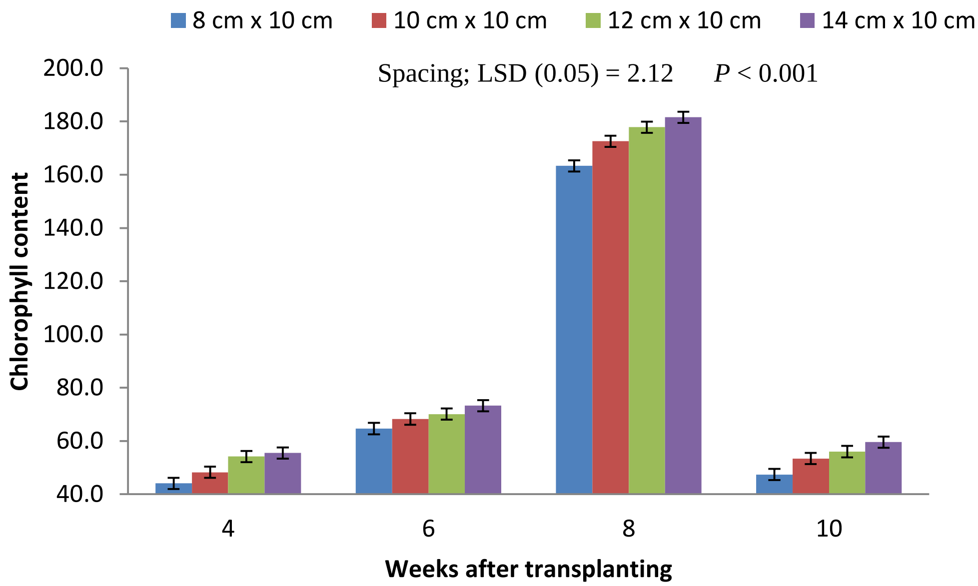
Table 4: Effect of cultivar on chlorophyll content

Cultivar	Year	
	2015	2016
Ares	86.6	87.9
Bawku Red	85.6	86.5
Red Creole	87.8	88.0
Top-Harvest	87.5	88.3
LSD (0.05)	1.1	0.9
P (Value)	< 0.001	< 0.001

Chlorophyll content was highly ($P < 0.001$) significant for spacing in 2015 and 2016 cropping seasons (Figure 7). The parameter increased with increasing weeks after transplanting and decreased when plants reached physiological maturity. The greatest chlorophyll content for 2015 was 59.6 and it was observed from 14 cm x 10 cm spacing at 8WAT and the least (44.1) was recorded in the 8 cm x 10 cm spacing at 4WAT (Figure 7a). Chlorophyll content for spacing in 2016 cropping season was similar to that of 2015 cropping season in that the highest chlorophyll content (65.1) was obtained from 14 cm x

10 cm spacing at 8WAT and the least (45.1) was found at 8 cm x 10 cm spacing at 4WAT (Figure 7b).

(a)



(b)

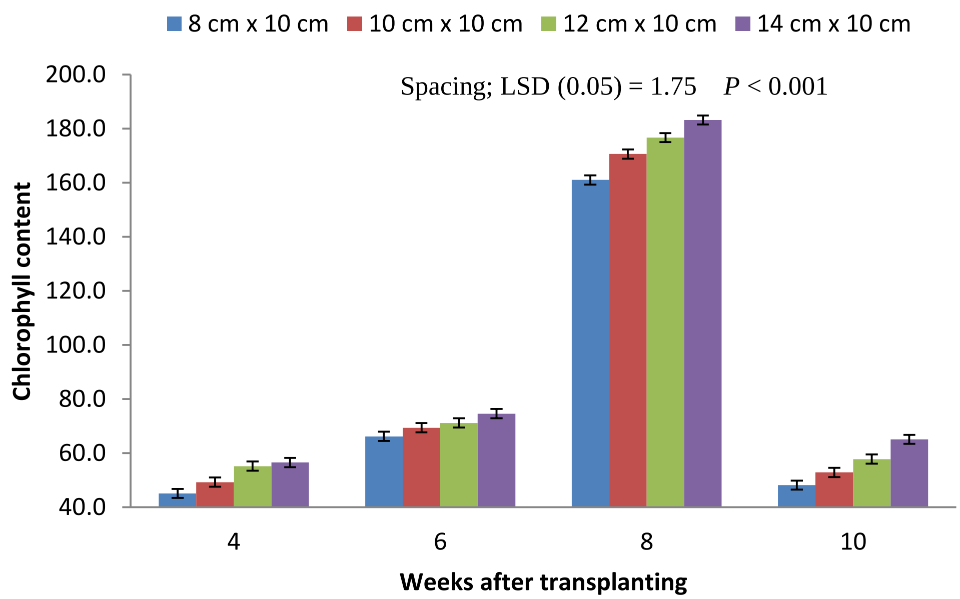


Figure 7: Effect of spacing on chlorophyll content during (a) 2015 cropping season and (b) 2016 cropping season.

4.1.9 Leaf area index

There was no significant interaction effect for cultivar and spacing in terms of leaf area index. However, there were highly significant differences ($P < 0.002$) among cultivars in season 2015 and 2016 (Table 5). The highest leaf area indices (0.24 and 0.47) were recorded from Ares, whereas the least leaf area indices (0.19 and 0.35) were recorded from Bawku Red for 2015 and 2016 seasons respectively.

Table 5: Effect of cultivar on leaf area index of onion

Cultivar	Year	
	2015	2016
Ares	0.24	0.47
Bawku Red	0.19	0.35
Red Creole	0.20	0.40
Top-Harvest	0.21	0.38
LSD (0.05)	0.03	0.04
P (Values)	< 0.002	< 0.001

The main effect of spacing on LAI was also significant ($P < 0.05$) for both seasons (Table 6). The highest leaf area indices (0.22 and 0.45) were recorded from spacing 8 cm x 10 cm, whereas the least leaf area indices (0.19 and 0.35) were recorded from 14 cm x 10 cm in both 2015 and 2016 cropping seasons respectively.

Table 6: Effect of spacing on leaf area index of onion

Spacing (cm)	Year	
	2015	2016
8 x 10	0.22	0.45
10 x 10	0.21	0.41
12 x 10	0.21	0.38
14 x 10	0.19	0.35
LSD (0.05)	0.03	0.04
P (values)	< 0.14	< 0.001

4.1.10 Bulb initiation

The cultivar and spacing interaction was not significant for number of days to bulb initiation in both cropping seasons. The results, however, showed highly significant ($P < 0.001$) difference among cultivars in the two cropping seasons for number of days to bulb initiation (Table 7). Bawku red cultivar was the earliest days to achieve hundred percentage bulb initiation, followed by Ares, Red Creole, whiles the Top-Harvest was late to bulb initiation.

Table 7: Effect of cultivar on number of days to bulb initiation of onions

Cultivar	Year	
	2015	2016
Ares	50.1	51.5
Bawku Red	49.0	50.2
Red Creole	53.2	54.6
Top-Harvest	54.6	55.5
LSD (0.05)	1.9	1.5
P (value)	< 0.001	< 0.001

Days to hundred percentage bulb initiation was also significantly ($P < 0.001$) different for spacing in both cropping seasons (Table 8). The spacing 8 cm x 10 cm was earliest days (47 days and 48 days) to achieve hundred percentage bulb initiation, whiles the spacing 14 cm x 10 cm was late to achieve bulb initiation (54 days and 55 days).

Table 8: Effect of spacing on number of days to bulb initiation of onion

Spacing (cm)	Year	
	2015	2016
8 x 10	47	48
10 x 10	52	54
12 x 10	53	54
14 x 10	54	55
LSD (0.05)	1.9	1.5
P (value)	< 0.001	< 0.001

4.1.11 Bulb neck girth

The interactions effect of cultivar and spacing were not significant for girth of bulb neck both in 2015 and 2016 cropping seasons. The parameter was highly significant ($P < 0.001$) among cultivars in both 2015 and 2016 cropping seasons (Table 9). Ares had the highest values of girth of 2.9 cm and 3.6 cm in 2015 and 2016 cropping seasons respectively, whereas Bawku Red recorded the lowest of 2.5 cm and 3.2 cm respectively for 2015 and 2016 cropping seasons.

Table 9: Cultivar effect on onion bulb neck girth

Cultivar	**Year**	
	2015	2016
	(cm)	(cm)
Ares	2.9	3.6
Bawku Red	2.5	3.2
Red Creole	2.8	3.5
Top-Harvest	2.6	3.3
LSD (0.05)	0.2	0.1
P (value)	< 0.001	< 0.001

Similarly girths of bulb neck were highly significant ($P < 0.001$) among plant spacing in both cropping seasons (Table 10). Plants from the 14 cm x 10 cm spacing recorded the highest girth of 2.9 cm and 3.5 cm respectively in 2015 and 2016 cropping seasons. Plants from 8 cm x 10 cm spacing however, recorded the lowest girth of 2.5 cm and 3.2 cm.

Table 10: Effect of spacing on bulb neck girth of onion

Spacing (cm)	Year	
	2015	2016
	(cm)	(cm)
8 x 10	2.5	3.2
10 x 10	2.6	3.3
12 x 10	2.8	3.5
14 x 10	2.9	3.5
LSD (0.05)	0.2	0.1
P (values)	< 0.001	< 0.001

4.1.12 Root number

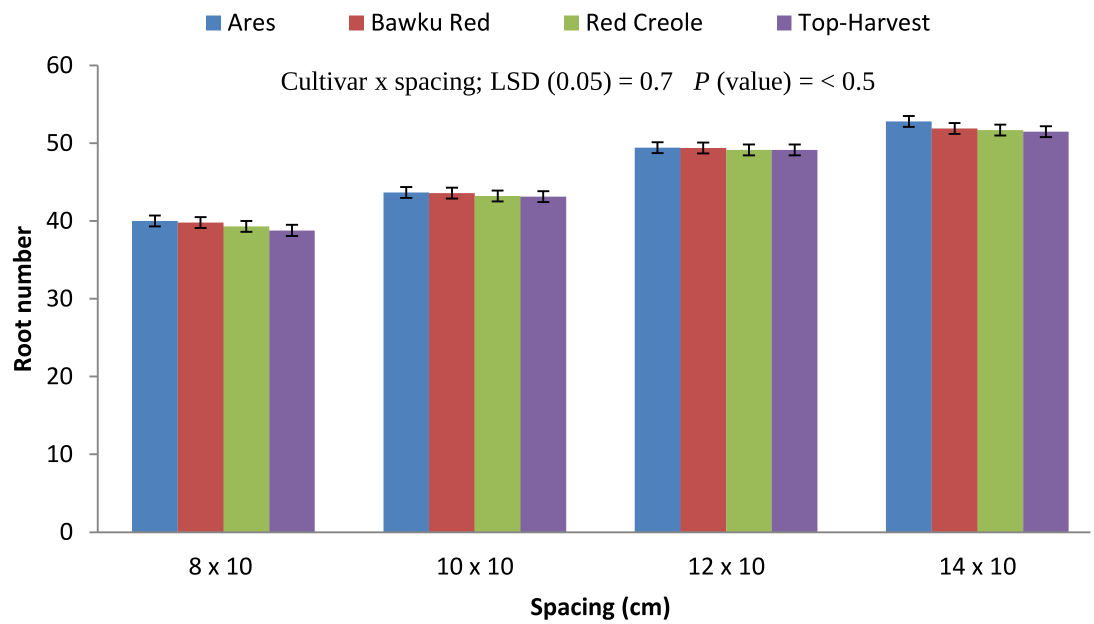
There was no significant difference for spacing in terms of root numbers in the two cropping seasons. There were however, significant differences for main effect of cultivars. There was highly significant (P < 0.001) differences for cultivar and spacing interaction (Table 11).The cultivar with the highest root numbers (47 and 49) was Ares in both cropping seasons, whiles the least root numbers (46 and 48) were recorded from Top-Harvest in the two cropping seasons respectively.

Table 11: Effect of cultivar on root number of onion

Cultivar	Year	
	2015	2016
Ares	47	49
Bawku Red	46	48
Red Creole	46	48
Top-Harvest	46	48
LSD (0.05)	0.3	0.4
P (value)	< 0.001	< 0.001

The main effects of cultivar and spacing interactions showed significant ($P < 0.05$ and $P < 0.043$) difference on root number during the 2015 and 2016 cropping seasons respectively (Figure 8). In the 2015 cropping season plants from the spacing of 14 cm x 10 cm recorded the highest root number of 53 from Ares, whiles the lowest root number of 39 was recorded at spacing of 8 cm x 10 cm from Top-Harvest. Similarly, in the 2016 cropping season, plants from 14 cm x 10 cm had the highest root number of 55, whiles the lowest root number of 41 was recorded from Top - Harvest at the 8 cm x 10 cm spacing.

(a)



(b)

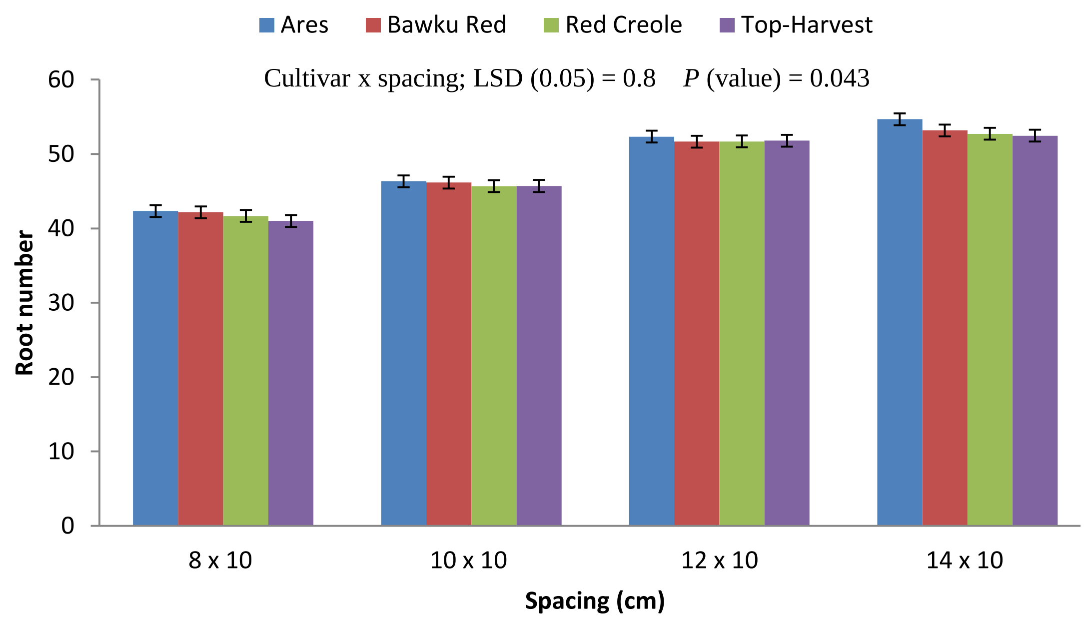


Figure 8: Effects of cultivar x spacing interaction on root number of onion during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

4.1.13 Root biomass

There was no significant difference in root biomass for the main effect of cultivar, as well as the interaction of cultivar and spacing. The main effect of spacing was however highly significant ($P < 0.001$) for fresh root biomass in both 2015 and 2016 cropping seasons (Table 12). The greatest values of root biomass of 3.8 g and 4.0 g were recorded at 14 cm x 10 cm spacing in 2015 and 2016 cropping seasons respectively, whereas the least root biomasses of 1.7 g and 2.0 g were recorded by plants from 8 cm x 10 cm spacing.

Table 12: Effect of spacing on fresh root biomass of onion

Spacing (cm)	Year	
	2015	2016
	(g)	(g)
8 x 10	1.7	2.0
10 x 10	1.8	2.1
12 x 10	2.7	2.9
14 x 10	3.8	4.0
LSD (0.05)	0.5	0.5
P (value)	< 0.001	< 0.001

4.1.14 Plant fresh biomass

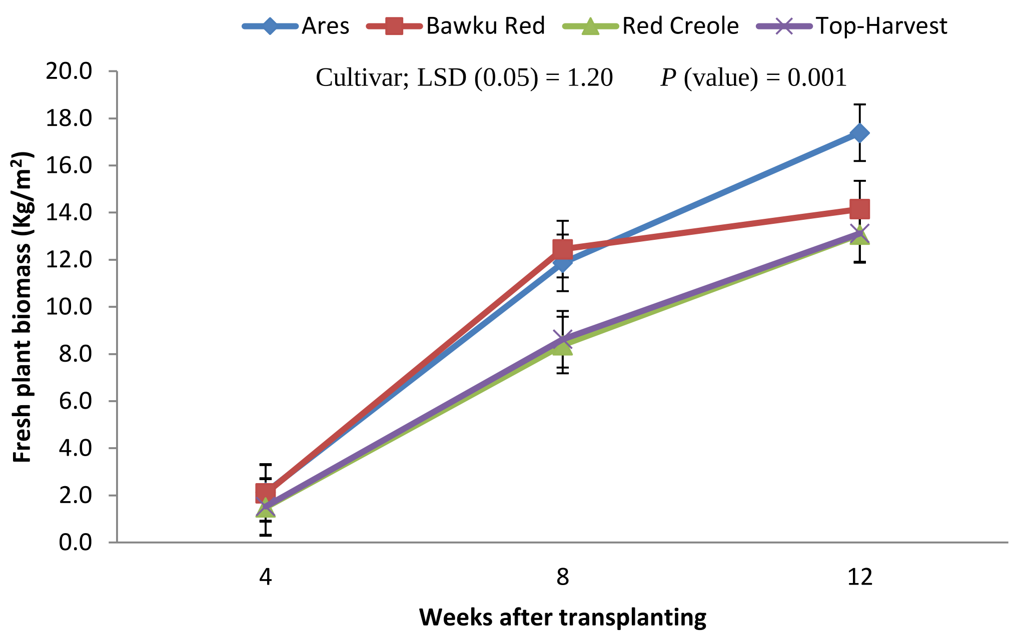
Cultivar x spacing interaction has no significant effect on plant fresh biomass for the two cropping seasons. There were significant ($P < 0.001$) differences for fresh plant biomass for spacing (Table 13) in both seasons. In both 2015 and 2016 cropping seasons, the greatest fresh biomass production of 10.8 kg/m^2 and 16.9 kg/m^2 were recorded by plants from 8 cm x 10 cm spacing, whiles the least fresh biomass production of 7.3 kg/m^2 and 10.1 kg/m^2 were recorded by plants from the 14 cm x 10 cm spacing.

Table 13: Effect of spacing on fresh biomass production of onion

Spacing (cm)	Year	
	2015	2016
	(kg/m^2)	(kg/m^2)
8 x 10	10.8	16.9
10 x 10	9.3	14.5
12 x 10	8.0	11.9
14 x 10	7.3	10.1
LSD (0.05)	0.7	1.1
P (value)	< 0.001	< 0.001

There were highly significant ($P < 0.001$) differences in cultivar effect in the 2015 and 2016 cropping seasons (Figure 9). The greatest fresh plant biomass production of 17.4 kg/m^2 was recorded from Ares in 2015 cropping season at 12WAT, whilst the least fresh plant biomass production of 1.5 kg/m^2 was recorded from Red Creole and Top-Harvest at 4WAT. Similarly in 2016, fresh plant biomass production showed highly significant ($P < 0.001$) difference among cultivar. The greatest biomass production of 31 kg/m^2 was recorded from Ares at 12WAT, whereas the least biomass of 1.6 kg/m^2 was recorded from Bawku Red cultivar at 4WAT.

(a)



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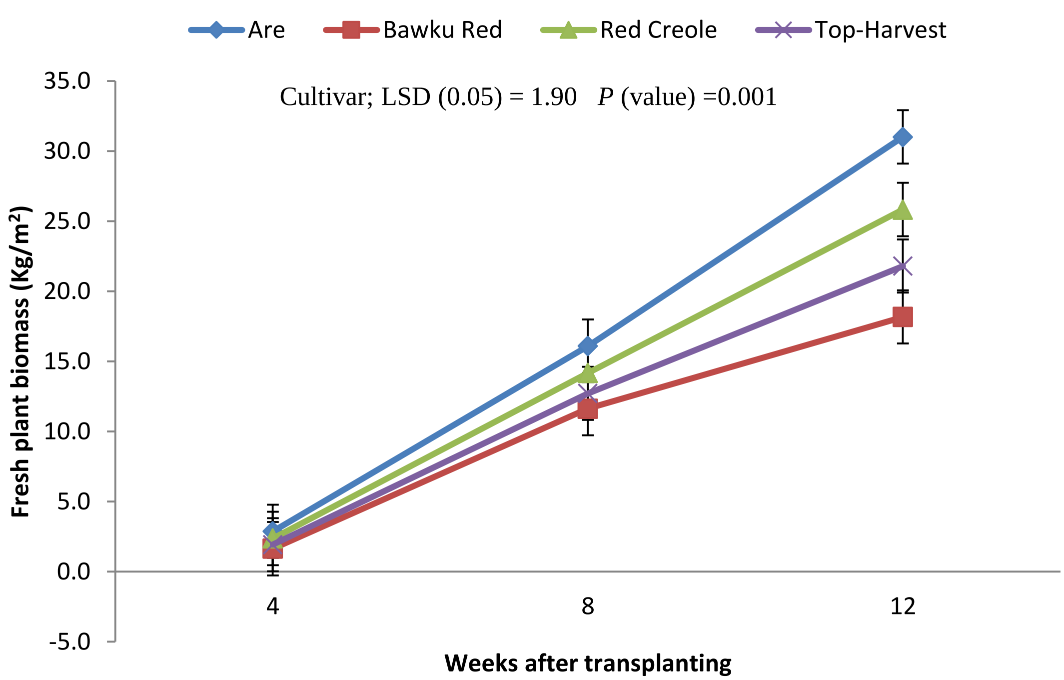


Figure 9: Effects of cultivar on fresh plant biomass of onion during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

4.1.15 Plant dry biomass

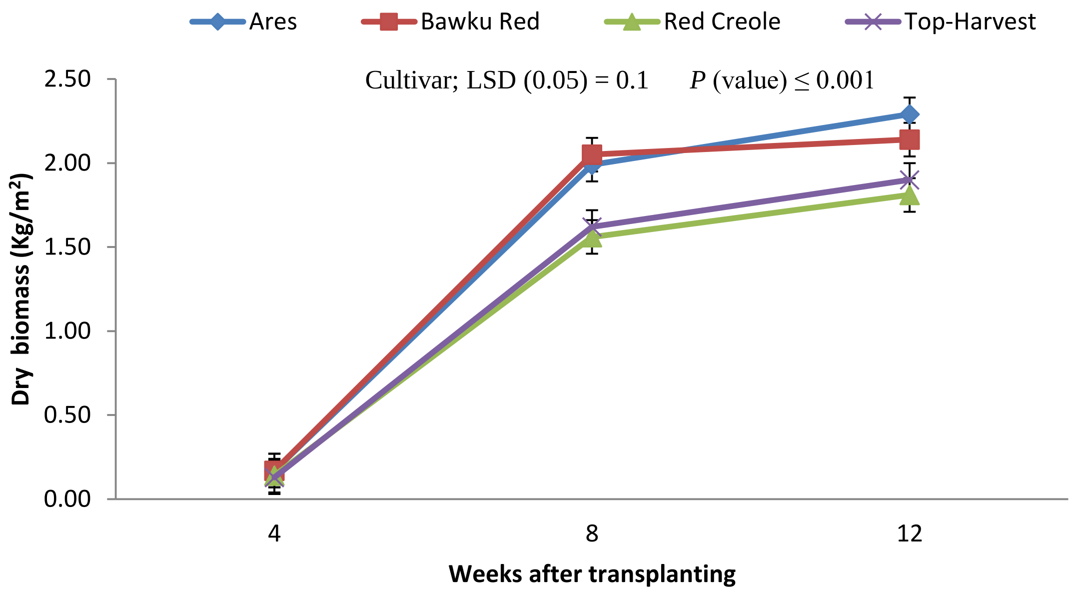
There was no cultivar x spacing interaction effect for dry biomass production in the 2015 and 2016 cropping seasons. Spacing showed highly significant ($P < 0.001$) differences for dry plant biomass production in the two cropping seasons (Table 14). The highest dry biomass production of 1.7 kg/m^2 and 2.5 kg/m^2 were recorded from plants from the 8 cm x 10 cm spacing, whiles the least dry biomass production of 1.1 kg/m^2 and 1.4 kg/m^2 were recorded from 14 cm x 10 cm spacing.

Table 14: Effect of spacing on dry plant biomass production of onion

Spacing (cm)	Year	
	2015	2016
	(kg/m^2)	(kg/m^2)
8 x 10	1.7	2.5
10 x 10	1.4	2.0
12 x 10	1.2	1.7
14 x 10	1.1	1.4
LSD (0.05)	0.08	0.09
P (value)	< 0.001	< 0.001

There were highly significant ($P < 0.001$) differences in cultivar effect for dry plant biomass production in both cropping seasons (Figure 10). The results showed that in the 2015 production season, the highest plant dry biomass production of 2.3 kg/m^2 was recorded from Ares at 12WAT, whilst the least dry biomass of 0.1 kg/m^2 was recorded from Red Creole and Top-Harvest at 4WAT. Similarly in 2016 season, the highest dry plant biomass of 3.9 kg/m^2 was also recorded from Ares at 12WAT, whereas the least dry plant biomass (0.1 kg/m^2) was recorded from Bawku Red and Top-Harvest at 4WAT.

(a)



(b)

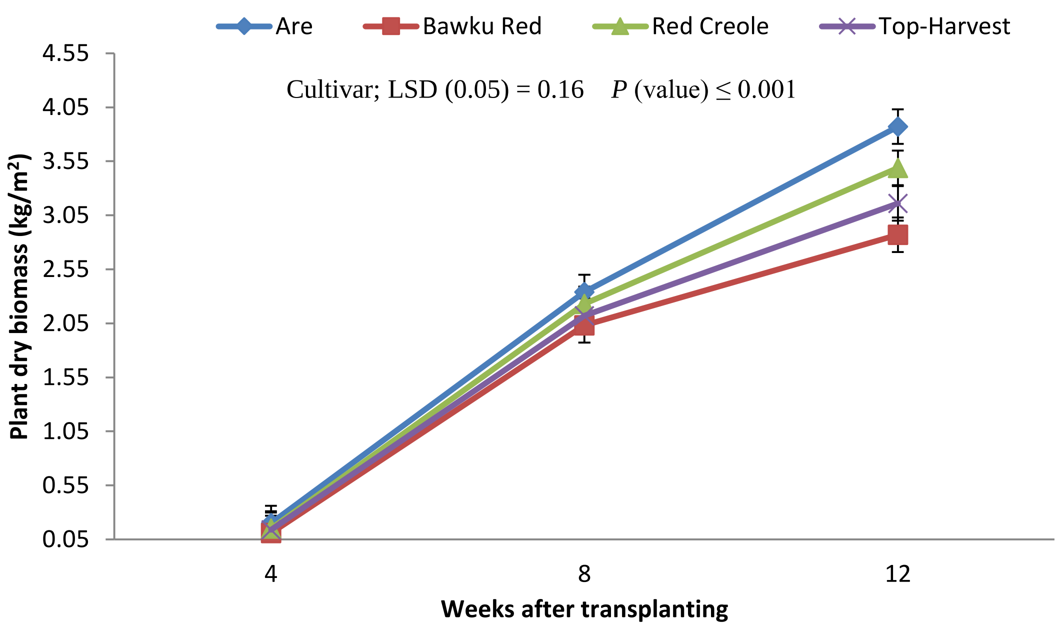


Figure 10: Effect of cultivar on dry plant biomass production (kg/m^2) of onion during (a) 2015 cropping season and (b) 2016 cropping season.

4.1.16 Days to maturity

The interactions of cultivar x spacing was not significant for maturity period. There were highly significant (*P* < 0.001) differences for days to maturity among cultivars (Table 15). The cultivar with the earliest days (123 and 131) to maturity was Bawku Red, whiles the cultivar that took the longest days (138 and 140) to mature was Top-Harvest in both 2015 and 2016 cropping seasons respectively.

Table 15: Maturity days among onion cultivars

Cultivar	**Year**	
	2015	2016
Ares	126	134
Bawku Red	123	131
Red Creole	137	139
Top-Harvest	138	140
LSD (0.05)	3.2	3.1
P (value)	< 0.001	< 0.001

Similarly, there were highly significant (*P* < 0.001) differences for days to maturity among spacing (Table 16). The spacing with the earliest days (127 and 129) to maturity was recorded at 8 cm x 10 cm in both 2015 and 2016 cropping seasons, whiles the spacing 14 cm x 10 cm recorded the longest days of 137 and 141 to maturity.

Table 16: Effect of spacing on days to maturity of onion

Spacing (cm)	Year	
	2015	2016
8 x 10	127	129
10 x 10	128	135
12 x 10	131	140
14 x 10	137	141
LSD (0.05)	3.2	3.1
P (values)	< 0.001	< 0.001

4.1.17 Total bulb yield

The interaction of the two main factors: cultivar x spacing had no significant effects on bulb yield in both cropping seasons (2015 and 2016). The main effect of cultivar however, showed highly significant ($P < 0.001$) difference for total bulb yield in 2015 and 2016 cropping seasons (Table 17). Ares was superior to the other cultivars. The highest bulb yields of 24.7 mt/ha and 28.6 mt/ha) were recorded from Ares in both 2015 and 2016 seasons respectively, whiles the least total bulb yields of 15.6 mt/ha and 17.8 mt/ha) were recorded from Bawku Red in both 2015 and 2016 seasons.

Table 17: Effect of cultivar on total bulb yield of onion

Cultivar	Year	
	2015	2016
	(mt/ha)	(mt/ha)
Ares	24.7	28.6
Bawku Red	15.6	17.8
Red Creole	16.9	19.0
Top-Harvest	15.9	18.4
LSD (0.05)	2.8	2.7
P (value)	< 0.001	< 0.001

The main effect of spacing was also significant in 2015 ($P < 0.016$) and in 2016 ($P < 0.008$) cropping seasons for total bulb yield (Table 18). Plants from 8 cm x 10 cm spacing recorded the highest total bulb yields of 19.9 mt/ha and 22.8 mt/ha in 2015 and 2016 respectively, whereas the least total bulb yields (15.5 mt/ha and 18.1 mt/ha) were recorded from 14 cm x 10 cm spacing in 2015 and 2016 cropping seasons respectively.

Table 18: Effect of spacing on total bulb yield of onion

Spacing (cm)	Year	
	2015	2016
	(mt/ha)	(mt/ha)
8 x 10	19.9	22.8
10 x 10	19.1	21.7
12 x 10	18.5	21.1
14 x 10	15.5	18.1
LSD (0.05)	2.8	2.7
P (values)	< 0.016	< 0.008

4.1.18 Average bulb weight

The interaction of cultivar x spacing had no significant effect on average bulb weight. Cultivars however, showed highly significant (P < 0.001) difference from each other in both cropping seasons of 2015 and 2016 (Table 19). The highest average bulb weights (90 g and 108.5 g) were recorded from Ares in both cropping seasons respectively, whiles the least average bulb weights of 68.1 g and 88.0 g were recorded from Bawku Red.

Table 19: Effect of cultivar on bulb weight of onion

Cultivar	Year	
	2015	2016
	(g)	(g)
Ares	90.0	108.5
Bawku Red	68.1	88.0
Red Creole	80.9	101.2
Top-Harvest	75.7	95.8
LSD (0.05)	3.4	3.8
P (value)	< 0.001	< 0.001

Spacing effect was also highly significant ($P < 0.001$) for average bulb weight in the two cropping seasons (Table 20). The highest average bulb weights of 86.3 g and 106.3 g were recorded from plants at 14 cm x 10 cm spacing in both cropping seasons, whiles the least average bulb weights of 69.2 g and 88.4 g were recorded from those planted at 8 cm x 10 cm spacing.

Table 20: Effect of spacing on bulb weight of onion

Spacing (cm)	Year	
	2015	2016
	(g)	(g)
8 x 10	69.2	88.4
10 x 10	74.4	94.1
12 x 10	84.8	104.7
14 x 10	86.3	106.3
LSD (0.05)	3.4	3.8
P (values)	< 0.001	< 0.001

4.1.19 Bulb diameter

Cultivar x spacing interaction had no significant effect in the two cropping seasons on bulb diameter but the main effect of cultivar showed highly significant ($P < 0.001$) for bulb diameter in both cropping seasons of 2015 and 2016 (Table 21). The greatest bulb diameters of 6.7 cm and 7.8 cm were recorded from Ares whiles the least bulb diameters of 6.1 cm and 7.1 cm were recorded from Bawku Red.

Table 21: Effect of cultivar on bulb diameter of onion

Cultivar	Year	
	2015	2016
	(cm)	(cm)
Ares	6.7	7.8
Bawku Red	6.1	7.1
Red Creole	6.3	7.3
Top-Harvest	6.2	7.2
LSD (0.05)	0.2	0.2
P (value)	< 0.001	< 0.001

The main effect of spacing was also highly significant ($P < 0.001$) for bulb diameter in both cropping seasons (Table 22). The greatest bulb diameters of 6.9 cm and 7.9 cm were recorded from plants at 14 cm x 10 cm spacing in both cropping seasons, whiles the least bulb diameters of 5.6 cm and 6.7 cm were recorded from onion planted at 8 cm x 10 cm spacing.

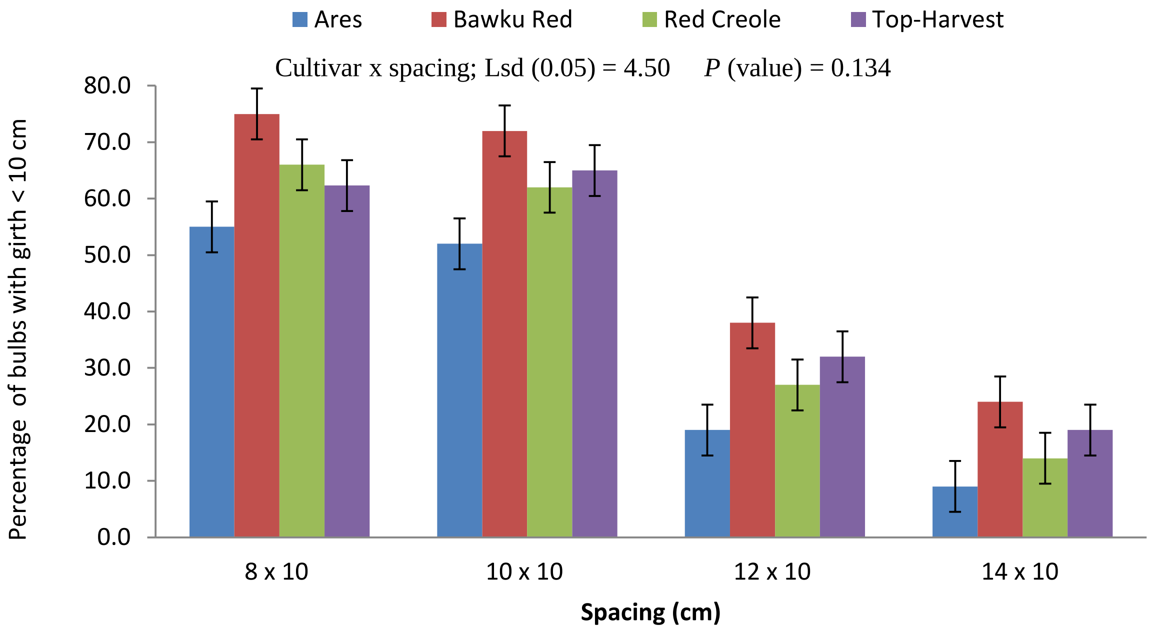
Table 22: Effect of plant spacing on bulb diameter of onion

Spacing (cm)	Year	
	2015	2016
	(cm)	(cm)
8 x 10	5.6	6.7
10 x 10	6.1	7.2
12 x 10	6.6	7.7
14 x 10	6.9	7.9
LSD (0.05)	0.2	0.2
P (value)	< 0.001	< 0.001

4.1.20 Grading

The main effects of cultivar, spacing and their interaction for the two cropping seasons were significant. For percentage bulb girth < 10 cm, The highest value for percentage of bulbs with girth < 10 cm (75%) was recorded from Bawku Red in 2015 cropping season at 8 cm x 10 cm spacing, whereas the least value of percentage of bulbs with girth < 10 cm (9%) was recorded from Ares at 14 cm x 10 cm spacing (Figure 11). Similarly, the highest value of percentage of bulbs with girth < 10 cm (74%) was also obtained from Bawku Red in 2016 cropping season at 8 cm x 10 cm spacing, whereas the least value (8%) of percentage of bulbs with girth < 10 cm was recorded from Ares at 14 cm x 10 cm spacing.

(a)



(b)

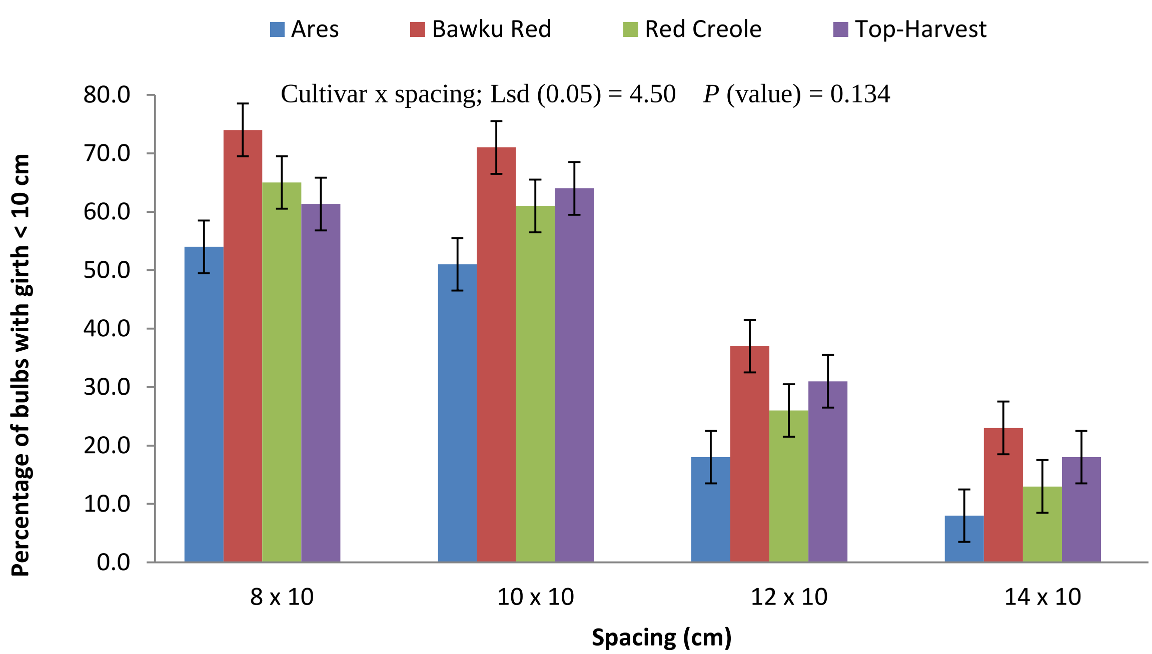


Figure 11: Effect of cultivar x spacing interaction on percentage of bulbs with girth < 10 cm during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

The Bawku Red cultivar recorded the highest percentage (52.3% and 51.3%) values of bulbs with girth < 10 cm in both cropping seasons and the lowest percentage values of 33.8% and 32.8% were obtained from Ares (Table 23).

Table 23: Effect of cultivar on percentage of bulbs with girth < 10 cm

Cultivar	**Year**	
	2015	2016
	(%)	(%)
Ares	33.8	32.8
Bawku Red	52.3	51.3
Red Creole	42.3	41.3
Top-Harvest	44.6	43.6
LSD (0.05)	2.25	2.25
P (value)	< 0.001	< 0.001

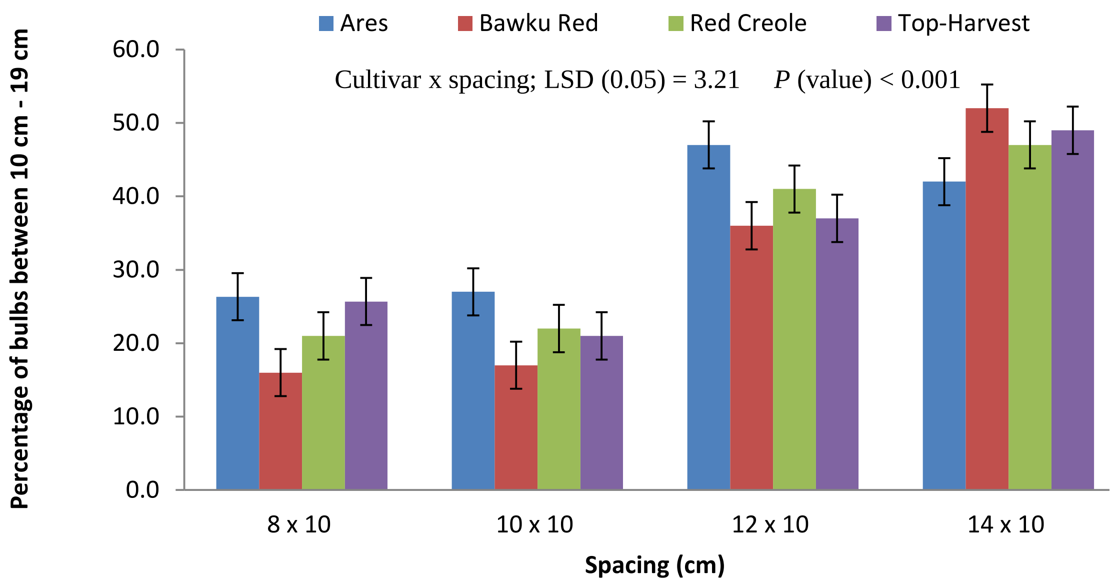
The highest percentage values (64.6% and 63.6%) of bulbs with girth < 10 cm were recorded from onions planted at 8 cm x 10 cm spacing in the two cropping seasons, whereas the lowest percentage values (16.5% and 15.5%) were recorded from those at the 14 cm x 10 cm spacing (Table 24).

Table 24: Effect of spacing on percentage of bulbs with girth < 10 cm

Spacing (cm)	**Year**	
	2015	2016
	(%)	(%)
8 x 10	64.6	63.6
10 x 10	62.8	61.8
12 x 10	29.0	28.0
14 x 10	16.5	15.5
LSD (0.05)	2.25	2.25
P (values)	< 0.001	< 0.001

The results for percentage of bulbs with girth of 10 cm - 19 cm in 2015 and 2016 cropping seasons showed cultivar x spacing interaction to be highly significant ($P < 0.001$). In 2015 cropping season, the highest value of 52% of bulbs with girth of 19 cm - 10 cm was obtained from Bawku Red at 14 cm x 10 cm spacing, whereas the least value of 16% of bulbs with girth of 10 cm - 19 cm was recorded from Bawku Red cultivar at 8 cm x 10 cm spacing. The result for percentage of bulbs with girth of 10 cm - 19 cm in the 2016 cropping season was similar to the 2015 (Figure 12).

(a)



(b)

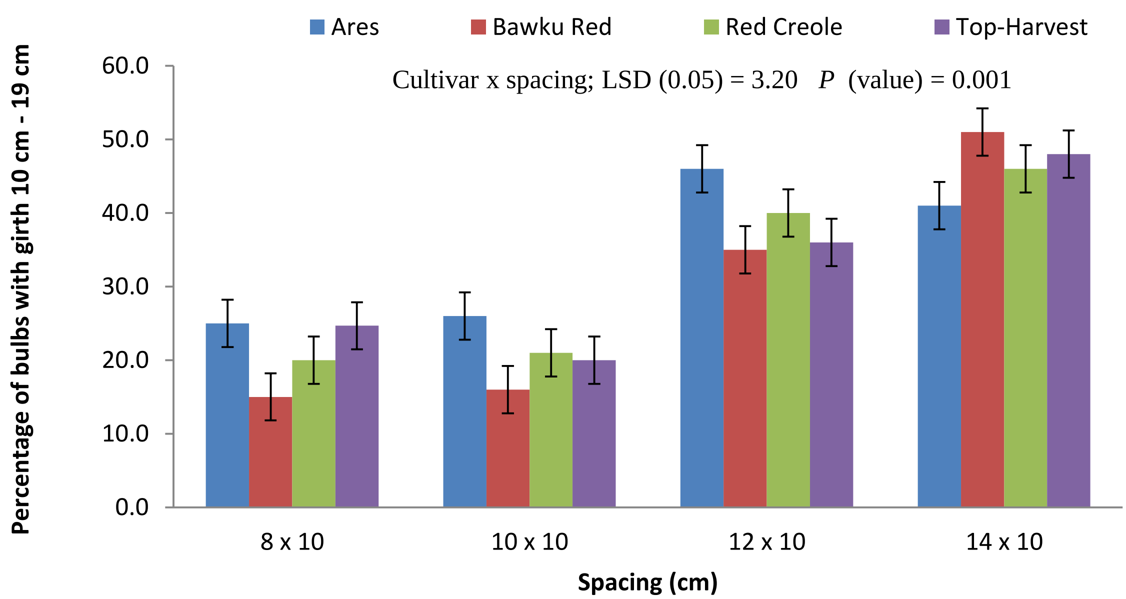


Figure 12: Effect of cultivar x spacing interaction on percentage of bulbs with girth 10 cm - 19 cm during (a) 2015 cropping season and (b) 2016 cropping season. Bar represent SEM.

The cultivar that recorded the highest percentage (35.6% and 34.5%) values of bulbs with girth of 10 cm - 19 cm in both cropping seasons was the Ares and the lowest percentage values of 30.3% and 29.3% were obtained from Bawku Red (Table 25).

Table 25: Effect of cultivar on percentage of bulbs with girth 10-19 cm

Cultivar	**Year**	
	2015	2016
	(%)	(%)
Ares	35.6	34.5
Bawku Red	30.3	29.3
Red Creole	32.8	31.8
Top-Harvest	33.2	32.2
LSD (0.05)	1.61	1.60
P (value)	< 0.001	< 0.001

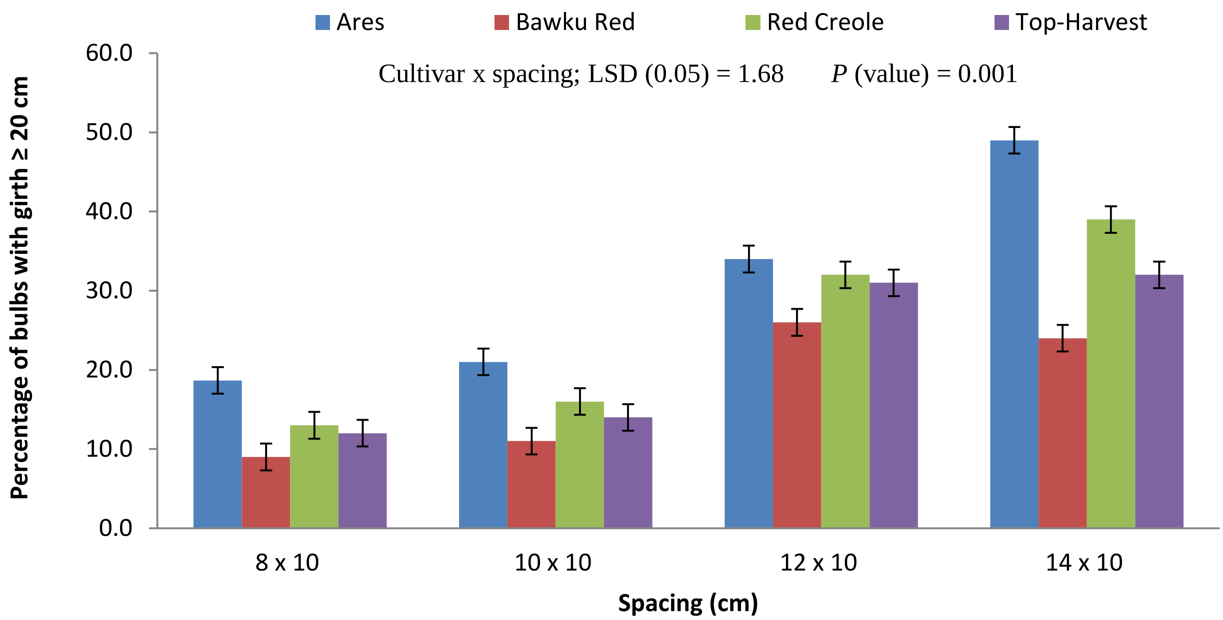
The highest percentage values (47.5% and 46.5%) of bulbs with girth of 10 cm - 19 cm were recorded at 14 cm x 10 cm spacing in the two production seasons, whiles the lowest percentage values (21.8% and 20.1%) were recorded at the 10 cm x 10 cm spacing in both seasons respectively (Table 26).

Table 26: Effect of spacing on percentage of bulbs with girth 10-19 cm

Spacing (cm)	Year	
	2015	2016
	(%)	(%)
8 x 10	22.3	21.2
10 x 10	21.8	20.1
12 x 10	40.3	39.3
14 x 10	47.5	46.5
LSD (0.05)	1.61	1.60
P (values)	< 0.001	< 0.001

The main effect of cultivar x spacing interaction showed highly significant ($P < 0.001$) difference on percentage of bulbs with girth ≥ 20 cm in both cropping seasons (Figure 13). In the 2015 cropping season, the highest value (49%) of percentage of bulbs with girth ≥ 20 cm was observed from Ares at 14 cm x 10 cm spacing, whereas the least value of 9% was recorded from Bawku Red at a spacing of 8 cm x 10 cm. The result for percentage of bulbs with girth ≥ 20 cm in 2016 was similar to that of 2015. The highest value of 51% was observed from Ares at 14 cm x 10 cm spacing, whereas the least value of 11% was recorded from Bawku Red at 8 cm x 10 cm.

(a)



(b)

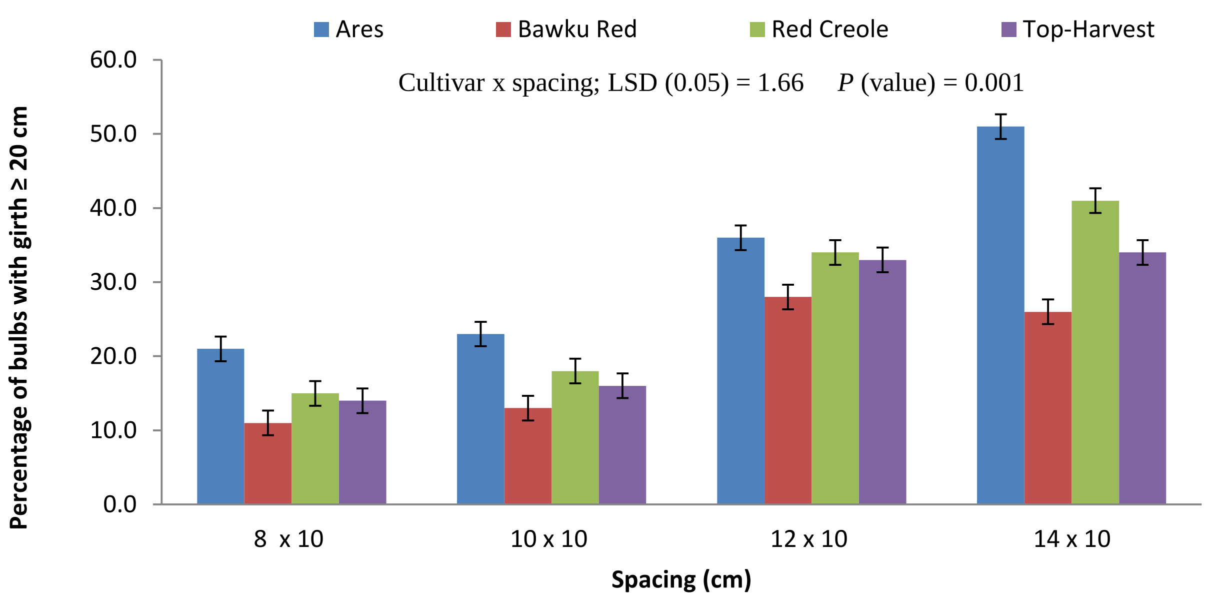


Figure 13: Effect of cultivar x spacing interaction on percentage of bulbs with girth ≥ 20 cm during (a) 2015 cropping season and (b) 2016 cropping season. Bars represent SEM.

Ares cultivar was superior to the other cultivars in that it recorded the highest percentage values (30.7% and 32.8%) of bulbs with girth ≥ 20 cm in both cropping seasons respectively, whiles the lowest percentage values of 17.5% and 19.5% were recorded from Bawku Red (Table 27).

Table 27: Effect of cultivar on percentage of bulbs with girth ≥ 20 cm

Cultivar	Year	
	2015	2016
	(%)	(%)
Ares	30.7	32.8
Bawku Red	17.5	19.5
Red Creole	25.0	27.0
Top-Harvest	22.3	24.3
LSD (0.05)	0.84	0.83
P (value)	< 0.001	< 0.001

The spacing that recorded the highest percentage values (36.0% and 38.0%) of bulbs with girth ≥ 20 cm was the 14 cm x 10 cm spacing in the two cropping seasons respectively, whereas the lowest percentage values of 13.2% and 15.3% were recorded at 8 cm x 10 cm spacing (Table 28).

Table 28: Effect of spacing on percentage of bulbs with girth ≥ 20 cm

Spacing (cm)	Year	
	2015	2015/2016
	(%)	(%)
8 x 10	13.2	15.3
10 x 10	15.5	17.5
12 x 10	30.8	32.8
14 x 10	36.0	38.0
LSD (0.05)	0.84	0.83
P (values)	< 0.001	< 0.001

4.2 Storage data

The crop was harvested on 7th April 2015 for the 2015 cropping season and 31 March 2016 for the 2016 cropping season when about 70-80% of the plants were physiologically matured. After harvest, bulbs were cured under a shade for 7 days before storage.

4.2.1 Relative humidity and temperature of storage structures

The results for minimum, maximum and mean daily temperatures and as well as the relative humidity at 6:00 am (GMT) and 15:00 pm (GMT) were recorded in both storage structures in 2015 and 2016 (Table 29 and Table 30). Generally, the results showed that thatch roofed storage structure in both 2015 and 2016 recorded low value numbers in relative humidity and temperature as compared with structure roofed with corrugated iron sheet. The minimum temperature range for the thatch roofed storage structure during 2015 storage was 20.5°C-29.7°C, whiles the maximum daily temperatures range was 30.1°C-38.2°C. The highest daily maximum temperature of 38.2°C was recorded 30 days after harvest (30 DAH) and the lowest maximum temperature of 30.1°C was recorded in 90 DAH. The relative humidity range for the thatch storage structure at 6:00 GMT was between 40% and 69%. The lowest relative humidity of 40% was recorded at 50 DAH and 60 DAH, whereas the highest relative humidity of 69% was recorded at 90 DAH. Whiles at the 15:00 GMT the range of relative humidity was 60% and 91%. The lowest relative humidity of 60% was recorded at the 30 DAH and the highest relative humidity of 90% was recorded at 90 DAH. However in the corrugated iron sheet roofed storage structure in 2015, the minimum daily temperature range was 24.0^oC-29.8^oC with the lowest temperature of 24.0^oC recorded at 80 DAH and 90 DAH. Whiles the highest minimum daily temperature of 29.8^oC was obtained at 10 DAH. Whereas the maximum daily temperature range was 31.1^oC-43.2^oC. The lowest maximum temperature recorded for the storage structure was 31.1^oC at 90DAH. Whiles the highest maximum temperature recorded was 43.2^oC, at 30 DAH. The relative humidity range for the corrugated iron sheet roofed storage structure at 6:00 GMT was between 43% and 70%. The lowest relative humidity of 43% was recorded at 50 DAH and the highest relative humidity of 70% was recorded at 90 DAH. Whiles at the 15:00 GMT the relative humidity range was 62% and 93%, the lowest relative humidity of 62% was recorded at 20 DAH whiles the highest relative humidity of 93% was recorded at 90 DAH (Table 29).

Table 29: Relative humidity and temperature during 90 days of storage period of bulbs in (a) thatch roof storage structure in 2015 and (b) corrugated iron sheet roof storage structure in 2015

(a)

Days	Relative Humidity % (Hours GMT)		Max. & Min. Temperature (°C)		
	06:00	15:00	Minimum	Mean	Maximum
10	44.0	62.0	29.1	33.6	38.0
20	43.0	61.0	29.0	33.0	37.0
30	45.0	60.0	29.7	34.0	38.2
40	42.0	69.0	25.5	30.8	36.0
50	40.0	72.0	25.1	30.5	35.9
60	40.0	74.0	25.0	30.0	35.0
70	58.0	86.0	22.2	26.9	31.5
80	60.0	90.0	21.4	26.1	30.7
90	69.0	91.0	20.5	25.3	30.1

(b)

Days	Relative Humidity % (Hours GMT)		Max. & Min. Temperature (°C)		
	06:00	15:00	Minimum	Mean	Maximum
10	46.0	63.0	29.8	35.9	42.0
20	45.0	62.0	29.5	34.8	40.0
30	45.0	63.0	29.2	36.2	43.2
40	44.0	75.0	28.4	33.7	39.0
50	43.0	75.6	28.0	33.5	38.9
60	45.0	76.0	28.0	33.0	38.0
70	62.0	90.0	26.2	30.4	34.5
80	63.0	91.0	24.0	29.3	34.5
90	70.0	93.0	24.0	27.6	31.1

Similar results were observed during the 2016 storage in both thatch roofed storage structure and corrugated iron sheet roofed storage structure (Table 30). In the thatch roofed structure, the minimum daily temperature range was 20°C-26°C. The lowest temperature of 20°C was recorded at 90 DAH and the highest (26°C) was recorded at 10 DAH and 30 DAH. Whiles the maximum daily temperature range was 30°C-38°C with the lowest of 30°C recorded at 70 DAH and 80 DAH, whiles the highest (38°C) was recorded at 30 DAH. The relative humidity range at 6:00 GMT was 69% - 86% with the lowest relative humidity of 69% recorded at the 90 DAH, whiles the highest (86%) was recorded at 60 DAH. At the

15:00 GMT, the relative humidity range was 37%-95%. The lowest relative humidity of 37% was obtained at the 10 DAH, whereas the highest (95%) was recorded at 90 DAH.

In the corrugated iron sheet roofed structure, the minimum daily temperature range was 25^{o}C-28^{o}C. The lowest (25^{o}C) was recorded at 90 DAH and the highest (28^{o}C) was recorded at the 30 DAH. However, at the maximum daily temperature range of 32^{o}C-40^{o}C the lower temperature of 32^{o}C was recorded at 90 DAH, whiles the highest temperature (40^{o}C) was recorded at both 20 DAH and 30 DAH. The relative humidity range for 6:00 GMT was 70%-86%. The lowest relative humidity (70%) was recorded at 90 DAH, whiles that of the highest (86%) was at 60 DAH. At the 15:00 GMT, the relative humidity range was 40%-96%. The lowest relative humidity (40%) was recorded at 10 DAH and the highest relative humidity (96%) was recorded 90 DAH.

Table 30: Relative humidity and temperature during 90 days storage period of bulbs from (a) Thatch roof storage structure in 2016 and (b) Corrugated iron sheet roof storage structure in 2016

(a)

Days	Relative Humidity % (Hours GMT)		Max. & Min. Temperature (°C)		
	06:00	15:00	Minimum	Mean	Maximum
10	71	37	26.0	31.0	36.0
20	73	41	25.0	31.0	37.0
30	78	40	26.0	32.0	38.0
40	82	46	25.0	30.5	36.0
50	84	54	24.0	30.0	36.0
60	86	56	22.0	28.5	35.0
70	72	90	22.0	26.0	30.0
80	70	92	21.0	25.5	30.0
90	69	95	20.0	25.5	31.0

(b)

Days	Relative Humidity % (Hours GMT)		Max. & Min. Temperature (°C)		
	06:00	15:00	Minimum	Mean	Maximum
10	72	40	27.0	33.0	39.0
20	75	43	27.0	33.5	40.0
30	76	44	28.0	34.0	40.0
40	84	48	26.6	32.1	37.6
50	85	59	26.5	31.8	37.1
60	86	58	26.4	31.7	37.0
70	74	92	25.5	29.0	32.5
80	73	95	25.1	28.6	32.1
90	70	96	25.0	28.5	32.0

4.2.2 Percentage bulb weight loss

The main effects of cultivar, spacing and their interaction in the two storage structures for percentage bulb weight losses during 2015 and 2016 were highly significant ($P < 0.001$). Percentage bulb weight loss was high in structure roofed with corrugated iron sheet than the thatch roofed structure in 2015 and 2016 (Table 31 and Table 32). During the 2015 storage, the cultivar with the highest percentage bulb weight loss of 39.47% at 90 DAH in the thatch roofed structure was Ares, followed by Bawku Red of 37.85%, Red Creole with

37.62% and 37.59% from Top-Harvest. Similar results were found in the corrugated iron sheet roofed structure at 90 DAH. The highest value for percentage of bulbs weight loss of 43.04% was recorded from Ares, followed by Red Creole of 41.71%, Top-Harvest of 40.76% and Bawku Red of 40.56% (Table 31).

Table 31: Effect of cultivar on total weight loss of onion bulbs during 90 days storage, (a) thatch roofed storage structure used in 2015 and (b) corrugated iron sheet roofed storage structure used in 2015

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	14.77	13.99	14.23	14.05
20	20.37	19.22	19.57	19.32
30	24.53	23.33	23.74	23.47
40	27.84	26.45	26.87	26.64
50	30.55	29.15	29.32	29.23
60	32.84	31.32	31.45	31.45
70	34.70	33.11	33.06	33.19
80	36.30	34.54	34.55	34.47
90	39.47	37.85	37.62	37.59
Cultivar; LSD (0.05) = 0.217, P (value); $P < 0.001$				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	16.29	15.45	15.95	15.73
20	22.50	21.30	21.93	21.55
30	26.81	25.34	26.13	25.58
40	30.40	28.77	29.58	28.98
50	33.45	31.51	32.37	31.74
60	36.05	33.95	34.83	34.10
70	38.26	36.04	37.01	36.18
80	39.19	36.89	38.00	37.17
90	43.04	40.56	41.71	40.76
Cultivar; LSD (0.05) = 0.155, P (value); $P < 0.001$				

In the 2016 storage, Ares again recorded the highest percentage of bulbs weight loss of 34.77% at 90 DAH in the thatch roofed structure, whiles Bawku Red recorded the least (33.29%). Whereas at the corrugated iron sheet roofed structure, Ares was again significantly higher than the other cultivars (Table 32).

Table 32: Effect of cultivar on total weight loss of onion bulbs during 90 days storage, (a) thatch roof storage structure used in 2016 and (b) corrugated iron sheet roof storage structure used in 2016

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	13.62	13.30	13.14	13.46
20	18.45	18.18	17.76	18.44
30	22.04	21.56	21.35	22.07
40	24.87	24.15	24.16	24.63
50	27.12	25.90	26.18	26.39
60	28.79	27.75	27.74	28.13
70	30.21	29.11	29.21	29.64
80	31.25	30.06	30.32	30.72
90	34.77	33.29	33.66	34.11
Cultivar; LSD (0.05) = 0.179, P (value); $P < 0.001$				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	14.77	13.99	14.23	14.05
20	20.37	19.22	19.57	19.32
30	24.53	23.33	23.74	23.47
40	27.84	26.45	26.87	26.64
50	30.55	29.15	29.32	29.23
60	32.84	31.32	31.45	31.45
70	34.70	33.11	33.06	33.19
80	36.30	34.54	34.55	34.47
90	39.47	37.85	37.62	37.59
Cultivar; LSD (0.05) = 0.217, P (value); $P < 0.001$				

Percentages of bulb weight loss were significantly affected by spacing during storage in 2015 and 2016 among the two storage structures used for the experiments (Table 33 and Table 34). The highest percentage bulb weight loss of 40.79% during the 2015 for the thatch roofed storage structure was recorded at the 14 cm x 10 cm spacing at 90 DAH, followed by percentage bulb weight loss of 38.97% at the 12 cm x 10 cm spacing, 37.22% at 10 cm x 10 cm spacing and 35.55% at the 8 cm x 10 cm spacing. In the corrugated iron sheet roofed structure the trend of percentage bulbs weight loss was similar as in the thatch roofed storage structure. The highest percentage bulbs weight loss at 90 DAH in the corrugated iron sheet roofed structure was 43.27% at the 14 cm x 10 cm spacing and the lowest percentage bulbs weight loss of 39.66% was obtained at 8 cm x 10 cm spacing (Table 33).

Table 33: Effect of spacing on total weight loss of onion bulbs during 90 days storage, (a) thatch roof storage structure used in 2015 and (b) corrugated iron sheet roof storage structure used in 2015

(a)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	13.74	13.96	14.41	14.91
20	18.90	19.39	19.73	20.46
30	22.86	23.50	23.87	24.86
40	25.69	26.60	27.25	28.26
50	28.00	29.18	29.96	31.11
60	29.91	31.29	32.29	33.57
70	31.35	32.91	34.14	35.67
80	32.64	34.25	35.66	37.31
90	35.55	37.22	38.97	40.79
Spacing; LSD (0.05) = 0.217, P (value); $P < 0.001$				

(b)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	15.62	15.75	15.95	16.11
20	21.32	21.69	21.97	22.30
30	25.32	25.76	26.20	26.58
40	28.60	29.13	29.77	30.23
50	31.25	31.90	32.66	33.27
60	33.53	34.31	35.20	35.89
70	35.49	36.36	37.42	38.22
80	36.20	37.26	38.43	39.38
90	39.66	40.91	42.25	43.27
Spacing; LSD (0.05) = 0.155, P (value); $P < 0.001$				

During the 2016 storage the highest percentage bulbs weight loss of 36.45% was recorded at 14 cm x 10 cm at 90 DAH, the next percentage bulbs weight loss of 34.87% was obtained at the 12 cm x 10 cm, 33.25% at the 10 cm x 10 cm whiles the 8 cm x 10 cm spacing was recorded the lowest percentage bulbs weight loss of 31.27% in the thatch roofed structure. Whiles in the corrugated iron sheet roofed structure, the highest percentage bulbs weight loss of 40.79% was recorded at the 14 cm x 10 cm spacing, followed by the 38.97% at 12 cm x 10 cm, 37.22% at the 10 cm x 10 cm spacing and the lowest percentage bulbs weight loss of 35.55% at 8 cm x 10 cm spacing (Table 34).

Table 34: Effect of spacing on total weight loss of onion bulbs during 90 days storage, (a) thatch roof storage structure used in 2015 and (b) corrugated iron sheet roof storage structure used in 2016

(a)

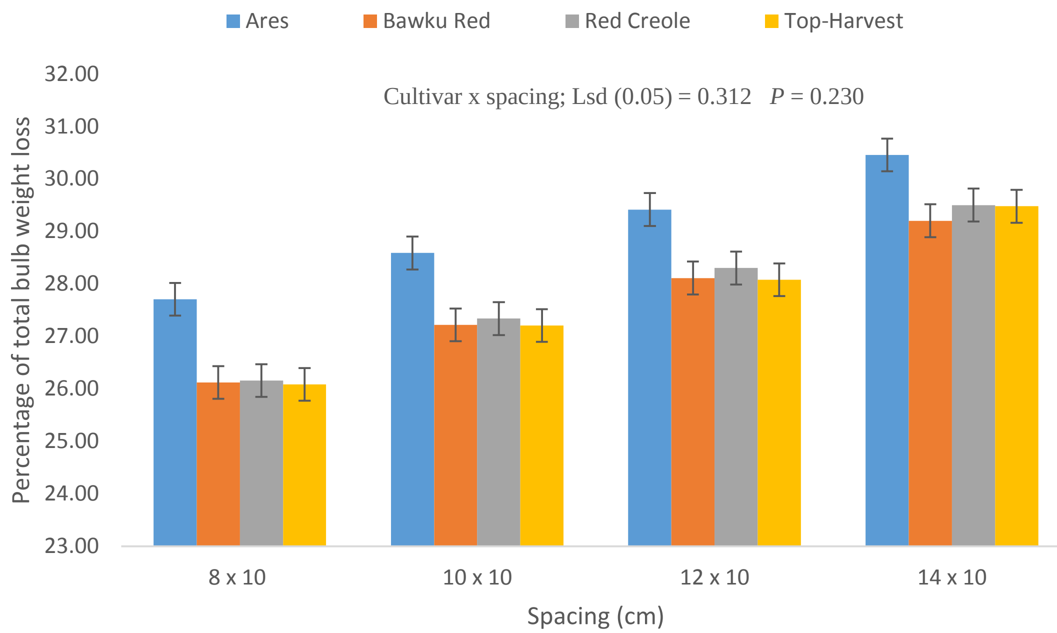
DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	12.59	13.24	13.66	14.03
20	17.03	18.00	18.65	19.16
30	20.25	21.53	22.31	22.94
40	22.67	24.12	25.13	25.89
50	24.41	25.96	27.12	28.10
60	25.90	27.59	28.85	30.08
70	27.14	28.96	30.38	31.69
80	27.96	29.96	31.49	32.94
90	31.27	33.25	34.87	36.45
Spacing; LSD (0.05) = 0.179, P (value); $P < 0.001$				

(b)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	13.74	13.96	14.41	14.91
20	18.90	19.39	19.73	20.46
30	22.86	23.50	23.87	24.86
40	25.69	26.60	27.25	28.26
50	28.00	29.18	29.96	31.11
60	29.91	31.29	32.29	33.57
70	31.35	32.91	34.14	35.67
80	32.64	34.25	35.66	37.31
90	35.55	37.22	38.97	40.79
Spacing; LSD (0.05) = 0.217, P (value); $P < 0.001$				

There was significant difference in percentage bulb weight loss for cultivar x spacing interaction for the two different storage structures used for the storage experiments in both 2015 and 2016 (Figure 14 and Figure 15). The results showed that the highest percentage bulbs weight loss for cultivar x spacing interaction during the 2015 storage in the Thatch roofed structure at the 14 cm x 10 cm spacing was 30.46% from the Ares cultivar, followed by 29.50% at 14 cm x 10 cm spacing from Red Creole, 29.48% at 14 cm x 10 cm spacing from Top-Harvest, whereas 29.20% at 14 cm x 10 cm spacing from Bawku Red. In the corrugated iron sheet roofed structure, the highest percentage bulbs weight loss for cultivar x spacing interaction was 32.50% and was recorded at the 14 cm x 10 cm spacing from Ares cultivar. The next higher percentage bulbs weight loss of 31.94% was recorded at the 14 cm x 10 cm spacing from Red Creole, 31.28% was obtained from Top-Harvest at the 14 cm x 10 cm and the lowest percentage bulbs weight loss of 31.04% was recorded from Bawku Red (Figure 14a and 14b).

(a)



(b)

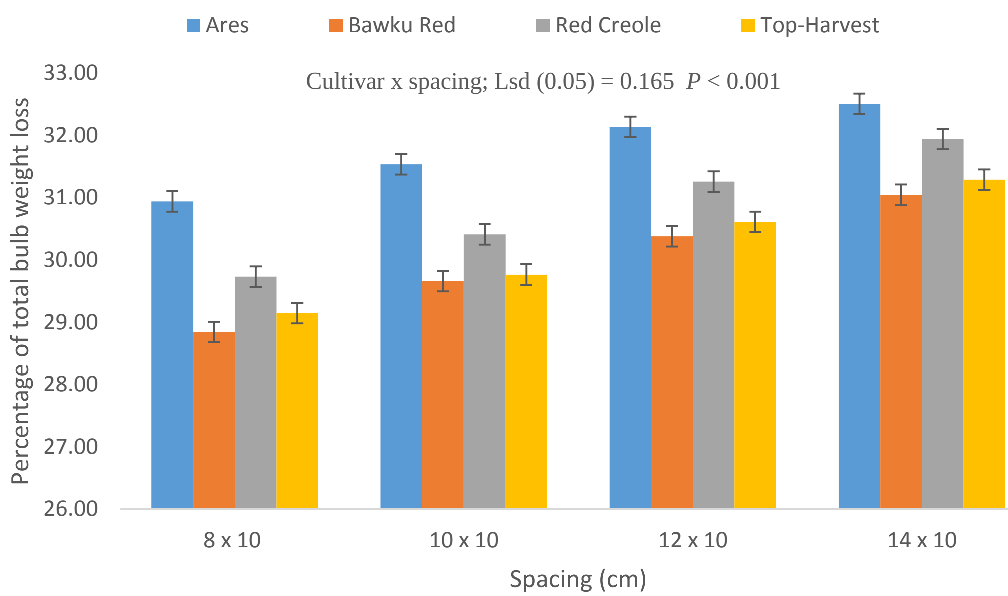
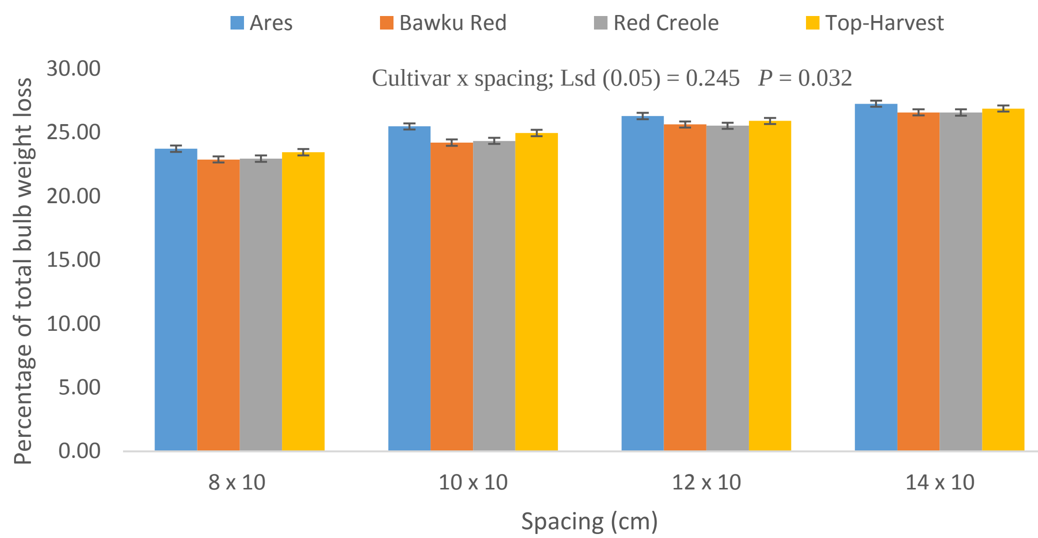


Figure 14: Effect of cultivar x spacing on total weight losses of onion bulbs during 90 days storage in (a) Thatch roofed storage structure used in 2015 and (b) Corrugated iron sheet roofed storage structure used in 2015. Bars represent SEM.

During the 2016 storage the cultivar and spacing interaction result trend was similar to the 2015 storage results. The highest percentage bulb weight loss of 27.25% was recorded at the 14 cm x 10 cm spacing from Ares cultivar, followed by 26.86% at 14 cm x 10 cm spacing from Top-Harvest, 26.57% at 14 cm x 10 cm from Bawku Red, whiles the lowest percentage bulb weight loss of 26.55% from Red Creole. Whereas in the corrugated iron sheet roofed structure the highest percentage of bulb weight loss of 30.46% was recorded from Ares at the spacing of 14 cm x 10 cm spacing, 29.50% at 14 cm x 10 cm spacing from Red Creole, 29.48% at 14 cm x 10 cm spacing from Top-Harvest, whiles the lowest of 29.20% at 14 cm x 10 cm was recorded from Bawku Red cultivar (Figure 15).

(a)



(b)

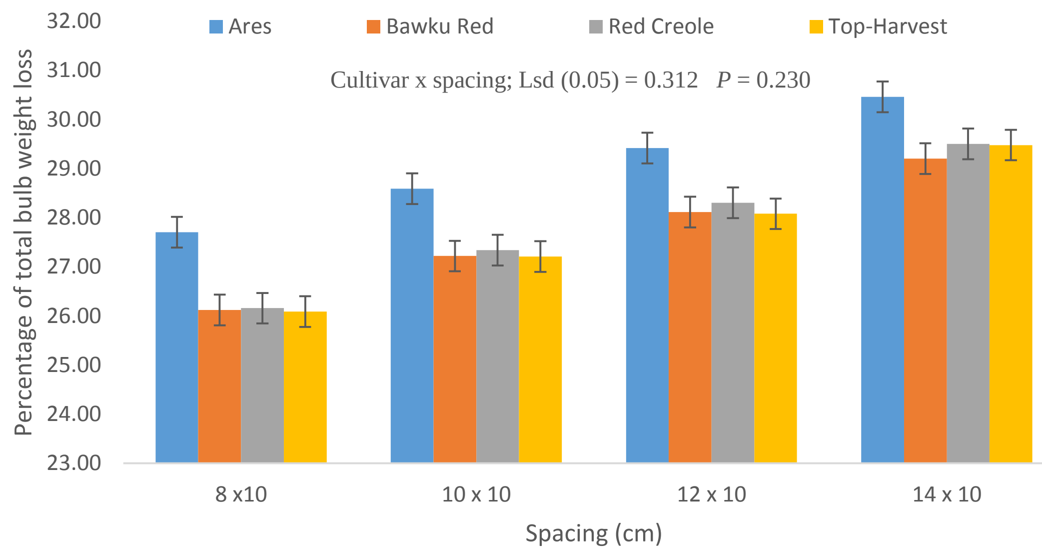


Figure 15: Effect of cultivar x spacing on total weight losses of onion bulbs during 90 days storage in (a) Thatch roofed storage structure used in 2016 and (b) Corrugated iron sheet roofed storage structure used in 2016. Bars represent SEM.

4.2.3 Percentage of rotting bulbs

Generally, there were significant ($P < 0.05$) effects for the main effects of cultivar, spacing and their interactions for the two storage structures. During the 2015 storage, Ares was the only cultivar in thatch roofed structure that recorded a percentage bulb rot of 0.75% at 70 DAH. In the corrugated iron sheet roofed structure, Ares cultivar at 90 DAH recorded the higher value of 2.92% and the lowest percentage bulb rot of 0.08% was recorded at 70 DAH from Top-Harvest (Table 35).

Table 35: Effect of cultivar on percentage of onion bulb rot during 90 days storage, (a) thatch roof storage structure used in 2015 and (b) corrugated iron sheet roof structure used in 2015

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.75	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00
Cultivar; LSD (0.05) = 0.164, P (value); *P* < 0.001				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.75	0.00	0.25	0.08
80	1.75	0.67	1.00	0.75
90	2.92	1.42	1.83	1.50
Cultivar; LSD (0.05) = 0.636, P (value); *P* = 0.070				

Similarly, during 2016, the Ares cultivar at 90 DAH recorded the highest percentage bulb rot of 0.83% in thatch roofed storage structure, whereas the lowest percentage bulb rot of 0.01% was recorded from Top-Harvest at 80 DAH. The corrugated iron sheet roofed structure at 90 DAH recorded the highest percentage bulb rot of 2.42% from Ares, whiles the lowest percentage of bulbs rot (0.03%) was recorded at 70 DAH from the same cultivar. Generally, the percentage bulb rot was lower in thatch roofed storage structure than that of the corrugated iron sheet roofed structure and the cultivar with the highest percentage bulb rot was Ares, followed by Red Creole, Top-Harvest and Bawku Red was the lowest during 2015 and 2016 storage periods (Table 36).

Table 36: Effect of cultivar on percentage of onion bulb rot during 90 days storage, (a) thatch roof structure used in 2016 and (b) corrugated iron sheet roof structure used in 2016

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.08	0.00	0.02	0.01
90	0.83	0.33	0.68	0.51
Cultivar; LSD (0.05) = 0.092, P (value); $P = 0.306$				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.03	0.00	0.00	0.00
80	0.58	0.00	0.17	0.00
90	2.42	0.75	1.50	0.88
Cultivar; LSD (0.05) = 0.247, P (value); $P < 0.001$				

Spacing showed highly significant ($P < 0.001$) difference for the two storage structures during storage in 2015 and 2016 (Table 37 and Table 38). During the 2015 storage, bulb rot of 0.75% was recorded at 70 DAH from onions planted at the 14 cm x 10 cm in thatch roofed structure. Whereas in the corrugated iron sheet roofed structure, the highest percentage bulb rot of 7.58% was recorded at 90 DAH, whiles the lowest percentage bulb rot of 1.08% was recorded at the 70 DAH in the 14 cm x 10 cm (Table 37).

Table 37: Effect of spacing on percentage of onion bulb rot during 90 days storage, (a) thatch roof structure used in 2015 and (b) corrugated iron sheet roof structure used in 2015

(a)

DAH	Spacing (cm)			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.75
80	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.00
Spacing; LSD (0.05) = 0.164, P (Value); $P < 0.001$				

(b)

DAH	Spacing (cm)			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	1.08
80	0.00	0.00	0.00	4.17
90	0.00	0.00	0.08	7.58
Spacing; LSD (0.05) = 0.636, P (Value); $P < 0.001$				

Similar result was obtained during 2016 storage, the highest percentage of bulb rot of 2.36% was recorded at 90 DAH in 14 cm x 10 cm spacing and the lowest percentage bulb rot of 0.11% was recorded at 80 DAH in 14 cm x 10 cm in thatch roofed structure. However, from the corrugated iron sheet roofed structure, the highest percentage bulb rot of 5.17% was recorded at the 14 cm x 10 cm spacing at 90 DAH and the lowest percentage bulb rot of 0.03% was recorded at 70 DAH at the 14 cm x 10 cm spacing (Table 38). The result revealed that the wider spacing of 14 cm x 10 cm with large onion bulb recorded the highest percentage bulb rot, followed by 12 cm x10 cm. there was no bulb rot in the spacing of 10 cm x 10 cm and as well as the 8 cmx 10 cm. The thatch roofed storage structure has low percentage bulb rot as compared to the corrugated iron sheet roofed structure.

Table 38: Effect of spacing on percentage of onion bulb rot during 90 days storage. (a) Thatch roof structure used in 2016 and (b) Corrugated iron sheet roof structure used in 2016

(a)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.11
90	0.00	0.00	0.00	2.36
Spacing; LSD (0.05) = 0.092, P (value); *P* < 0.001				

(b)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.03
80	0.00	0.00	0.00	0.75
90	0.00	0.00	0.38	5.17
Spacing; LSD (0.05) = 0.247, P (value); *P* < 0.001				

The results also showed high significant difference for cultivar x spacing for the two different storage structures both in 2015 and 2016 (Table 39 and Table 40). The percentage bulb rot for cultivar x spacing interaction during the 2015 storage in thatch roofed structure was 0.33% and this was recorded from onions planted at the 14 cm x 10 cm spacing from the Ares cultivar. In the corrugated iron sheet roofed structure, the highest percentage bulb rot of 2.37% was recorded from plants at the 14 cm x 10 cm spacing from Ares cultivar. The lowest percentage bulb rot of 0.04% was recorded at the 12 cm x 10 cm spacing from Ares (Table 39).

Table 39: Cultivar x Spacing interaction effect on percentage of onion bulbs rot during 90 days storage, (a) thatch roof structure used in 2015 and (b) corrugated iron sheet roof structure used in 2015

(a)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.33
Bawku Red	0.00	0.00	0.00	0.00
Red Creole	0.00	0.00	0.00	0.00
Top-Harvest	0.00	0.00	0.00	0.00
Cultivar x Spacing; LSD (0.05) = 0.093, P (value); *P* < 0.001				

(b)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.04	2.37
Bawku Red	0.00	0.00	0.00	0.93
Red Creole	0.00	0.00	0.00	1.37
Top-Harvest	0.00	0.00	0.00	1.04
Cultivar x Spacing; LSD (0.05) = 0.481, P (value); *P* < 0.003				

The 2016 storage result of cultivar and spacing interaction was similar to 2015. The highest percentage bulb rot of 0.41% was recorded at the 14 cm x 10 cm spacing from Ares, whereas the lowest percentage bulbs rot of 0.15% was also recorded at the14 cm x 10 cm spacing from Bawku Red in thatch roofed structure. In the corrugated iron sheet roofed structure the highest percentage bulb rot of 1.23% was recorded at the 14 cm x 10 cm spacing from Ares. The lowest percentage bulb rot of 0.33% was recorded from Bawku Red at the same spacing of 14 cm x 10 cm. Also from the 12 cm x 10 cm spacing, the highest bulbs rot of 0.11% was recorded from Ares and the lowest bulb rot of 0.02% was recorded from the Top-harvest and Bawku Red recorded no bulb rot (Table 40).

Table 40: Cultivar x spacing interaction effect on percentage of onion bulb rot during 90 days storage, (a) thatch roof structure used in 2016 and (b) corrugated iron sheet roof structure used in 2016

(a)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.41
Bawku Red	0.00	0.00	0.00	0.15
Red Creole	0.00	0.00	0.00	0.31
Top- Harvest	0.00	0.00	0.00	0.23
Cultivar x Spacing; LSD (0.05) = 0.136, P (value); *P* = 0.236				

(b)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.11	1.23
Bawku Red	0.00	0.00	0.00	0.33
Red Creole	0.00	0.00	0.04	0.70
Top-Harvest	0.00	0.00	0.02	0.37
Cultivar x Spacing; LSD (0.05) = 0.151, P (value); *P* < 0.001				

4.2.4 Percentage of sprouted bulbs

There were significant differences of sprouted bulbs for the main effects of cultivar, spacing and as well as their interaction for the two storage structures during the 2015 and 2016 storage (Table 41 and Table 42). In the thatch roofed structure of 2015, percentage bulb sprout in Ares cultivar (0.26%) was significantly higher than the Red Creole (0.25%), Top-Harvest (0.17%) and Bawku Red (0.17%) in that order at 90 DAH. The trend was similar to the corrugated iron sheet roofed storage structure. The Ares again recorded the highest percentage bulb sprout of 0.75% at 90 DAH, whiles the Bawku Red cultivar at 90 DAH recorded the lowest value of 0.21% (Table 41).

Table 41: Cultivar effect on percentage of onion bulb sprout during 90 days storage, (a) thatch roof structure used in 2015 and (b) corrugated iron sheet roof structure used in 2015

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00
90	0.26	0.17	0.25	0.17
Cultivar; LSD (0.05) = 0.131, P (value); *P* = 0.901				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00
90	0.75	0.42	0.67	0.21
Cultivar; LSD (0.05) = 0.193, P (value); *P* = 0.118				

In the 2016 storage the Ares cultivar dominated in the percentage bulb sprout of 0.83% at 90 DAH, followed by the Red Creole of 0.68%, Top-Harvest of 0.51% and Bawku Red of 0.33% in the thatch roofed structure. For the corrugated iron sheet roofed structure the highest percentage bulb sprout of 2.42% was recorded from Ares and the lowest was 0.75% was recorded from Bawku Red at 90 DAH (Table 42).

Table 42: Cultivar effect on percentage of bulb sprout during 90 days storage, (a) thatch roof structure used in 2016 and (b) corrugated iron sheet structure used in 2016

(a)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.08	0.00	0.02	0.01
90	0.83	0.33	0.68	0.51
Cultivar; LSD (0.05) = 0.222, P (value); $P = 0.306$				

(b)

DAH	**Cultivar**			
	Ares	Bawku Red	Red Creole	Top-Harvest
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.03	0.00	0.00	0.00
80	0.58	0.00	0.17	0.00
90	2.42	0.75	1.50	0.88
Cultivar; LSD (0.05) = 0.247, P (value); $P < 0.001$				

During the 2015 storage in thatch roofed structure, the percentage sprout was 0.84% for the 14 cm x 10 cm spacing. There were no bulb sprout in the 12 cm x 10 cm, 10 cm x 10 cm and 8 cm x 10 cm spacing. Also in the corrugated iron sheet roofed structure the higher percentage bulb sprout of 2.04% was recorded at the 14 cm x 10 cm spacing. There were no percentage bulb sprout in any of the other spacing (Table 43).

Table 43: Spacing effect on percentage of onion bulb sprout during 90 days storage, (a) thatch roof structure used in 2015 and (b) corrugated iron sheet roof structure used in 2015

(a)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	0.84
Spacing; LSD (0.05) = 0.131, P (value); *P* < 0.001				

(b)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00
90	0.00	0.00	0.00	2.04
Spacing; LSD (0.05) = 0.193, P (value); *P* < 0.001				

In the 2016 storage the highest percentage bulb sprout of 2.36% in the thatch roofed structure was obtained from the 14 cm x 10 cm spacing at 90 DAH, whiles the corrugated iron sheet roofed structure also recorded the highest percentage bulb sprout of 5.17% from the 14 cm x 10 cm spacing at 90 DAH. The lowest percentage bulb sprout of 0.03% at 90 DAH was recorded at the 12 cm x 10 cm spacing (Table 44).

Table 44: Spacing effect on percentage of onion bulb sprout during 90 days storage, (a) thatch roof structure used in 2016 and corrugated iron sheet roof structure used in 2016

(a)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.11
90	0.00	0.00	0.00	2.36
Spacing; LSD (0.05) = 0.222, P (value); $P < 0.001$				

(b)

DAH	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
10	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00
60	0.00	0.00	0.00	0.00
70	0.00	0.00	0.00	0.03
80	0.00	0.00	0.00	0.75
90	0.00	0.00	0.38	5.17
Spacing; LSD (0.05) = 0.247, P (value); $P < 0.001$				

The cultivar x spacing interaction for percentage bulb sprout was significantly affected by the storage structures during the 2015 and 2016 storage (Table 45 and Table 46). During the 2015 storage in thatch roofed structure, the highest percentage bulb sprout of 0.11% was recorded at the 14 cm x 10 cm spacing from Ares and Red Creole cultivars, whiles the lowest 0.07% was recorded from Bawku Red and Top-Harvest at 14 cm x 10 cm. Whereas in the corrugated iron sheet roofed structure the highest percentage bulb sprout of 0.33% was recorded from Ares at 14 cm x 10 cm spacing, whiles the lowest (0.09%) was recorded from Top-Harvest at 14 cm x 10 cm (Table 45).

Table 45: Cultivar x spacing interaction effect on percentage of bulb sprout during 90 days storage, (a) thatch roof structure and (b) corrugated iron sheet roof structure used in 2015

(a)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.11
Bawku Red	0.00	0.00	0.00	0.07
Red Creole	0.00	0.00	0.00	0.11
Top-Harvest	0.00	0.00	0.00	0.07
Cultivar x Spacing; LSD (0.05) = 0.068, P (value); *P* = 0.987				

(b)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.33
Bawku Red	0.00	0.00	0.00	0.19
Red Creole	0.00	0.00	0.00	0.30
Top-Harvest	0.00	0.00	0.00	0.09
Cultivar x Spacing; LSD (0.05) = 0.111, P (value); *P* = 0.070				

In 2016 storage, the thatch roofed structure has recorded a percentage bulb sprout of 0.04% from Ares cultivar at the 14 cm x 10 cm spacing. Whiles in the corrugated iron sheet roofed structure, a percentage of bulb sprout of 0.11% was recorded from Ares cultivar at 14 cm x 10 cm spacing. Whereas 0.04% of bulb sprout were recorded from Bawku Red at 14 cm x 10 cm spacing. There were no bulb sprout in the spacing of 8 cm x 10 cm and 10 cm and 10 cm spacing (Table 46).

Table 46: Cultivar x Spacing interaction effect on percentage of onion bulb sprout during 90 days storage, (a) thatch roof structure used in 2016 and (b) corrugated iron sheet roof structure used in 2016

(a)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.04
Bawku Red	0.00	0.00	0.00	0.00
Red Creole	0.00	0.00	0.00	0.00
Top- Harvest	0.00	0.00	0.00	0.00
Cultivar x Spacing; LSD (0.05) = 0.027, P (value); *P* = 0.461				

(b)

Cultivar	**Spacing (cm)**			
	8 x 10	10 x 10	12 x 10	14 x 10
Ares	0.00	0.00	0.00	0.11
Bawku Red	0.00	0.00	0.00	0.00
Red Creole	0.00	0.00	0.00	0.04
Top- Harvest	0.00	0.00	0.00	0.00
Cultivar x Spacing; LSD (0.05) = 0.521, P (value); *P* < 0.061				

CHAPTER FIVE

5.0 DISCUSSION

5.1 Vegetative parameters

The results of the germination test for the two cropping seasons indicated that onion seeds used for the study were very viable. Generally seeds from the exotic cultivars such as Ares, Red Creole and Top-Harvest performed slightly better than the local Bawku Red cultivar. This could be attributed to the fact that the seeds from exotic cultivars had been treated with fungicide 'Topsin' before they were purchased while the local cultivar was not.

The results of plant establishment indicated that the 2015 cropping season was better than that of 2016 cropping season. This could be attributed to environmental factors that prevailed in the two cropping seasons. According to Jim (1994) excessively high or low temperatures may have negative effect on early seedling growth as well as general health of onion plants at all stages of vegetative development. Spacing however, showed no significant difference among the various cultivars. This could be ascribed be to proper agronomic practices coupled with good climatic conditions accounted for lack of significant differences in crop establishment among cultivars in their various spacing. Good land preparation coupled with judicious application of both organic and inorganic fertilizers in addition to good quality seeds used might have resulted in a greater percentage of crop establishment (Tweneboah, 2000). The cultivar Ares had significantly higher establishment than the other cultivars in both cropping seasons. This could be as a result of cultivar difference probably due to genetic constitution of the cultivars.

The results showed that plant height among cultivars in the 2016 cropping season were higher than those in the 2015 cropping seasons. Environmental factors such as adequate moisture, carbon dioxide assimilation and optimum sunlight accumulation by plants were probably higher in 2016 season which promoted rapid increase in plant height. Mohammed (1994) stated that tillering has been observed in many plants species grown at high carbon dioxide levels and optimum conditions. Plant height was observed to increase with increasing spacing. The increased in plant height as spacing increased could be as a result of less competition among crops for growth factors, such as sunlight, water and nutrients. Highly populated plants are more likely to receive less sunlight than carbon dioxide (Clipson *et al*., 1994). Yoshida (1994) observed that plants at higher density grow taller than those planted at lower density. The findings are similar to Aliyu *et al*. (2008) who also found superior plant height at 25 cm intra-row spacing than at 15 cm intra-row spacing. Variation in plant height among cultivars probably was as a result of their genetic make-up. Jilani and Ghafoor (2003), Islam *et al.* (2007), Jilani *et al.* (2010) and Yemane *et al.* (2014) all found significant genotypic variations among onion varieties in plant height. Plant height increased with weeks after transplanting, but declined from 10WAT to 11WAT as the plants lose their leaves at physiological maturity.

Crops planted during the 2016 cropping season had long leaf lengths than those of the 2015 cropping seasons. Accumulation of dry matter is as a result of carbon dioxide exchange between the atmosphere and the crops (Bugbee and Monje, 1992). Leaf length was observed to increase with increasing spacing. The high leaf length obtained at 14 cm x 10 cm spacing could be because of inter-plant competition for limited growth factors such as sunlight, soil water and nutrients which favoured plants at the wider spacing than the narrow spacing. Jilani *et al.* (2010) also reported of highest leaf length at wider spacing whereas shortest leaves were observed at closest plant spacing. The leaf length of Ares cultivar was significantly higher than Red Creole, Top Harvest and Bawku Red cultivars in both cropping seasons. This could be due to genetic variation among cultivars. Smittle (1993), Jilani and Ghaffoor (2003) and Jilani *et al*. (2009) reported that cultivars varied significantly from each other with respect to leaf length.

From the results, it was observed that leaf number increase with increasing spacing. The greatest leaf numbers were obtained at the 14 cm x 10 cm spacing. According to Karaye and Yakubu (2006), garlic planted at 15 cm and 20 cm intra-row spacing produced significantly greater number of leaves per plant than the 10 cm intra-row spacing. It has been reported by several workers that increase in planting density resulted in reduction in number of leaves (Jan *et al.*, 2003, Akoun, 2005, Aliyu *et al*., 2008, Ahmed *et al*., 2010, Jilani *et al*., 2010 and Yemane *et al*., 2014). The low leaf numbers obtained at the narrow spacings was as a result of inter-plant competition for limited growth factors such as light, moisture, mineral nutrient, space and carbon dioxide among plants. Again Ares was significantly higher than Bawku Red, Red Creole and Top-Harvest in the two cropping seasons in terms of leaf numbers.

Leaf area index was significantly higher during the 2016 cropping season than that of the 2015. The highest LAI values obtained during the 2016 cropping season might have resulted from favourable environmental factors which might have favoured vegetative growth and thus increasing the leaf area index. An increase in leaf area, which is usually associated with increased branching or tillering, has been observed in many plants grown at high carbon dioxide levels, optimum sunlight and high moisture conditions (Mohammed, 1994). Leaf area index decreased with increasing spacing. The highest leaf area index values were from the 8 cm x 10 cm spacings. Both early sowing and an increase in plant population increased the LAI according to Mondal *et al.* (1986). Herbert and Litchfield (1984) also reported that narrow rows with higher densities produced higher LAI than narrow row with lower densities. High leaf area index values were obtained from the Ares cultivar than Red Creole, Top Harvest and Bawku Red, implying a possible genotypic differences among the cultivars used.

Girth of bulb neck for onions planted in 2016 cropping season was greater than those planted in 2015. Onion plants planted at the wider spacings had the greatest girth of bulb neck than those planted at the narrow spacings. Onion plants grown at the wide spacing received more soil water, mineral and solar radiation under less interplant competition which promoted vigorous growth resulting in positive bulb traits (Khan *et al.*, 2003). Gagopale *et al.* (2015) reported that as plant population increased, bulb necks tended to be thinner. Ares performed better than the other cultivars in both seasons. Lemma and Shimeles (2003) explained that the cause of thick neck in onion is lack of inter-plant competition in addition to genetic inheritance. Variation in bulb neck diameter among cultivars has also been reported by Jilani and Ghaffoor (2003) and Jilani *et al.* (2009).

The greatest fresh plant biomasses of 10.8 kg/m^2 and 16.9 kg/m^2 obtained at the lower spacing of 8 cm x 10 cm in both cropping seasons of 2015 and 2016 could be attributed to more crops per unit land area as compared to fewer crops per unit land area at the wider spacing. Increasing plant density resulted in suppression of biological yield of individual plant, but production increases on per plant basis of unit land area and this is in accordance with Harris *et al*. (2016). In the present study, it was observed that plant biomass increased with increasing weeks after transplanting. Ares recorded the highest biomasses of 17.4 kg/m^2 and 31.0 kg/m^2 at 12WAT in both cropping seasons. Variation in biomass production might be due to genetic constitution of the cultivars. Brewster (2008) reported that the growth of various onion cultivars differs, and will not be the same due to differences in genotype.

Generally dry biomass was low among crops planted in the 2015 cropping season as compared to those planted in the 2016 cropping season. The low dry biomass obtained from the 2015 cropping season could be due to the late planting (February 2015) of the crops as compared to the higher yield obtained in the early planting (January, 2016) of crops in the 2016 cropping season. The yield of late sown plants will be lower than earlier sown plants because leaf blade production that switches to bulb initiation while the leaf area index and light inception is low (Pakyurek *et al*., 1994; Brewster, 2008). The highest dry biomass values of 1.7 kg/m^2 and 2.5 kg/m^2 were also obtained from 8 cm x 10 cm spacing in both seasons. Ares cultivar again recorded the highest dry biomasses of 2.3 kg/m^2 and 3.9 kg/m^2 in both 2015 and 2016 seasons respectively at 12WAT. Brewster (2008) reported that the growth of various onion cultivars differs, and will not be the same due to differences in genotype.

5.2 Yield and components of yield

Total bulb yield (mt/ha) recorded was higher in 2016 cropping season than in 2015. The early planting of onions during the cropping season of the 2016 might have account for this. According to Leilah *et al.* (2003), a yield of 46.95 t/ha was obtained with December planting, followed by 38.10 t/ha for January and 31.80 t/ha for February. Boyan *et al.* (2009) noted that growers try to have all their onions transplanted by the end of December. Higher total bulb yields of 19.9 mt/ha and 22.8 mt/ha were recorded at the 8 cm x 10 cm spacing in the cropping seasons of 2015 and 2016. The result is similar to the findings of

Kumar *et al*. (1998), Resende *et al.* (1999), Jilani *et al*. (2010) and Harris *et al*. (2016) who reported that decreasing the plant spacing increases total yield of onion. Although highest yield of total bulbs were obtained from the narrow spacing of 8 cm x 10 cm, most of the bulbs were small in size. The results is similar to the findings of Coleo *et al.* (1996) who reported that highest commercial bulb yield was recorded at closest spacing, while the highest proportion of large bulbs and average bulb weight were obtained at the wider spacing. The least yields of 15.5 mt/ha and 18.1 mt/ha recorded at the wider spacing of 14 cm x 10 cm in the 2015 and 2016 production seasons could be as a result of fewer plants per unit area. Ares recorded the highest bulb yields of 24.7 mt/ha and 28.6 mt/ha in both cropping seasons respectively, whiles the least total bulb yields of 15.6 mt/ha and 17.8 mt/ha were from Bawku Red, in both cropping seasons. The overall best performance was from Ares and differences in bulb yield among cultivars could be attributed to genotypic difference. The findings agrees with Jilani and Ghaffoor, 2003 who stated that cultivar performs differently under different agro-climatic conditions and various cultivars of the same species grown at the same environment often yield differently.

The highest average bulb weight for crops planted in the 2016 cropping season could be attributed to the early planting (January, 2016) of onions as compared to the late planting (February, 2015) of crops in the 2015. The result is in conformity with the findings of Gagopale *et al*. (2013) who reported that onion bulb fresh mass tended to be lower with delayed sowing dates. The highest bulb weights of 86.3g and 106.3g were obtained at the 14 cm x 10 cm spacing in 2015 and 2016 cropping seasons respectively, whiles the lowest values of 69.2g and 88.4g were obtained at the 8 cm x 10 cm spacing. The low bulbs weight observed at the narrow spacings could be due to the early maturity of onion in such spacings, because of competition among plants for limited nutrients, space and water. According to Rumpel and Felczynski (2000), decrease in bulb yield as plant population increases may be due to early maturation of bulbs. The result also agrees with the findings of Kumar *et al*. (1998), Resendle *et al.* (1999) and Jilani *et al.* (2010) who reported that decreasing the plant spacing increases total yield of onion. The high average bulb weight observed in the wider spacing could be as a result of less intra-plant competitions. In wider spacing, the competition between onion plants are minimized and consequently encouraged the capacity of onion plants in building metabolites and increased weight of bulb (El-Gamili, 1996).

Onion cultivars planted in 2016 cropping season had the highest bulb diameter at 12 DAT than those planted in the 2015. This may be due to the early planting of onions in the 2016 cropping season which might have favoured accumulation of dry matter resulting in higher bulb diameter formation in plants planted in 2016 cropping season. To produce higher yield in onion, onion transplants had to be planted early which allows development of large vegetative parts (Al-Moshileh, 2007; Mahadeen, 2008). Accumulation of dry matter is as a result of carbon dioxide exchange between the atmosphere and the crops (Bugbee and Monje, 1992). The causes for low bulb diameter values obtained at the decreasing plant spacing may be due to limited nutrients and water for onions planted at the decreased spacing. Harris *et al.* (2016) stated that inadequate nutrients and space limits enlargement of bulbs. Similar findings were also reported by Farooq-Ch *et al*. (1990), Islam *et al*. (1997), and Katon *et al*. (2003). The highest bulb diameter recorded from Ares as compared with the other cultivars in both cropping seasons could mean that it was able to convert its early leaf growth for larger bulbs formation whereas the lowest bulb diameters obtained from Bawku Red in the two cropping seasons could be attributed to its inferior. Judith (2012) reported smaller onion bulb sized from Bawku Red in her studies.

5.3 Grading of harvested bulbs

Onion cultivars planted in the 2015 has higher percentage of bulbs with girth < 10 cm and 10-19 cm than those planted in 2016. This could be as a result of the low maximum monthly temperature values exhibited throughout the cropping season of 2015 that might have necessitated the production of higher percentage of smaller bulb size. However, low percentage of bulbs with girth < 20 cm were observed during the 2015 season. Raemaekers (2001) stated that bulb formation is favoured by relatively high temperatures.

Generally, percentages of bulbs with girth < 10 cm and 10-19 cm were observed at the decreasing spacings. The higher percentages of bulbs with girth < 10 cm and 10-19 cm recorded at the narrow spacings of 8 cm x 10 cm and 10 cm x 10 cm as compared with wider spacings of 12 cm x 10 cm and 14 cm x 10 cm could be attributed to competition for limited nutrients, soil water and space among plants which resulted in smaller bulb formation. The present finding is similar to that of Khan *et al.* (2002) who reported a significant effect of all the growth and yield components of onion and larger percentage of small and medium bulbs obtained with narrowest spacing. Coleo *et al*. (1996) also stated that highest commercial bulb yield was recorded at higher planting density (closest spacing). However, at the wider spacing the higher percentage of bulbs with girth ≥ 20 cm could be as a result of available nutrients, space and water. The finding is in line with Coleo *et al*. (1996) who reported that highest proportion of large bulbs and average bulb weight were obtained at the lowest planting density (wider spacing). In addition, with wide space, the competition between onion plants are minimized and consequently this encouraged the capacity of onion plants in building metabolites and increased diameter of bulb (El-Gamili, 1996). Ares recorded the highest percentage of bulbs with girth $\geq$ 20 cm followed by Red Creole, Top-Harvest and Bawku Red in that order. Kanton *et al.* (2003) stated that varieties as well as planting densities significantly affect onion bulb yield.

5.4 Storage of bulbs

The storage experiments were conducted in 2015 and 2016 using two different storage structures namely; thatch roofed structure and corrugated iron sheet roofed structure in Bawku. Relative humidity and temperature played an important role in the quality of onion bulbs during storage. Abbey *et al.* (2000) reported that onion bulbs deterioration in storage was largely influenced by the presence of microorganisms such as fungus and unfavourable environmental factors such as high temperature, high relative humidity and high moisture content of the bulbs.

Generally, percentage of total weight loss in both structures was higher in 2015 storage than it was in 2016. This could be as a result of the higher mean temperatures recorded from 10 DAP to 60 DAP during storage in 2015 than in 2016. This observation is in agreement with Abbey *et al.* (2000) that onion bulbs deterioration in storage is largely influenced by the presence of unfavourable environmental factors such as temperature, relative humidity and moisture content of the bulbs. Corrugated iron sheet roofed structure recorded higher percentages of bulb weight losses than the thatch roofed structure during 2015 and 2016 storage. This implies that the rate of decay of onion bulbs at storage in corrugated iron sheet was faster than that of thatch structure. This might be as a result of the higher temperatures and relative humidity recorded in the corrugated iron sheet roofed structure as compared to the thatch roofed structure. Powell (1996) reported that onion could be stored for five months at 22-25°C and relative humidity of 70% with total loss of 14%.

Percentage of bulb weight loss during storage was observed to increase with onion bulbs harvested at wider plant spacing than narrow spacing. The large bulbs recorded from spacing of 14 cm x 10 cm had the highest bulb decay, whereas the low percentage bulb weight recorded from onion of bulbs harvested at 8 cm x 10 cm spacing had relatively low rot. Large bulbs have large surface area and are prone to damages resulting from physical bruises, microorganisms and climatic factors. The results obtained is in agreement with that of Sing and Sing (2003) who reported that bulbs of large sizes showed highest weight loss compared to smaller sized bulbs.

Ares cultivar recorded the highest percentages of bulbs weight losses, followed by Red Creole, Top-Harvest and Bawku Red in that order. The low percentage of bulb weight losses recorded from Bawku Red could be attributed to its ability to adapt to the environmental conditions in Northern Ghana. The result of the findings is similar to Addai *et al*. (2014) who reported that Bawku Red onion had superiority in terms of adaptation to the environmental conditions in Northern Ghana as compared to the other cultivars. According to Shika *et al*. (2001) different onion cultivars have different storage potentials. Ko (2001) reported storage losses among 10 cultivars varied from 14% to 100% after 3 months of storage. Msika and Jackson (1997) also reported cultivar specific weight losses between 2% and 5% per month in warm ambient storage in Zimbabwe.

The higher percentages of bulb rot observed during the 2015 storage than values recorded in 2016 might be due to the late harvesting of onion plants in 2015 as compared to 2016. Tucker and Drew (1982) stated that the rate of bulb rot in storage increases with the lateness of harvesting. The low percentage of bulb rot recorded in thatch roofed structure in 2015 and 2016 storage than the corrugated iron sheet roofed structure could be as a result of low temperatures and relative humidity exhibited in the thatch roofed structure in both seasons. Yemane *et al*. (2013) reported that onions are best suited to low humidity in storage.

In both storage structures, onion bulbs harvested at widest spacing of 14 cm x 10 cm recorded higher percentage of bulb rot at 90 DAH as compared to the narrow spacings. Higher percentages of bulb rot observed during storage could be attributed to the large bulb size found in such spacing. Grevsen and Sorensen (1999) pointed out losses due to rotting is increased with bulb size and this probably is due to high infection rate among bulbs. Yemane *et al*. (2013) reported that higher spacing encourage plants to produce large bulbs with soft succulent tissues which make them susceptible to attack by disease-causing microorganisms. The finding was also in conformity with Cho *et al.* (2010) who reported that larger onions are more susceptible to bruising, disease and other damages than smaller bulbs. Ward (1979) observed that the number of rotted bulbs increased with increasing bulb size. Ares recorded more percentages of bulb rots at 90 DAH in both storage structures during 2014 and 2015 storage than the other cultivars. The variation in onion bulb rot recorded could be due to cultivar differences and bulbs size. Lancaster *et al.* (2001) reported that, some onion varieties became more elongated during storage time.

The greater percentage of bulb sprouts recorded in the 2016 storage than those in the 2015 might probably have been caused by high temperatures and relative humidity. According to Yemane *et al*. (2013) onions are best suited to low humidity in storage. During storage in 2015 and 2016, the thatch roofed storage structure recorded fewer onion bulb sprout as compared to the corrugated iron sheet roofed structure. The relatively high onion bulbs sprout recorded at the corrugated iron sheet roofed structure could be due to fast absorption and retention of heat as compared to thatch roofed structure. The finding is in conformity with Imoukhuede *et al*. (2015).

In both thatch roofed and corrugated iron sheet roofed structures bulbs sprouts were observed on onions harvested at wider spacing of 14 cm x 10 cm. Large bulbs of onion at the wider spacing might be the cause of sprout at the wider spacing since large bulbs contain more food reserves which might trigger bulb sprout at storage. Large bulbs contain more carbohydrates and other food reserves than medium and small bulbs (Addai and Scott, 2011). Small or medium sized bulbs store better in storage than larger bulbs (Ward, 1979; Peters, 1990). Generally, Ares cultivar in either storage structures had higher percentages of sprouted onion bulbs than Red Creole, Top-Harvest and Bawku Red and variation in sprouting could be attributed to difference in cultivar genotypes. Immediately after harvest, bulbs come to a natural state of rest that is controlled by endogenous hormone levels, and this varies with genetic makeup of cultivars (Salamal *et al*., 1990). Lower percentages of sprouted onion bulbs recorded from Bawku Red and Top-Harvest might be as a result of small onion bulbs size obtained from them. Grevsen and Sorensen (1999) pointed out that losses due to sprouting were increased with bulb size and may be due to the high infection rate among bulbs. Grevsen and Sorensen (1999) also reported that the longer the storage period the higher is sprouting after storage.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Both cultivar and spacing are essential for increased onion yield. The present study reveals a number of findings and conclusions as follows:

- Bawku Red and Ares matured earlier than Red Creole and Top-Harvest.
- The 10 cm x 10 cm spacing gave optimum bulb yield for the various cultivars.
- The Ares cultivar was adjudged the best, followed by Red Creole, Top-Harvest and Bawku Red in that order in terms of bulb yield.
- The thatch roofed storage structure was superior to the corrugated iron sheet roofed storage structure in terms of losses caused by rot, sprout and general weight loss.
- Bawku Red cultivar was superior to the others in terms of shelf-life at storage, followed by Top-harvest, Red Creole and the one with lowest shelf-life was Ares.

6.2 Recommendations

The following are recommended for farmers in the locality and future researchers:

- More onion cultivars should be evaluated under a similar study to assess their response to different spacing.
- Further research should be conducted on more storage structures to assess the storability of different onion cultivars in the study area.
- The experiment should be conducted on cultivars and plant spacing in different Agro-ecological zone to evaluate yield and storability.

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APPENDICES

Analysis of variance of data collected on growth, yield and storage

Appendix 1: Percentage of plant establishment at 4 WAT during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	37.417	12.472	5.65	0.003
SP	3	34.250	11.417	5.17	0.005
CV.SP	9	43.583	4.843	2.19	0.050
Residual	32	70.667	2.208		
Total	47	185.917			

Appendix 2: Percentage of plant establishment at 4 WAT during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	48.667	16.222	7.71	<.001
SP	3	1.833	0.611	0.29	0.832
CV.SP	9	6.167	0.685	0.33	0.960
Residual	32	67.333	2.104		
Total	47	124.000			

Appendix 3: Plant height during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	630.0645	210.0215	353.30	<.001
SP	3	1530.9628	510.3209	858.47	<.001
WAT	7	11177.3958	1596.7708	2686.12	<.001
CV.SP	9	24.2634	2.6959	4.54	<.001
CV.WAT	21	3913.0133	186.3340	313.45	<.001
SP.WAT	21	174.6633	8.3173	13.99	<.001
CV.SP.WAT	63	329.5714	5.2313	8.80	<.001
Residual	256	152.1800	0.5945		
Total	383	17932.1143			

Appendix 4: Plant height during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	395.427	131.809	42.74	<.001
SP	3	1172.781	390.927	126.76	<.001
WAT	7	10788.385	1541.198	499.76	<.001
CV.SP	9	58.472	6.497	2.11	0.029
CV.WAT	21	1952.665	92.984	30.15	<.001
SP.WAT	21	302.260	14.393	4.67	<.001
CV.SP.WAT	63	420.835	6.680	2.17	<.001
Residual	256	789.480	3.084		
Total	383	15880.305			

Appendix 5: Leaf length during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	482.830	160.943	16.69	<.001
SP	3	5055.640	1685.213	174.78	<.001
WAT	7	18011.737	2573.105	266.87	<.001
CV.SP	9	319.751	35.528	3.68	<.001
CV.WAT	21	442.101	21.052	2.18	0.003
SP.WAT	21	223.930	10.663	1.11	0.342
CV.SP.WAT	63	430.215	6.829	0.71	0.948
Residual	256	2468.300	9.642		
Total	383	27434.504			

Appendix 6: Leaf length during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	473.892	157.964	18.84	<.001
SP	3	5178.659	1726.220	205.90	<.001
WAT	7	17246.516	2463.788	293.87	<.001
CV.SP	9	230.848	25.650	3.06	0.002
CV.WAT	21	437.134	20.816	2.48	<.001
SP.WAT	21	226.207	10.772	1.28	0.185
CV.SP.WAT	63	410.657	6.518	0.78	0.883
Residual	256	2146.287	8.384		
Total	383	26350.200			

Appendix 7 Leaf number during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	195.6354	65.2118	147.30	<.001
SP	3	62.3021	20.7674	46.91	<.001
WAT	7	452.8646	64.6949	146.13	<.001
CV.SP	9	39.3021	4.3669	9.86	<.001
CV.WAT	21	82.9896	3.9519	8.93	<.001
SP.WAT	21	56.3229	2.6820	6.06	<.001
CV.SP.WAT	63	41.2396	0.6546	1.48	0.019
Residual	256	113.3333	0.4427		
Total	383	1043.9896			

Appendix 8: Leaf number during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	170.9661	56.9887	126.50	<.001
SP	3	61.2161	20.4054	45.29	<.001
WAT	7	481.7057	68.8151	152.75	<.001
CV.SP	9	38.3359	4.2595	9.45	<.001
CV.WAT	21	77.1380	3.6732	8.15	<.001
SP.WAT	21	54.5547	2.5978	5.77	<.001
CV.SP.WAT	63	36.9766	0.5869	1.30	0.080
Residual	256	115.3333	0.4505		
Total	383	1036.2266			

Appendix 9: Chlorophyll content during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	134.246	44.749	6.51	<.001
SP	3	4270.542	1423.514	207.10	<.001
WAT	3	493253.042	164417.681	23920.37	<.001
CV.SP	9	67.430	7.492	1.09	0.375
CV.WAT	9	254.097	28.233	4.11	<.001
SP.WAT	9	408.583	45.398	6.60	<.001
CV.SP.WAT	27	123.266	4.565	0.66	0.892
Residual	128	879.813	6.874		
Total	191	499391.020			

Appendix 10: Chlorophyll content during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	97.549	32.516	6.95	<.001
SP	3	5739.274	1913.091	408.85	<.001
WAT	3	473949.812	157983.271	33763.12	<.001
CV.SP	9	74.592	8.288	1.77	0.08
CV.WAT	9	382.581	42.509	9.08	<.001
SP.WAT	9	805.609	89.512	19.13	<.001
CV.SP.WAT	27	97.320	3.604	0.77	0.782
Residual	128	598.933	4.679		
Total	191	481745.670			

Appendix 11: LAI during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	0.065637	0.021879	5.35	0.002
SP	3	0.022635	0.007545	1.84	0.143
WAT	3	6.112623	2.037541	497.83	<.001
CV.SP	9	0.037844	0.004205	1.03	0.422
CV.WAT	9	0.085451	0.009495	2.32	0.019
SP.WAT	9	0.067566	0.007507	1.83	0.068
CV.SP.WAT	27	0.078033	0.002890	0.71	0.853
Residual	128	0.523881	0.004093		
Total	191	6.993670			

Appendix 12: LAI during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	0.386702	0.128901	15.53	<.001
SP	3	0.245944	0.081981	9.87	<.001
WAT	3	9.823661	3.274554	394.41	<.001
CV.SP	9	0.017637	0.001960	0.24	0.989
CV.WAT	9	0.158282	0.017587	2.12	0.032
SP.WAT	9	0.161045	0.017894	2.16	0.029
CV.SP.WAT	27	0.036624	0.001356	0.16	1.000
Residual	128	1.062707	0.008302		
Total	191	11.892604			

Appendix 13: Bulb neck girth during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	5.28509	1.76170	34.84	<.001
SP	3	2.30176	0.76725	15.17	<.001
WAT	3	86.40000	28.80000	569.57	<.001
CV.SP	9	0.49341	0.05482	1.08	0.379
CV.WAT	9	0.00000	0.00000	0.00000	1.000
SP.WAT	9	0.00000	0.00000	0.00000	1.000
CV.SP.WAT	27	0.00000	0.00000	0.00000	1.000
Residual	128	6.47227	0.05056		
Total	191	100.95252			

Appendix 14: Bulb neck girth during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	7.10424	2.36808	38.81	<.001
SP	3	2.54649	0.84883	13.91	<.001
WAT	3	244.40627	81.46876	1335.19	<.001
CV.SP	9	0.17581	0.01953	0.32	0.967
CV.WAT	9	0.08235	0.00915	0.15	0.0998
SP.WAT	9	0.10810	0.01201	0.20	0.0994
CV.SP.WAT	27	0.18559	0.00687	0.11	1.000
Residual	128	7.81013	0.06102		
Total	191	262.41900			

Appendix 15: Root biomass during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	3.112	1.037	0.87	0.458
SP	3	96.382	32.127	27.04	<.001
WAT	2	20.160	10.080	8.48	<.001
CV.SP	9	0.701	0.078	0.07	1.000
CV.WAT	6	0.00	0.00	0.00	1.000
SP.WAT	6	0.00	0.00	0.00	1.000
CV.SP.WAT	18	0.00	0.00	0.00	1.000
Residual	96	114.080	1.188		
Total	143	234.434			

Appendix 16: Root biomass during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	3.272	1.091	0.93	<.001
SP	3	96.087	32.029	27.21	<.001
WAT	2	19.520	9.760	8.29	<.001
CV.SP	9	0.711	0.079	0.07	1.000
CV.WAT	6	0.00	0.00	0.00	1.000
SP.WAT	6	0.00	0.00	0.00	1.000
CV.SP.WAT	18	0.00	0.00	0.00	1.000
Residual	96	113.020	1.177		
Total	143	232.609			

Appendix 17: Root number during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	14.6352	4.8784	8.76	<.001
SP	3	3446.7474	1148.9158	2063.66	<.001
WAT	2	1735.2613	867.6306	1558.42	<.001
CV.SP	9	4.8195	0.5355	0.96	0.476
CV.WAT	6	8.3004	1.3834	2.48	0.028
SP.WAT	6	84.6615	14.1103	25.34	<.001
CV.SP.WAT	18	5.5924	0.3107	0.56	0.921
Residual	96	53.4467	0.5567		
Total	143	5353.4644			

Appendix 18: Root number during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	28.6819	9.5606	13.81	<.001
SP	3	3065.2119	1021.7373	1475.88	<.001
WAT	2	1184.0000	592.0000	855.13	<.001
CV.SP	9	12.6806	1.4090	2.04	0.043
CV.WAT	6	0.0000	0.0000	0.00	1.000
SP.WAT	6	0.0000	0.0000	0.00	1.000
CV.SP.WAT	18	0.0000	0.0000	0.00	1.000
Residual	96	66.4600	0.6923		
Total	143	4357.0344			

Appendix 19: Fresh biomass weight during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	14907.	4969.	0.55	0.651
SP	3	7192065.	2397355.	264.37	<.001
WAT	2	109106426	54553213.	6015.81	<.001
CV.SP	9	3001.	333.	0.04	1.000
CV.WAT	6	22353.	3726.	0.41	0.870
SP.WAT	6	13016522	2169420	239.23	<.001
CV.SP.WAT	18	6421.	357.	0.04	1.000
Residual	96	870557.	9068.		
Total	143	130232252			

Appendix 20: Fresh biomass weight during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	14.4933	4.8311	7.36	<.001
SP	3	447.4160	149.1387	227.26	<.001
WAT	2	13291.0913	6645.5457	10126.56	<.001
CV.SP	9	0.7445	0.0827	0.13	0.999
CV.WAT	6	6.5100	1.0850	1.65	0.141
SP.WAT	6	346.5203	57.7534	88.01	<.001
CV.SP.WAT	18	3.2167	0.1787	0.27	0.999
Residual	96	62.9999	0.6562		
Total	143	14172.9921			

Appendix 21: Dry biomass weight during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	12.4600	4.1533	5.83	0.001
SP	3	431.2123	143.7374	201.83	<.001
WAT	2	13157.2289	6578.6145	9237.43	<.001
CV.SP	9	0.4291	0.0477	0.07	1.000
CV.WAT	6	6.3837	1.0639	1.49	0.188
SP.WAT	6	338.9006	56.4834	79.31	<.001
CV.SP.WAT	18	3.2418	0.1801	0.25	0.999
Residual	96	68.3682	0.7122		
Total	143	14018.2247			

Appendix 22: Dry biomass weight during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	14899.	4966.	0.55	0.650
SP	3	7195625.	2398542.	265.01	<.001
WAT	2	109109196.	54554598.	6027.57	<.001
CV.SP	9	3000.	333.	0.04	0.999
CV.WAT	6	22352.	3725.	0.41	0.870
SP.WAT	6	13016048.	2169341.	239.68	<.001
CV.SP.WAT	18	6420.	357.	0.04	1.000
Residual	96	868880	9051.		
Total	143	130236420.			

Appendix 23: Total bulb yield during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	678.52	226.17	19.72	<.001
SP	3	136.38	45.46	3.96	0.016
CV.SP	9	9.92	1.10	0.10	1.000
Residual	32	367.10	11.47		
Total	47	1191.93			

Appendix 24: Total bulb yield during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	937.40	312.47	30.26	<.001
SP	3	145.47	48.49	4.70	0.008
CV.SP	9	19.73	2.19	0.21	0.991
Residual	32	330.49	10.33		
Total	47	1433.09			

Appendix 25: Average bulb weight during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	3054.17	1018.06	60.03	<.001
SP	3	2449.17	816.39	48.14	<.001
CV.SP	9	242.67	26.96	1.59	0.160
Residual	32	542.67	16.96		
Total	47	6288.67			

Appendix 26: Average bulb weight during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	2692.92	897.64	42.83	<.001
SP	3	2646.08	882.03	42.08	<.001
CV.SP	9	261.58	29.06	1.39	0.235
Residual	32	670.67	20.96		
Total	47	6271.25			

Appendix 27: Bulb diameter during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	2.80333	0.93444	17.39	<.001
SP	3	11.39167	3.79722	70.65	<.001
CV.SP	9	0.38167	0.04241	0.79	0.628
Residual	32	1.72000	0.05375		
Total	47	16.29667			

Appendix 28: Bulb diameter during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	3.23562	1.07854	19.76	<.001
SP	3	11.25229	3.75076	68.72	<.001
CV.SP	9	0.32354	0.03595	0.66	0.739
Residual	32	1.74667	0.05458		
Total	47	16.55813			

Appendix 29: Percentages of bulbs with girth ≥ 20 cm during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	1088.063	362.688	355.29	<.001
SP	3	4549.062	1516.354	1485.41	<.001
CV.SP	9	336.188	37.354	36.59	<.001
Residual	32	32.667	1.021		
Total	47	6005.979			

Appendix 30: Percentages of bulbs with girth ≥ 20 cm during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	1101.750	367.250	367.25	<.001
SP	3	4527.750	1509.250	1509.25	<.001
CV.SP	9	333.750	37.083	37.08	<.001
Residual	32	32.000	1.000		
Total	47	5995.250			

Appendix 31: Percentage of bulbs with girth 10-19 cm during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	171.729	57.243	15.35	<.001
SP	3	6059.062	2019.688	541.59	<.001
CV.SP	9	570.688	63.410	17.00	<.001
Residual	32	119.333	3.729		
Total	47	6920.812			

Appendix 32: Percentage of bulbs with girth 10-19 cm during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	166.500	55.500	14.97	<.001
SP	3	6080.500	2026.833	546.56	<.001
CV.SP	9	568.000	63.111	17.02	<.001
Residual	32	118.667	3.708		
Total	47	6933.667			

Appendix 33: Percentage of bulbs with girth < 10 cm during 2015 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	2088.250	696.083	94.92	<.001
SP	3	21047.750	7015.917	956.72	<.001
CV.SP	9	111.250	12.361	1.69	0.134
Residual	32	234.667	7.333		
Total	47	23481.917			

Appendix 34: Percentage of bulbs with girth < 10 cm during 2016 cropping season

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
CV	3	2088.250	696.083	94.92	<.001
SP	3	21047.750	7015.917	956.72	<.001
CV.SP	9	111.250	12.361	1.69	0.134
Residual	32	234.667	7.333		
Total	47	23481.917			

Appendix 35: Percentage of bulb rot in thatch roofed storage structure in 2015

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.05556	0.02778	1.00	
CV	3	0.56250	0.18750	6.75	0.001
SP	3	0.56250	0.18750	6.75	0.001
CV.SP	9	1.68750	0.18750	6.75	<.001
Residual	30	0.83333	0.02778	1.00	

Appendix 36: Percentage of bulb rot in corrugated iron sheet roofed storage structure in 2015

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	4.7095	2.3547	3.14	
CV	3	9.2292	3.0764	4.10	0.015
SP	3	163.9884	54.6628	72.90	<.001
CV.SP	9	25.7986	2.8665	3.82	0.003
Residual	30	22.4942	0.7498	2.06	

Appendix 37: Percentage of bulb sprout in thatch roofed storage structure in 2015

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.12505	0.06252	4.20	
CV	3	0.01025	0.00342	0.23	0.875
SP	3	0.70840	0.23613	15.88	<.001
CV.SP	9	0.03076	0.00342	0.23	0.987
Residual	30	0.44606	0.01487	0.83	

Appendix 38: Percentage of bulb sprout in corrugated iron sheet roofed storage structure in 2015

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.03241	0.01620	0.41	
CV	3	0.24248	0.08083	2.04	0.130
SP	3	4.16840	1.38947	35.03	<.001
CV.SP	9	0.72743	0.08083	2.04	0.070
Residual	30	1.18981	0.03966	1.04	

Appendix 39: Percentage of bulb rot in thatch roofed storage structure in 2016

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.19685	0.09843	1.65	
CV	3	0.24963	0.08321	1.39	0.265
SP	3	6.08444	2.02815	33.91	<.001
CV.SP	9	0.74889	0.08321	1.39	0.236
Residual	30	1.79426	0.05981	1.21	

Appendix 40: Percentage of bulb rot in corrugated iron sheet roofed storage structure in 2016

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.46644	0.23322	3.15	
CV	3	4.37528	1.45843	19.72	<.001
SP	3	33.95861	11.31954	153.05	<.001
CV.SP	9	9.88972	1.09886	14.86	<.001
Residual	30	2.21875	0.07396	1.22	

Appendix 41: Percentage of bulb sprout in thatch roofed storage structure in 2016

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.004630	0.002315	1.00	
CV	3	0.006944	0.002315	1.00	0.406
SP	3	0.006944	0.002315	1.00	0.406
CV.SP	9	0.020833	0.002315	1.00	0.461
Residual	30	0.069444	0.002315	1.00	

Appendix 42: Percentage of bulb sprout in corrugated iron sheet roofed storage structure in 2016

Source of variation	D.f.	S.s.	M.s.	V.r.	F.pr.
REP stratum	2	0.032407	0.016204	1.84	
CV	3	0.055556	0.018519	2.11	0.120
SP	3	0.111111	0.037037	4.21	0.013
CV.SP	9	0.166667	0.018519	2.11	0.061
Residual	30	0.263889	0.008796	0.95	