# THE COMBINED EFFECTS OF DAYLENGTH AND TEMPERATURE ON ONION BULB WHEN GROWN UNDER GREENHOUSE ENVIRONMENT

**Felicia Nobuhle Mpanza**

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**Discipline of Horticultural Science,**

**School of Agriculture, Earth and Environmental Science,**

**University of KwaZulu-Natal,**

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**DECLARATION**

**I, Felicia Nobuhle Mpanza** declare that the research reported in this thesis except where otherwise indicated, is my original work. This thesis has not been submitted for any degree or examination at any other university

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**Felicia Nobuhle Mpanza**

Certify that the above statement is correct

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**Dr Samson Tesfay**
Supervisor

**ABSTRACT**

Lack of understanding the suitable level of day/night temperature that will give maximum yield (good bulbing) of onion resulted in poor yields due to poor onset of onion bulbing in KZN. Three different onion cultivars namely Red Creole( RC), Star 5516 and Star 5517( STR 1 and 2) seeds were purchased from MacDonald's & STAKE AYRES , were germinated in 200 cubicles germination trays, and grown for 40 days till the seedlings were ready for transplanting. The seedlings were later transferred into three growth chambers under the combination of three daylengths (11.5 h, 12 h, and 12.5 h) and three varying day/night temperatures (25/12$^0$C, 30/15$^0$C, and 35/18$^0$C). In experiment 1, this study investigated the effect of temperature (25/12$^0$C, 30/15$^0$C, and 35/18$^0$C) and daylength (11.5 h, 12 h, and 12.5 h) in the initiation of bulbing process. The 4-6 weeks onion seedlings were transplanted to plastic pots and left for one week in the same environment where the seedlings were growing to condition themselves from transplanting shock. Thereafter, the seedlings' pots were transported to assigned treatment combinations. The onions seedlings were monitored for bulb initiation in response to growing conditions .All three cultivars required at least 12 h daylength for bulb initiation when assessed by a bulbing ratio ≥2.0. A bulbing ratio ≥2.0 characterizes the onset of bulbing. Under a 11.5 h daylength, a temperature higher than 25/12°C decreased vegetative growth. Temperature may be above the required condition for the growth of these cultivars at this daylength. However, the 25/12°C and 30/15°C temperatures were found to be ideal for onion bulb production under 12 h and 12.5 h daylengths. The three cultivars (STR I, STR 2 and RC) showed a comparable growth response to the daylength and temperature interactions.

Observation was recorded fortnightly on plant height and leaf area, leaf number and bulb diameter and length. More, plant carbohydrates was determined using HPLC-RID as well as invertase and sucrose synthase enzyme activities were also determined using Spectrophotometer (Shimadzu UVprobe-1800).The results revealed that the interaction effects of daylengths at 12h, 12.5h and temperatures levels of 25/12$^0$C, 30/15$^0$C significantly increased onset of bulbing due to high concentration of fructose and glucose produced in the leaf area. To these temperatures, overall the plants recorded plant height (583 and 640 mm),leaf number (8.4,9.8) and bulb ratio (2.2,2.7).Interestingly, plant carbohydrates, mainly fructose (14-16mg/g dw) and glucose (10-14 mg/d dw) increased for the daylengths 12h,12.5h and temperatures 25/12$^0$C,30/15$^0$C in the bulb .And sucrose synthase (3-8 U) activities also increased ,thus resulted in timely onset of bulbing and progressing for bulb development which eventually produces sound onion bulbs .

In Experiment 2, the 4-6 weeks onion seedlings were transplanted to plastic pots and left for one week in the same environmental condition where the seedlings were growing to conditioning of the seedlings from transplanting shock. Thereafter the seedlings' pots were transported to assigned treatment combinations. The onions seedlings were monitored for bulb yield in response to growing conditions. Observation was recorded on bolting, maturity, and plant height, number of leaves, leaf length and diameter during bulb development. There were significant differences ($p<0.05$) in all onion cultivars growing under different levels of day/night temperatures (25/12$^{0}$C, 30/15$^{0}$C, 35/18$^{0}$C). Observation was recorded on bolting, maturity, plant height, number of leaves, leaf length and leaf diameter during bulb development.In both cultivars Star 5516 and Star 5517, had a consistently difference on Red creole cultivar across temperature regime on bolting. The onion bulb diameter and length were different for all cultivars when seedling were exposed to varying temperatures, under 30/15$^{0}$C, the highest bulb weight was achieved compared to others followed by 25/12 $^{0}$C and 35/18$^{0}$C consequently.

Onion seedlings grown under varying temperature levels showed significant differences post transplanting onion bulbs. Seedlings which were raised at 25/12$^{0}$C, the bulb yield was significantly little compared to 30/15$^{0}$C and 35/18$^{0}$C. However, there were no significant differences between 30/15$^{0}$C and 35/18$^{0}$C. Onion plant bulb development was determined by the 'onset of onion bulbing' and final yield as well as its quality. In conclusion, the onion seedlings grow well in a conducive environment with optimum photoperiod and temperature combinations, result in timely onset of bulbing and this progressing for bulb development, which eventually produces sound bulbs.

**Keywords:** Bulbing, Onion, photoperiod, temperature, enzymes, carbohydrates

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# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Onion (*Allium* cepa L.) belongs to the genus *Allium* of the family Alliaceae is a biennial plant and the bulb is a vegetative overwintering stage in the life cycle of the plant. Onion is by far the most important of the bulb crops cultivated commercially in nearly most parts of the world and form an important part of many national diets .The crop is grown for consumption both in the green state as well as in mature bulbs. It is significantly important in the daily diet of South Africans. All the plant parts are edible, but the bulbs and the lower stem sections are the most popular as seasonings or as vegetables in stews (Khan et al. 2002). It is one of the richest sources of flavonoids in the human diet and flavonoid consumption has been associated with a reduced risk of cancer, heart disease and diabetes, antibacterial, antiviral, anti-allergenic and anti-inflammatory. Development rate of onion is governed by the environmental and growing conditions which then influences the earliness of the crop. This, in turn can influence the quality of the bulb which is the most important characteristic of onion. *Allium*s are typically plants of open, sunny, dry sites in fairly arid climates, however many species are also found in dry mountain slopes, summer dry, open, scrubby vegetation.

Onions exhibit particular diversity in the eastern Mediterranean countries, such as Pakistan and India, which are the most important sources of genetic diversity and believed to be centre of origin (Brewster, 2008). Onion is cultivated since ancient times and is a commercially significant crop on all continents. Onions are like garlic, they are a rich in sulfur containing compounds that are responsible for their pungent odours, fibers, potassium, vitamin B, vitamin C and they are low in fat (Ayyachamy et al, 2007), cholesterol and sodium and for many of their health-promoting effects. It is also an outstanding source of polyphenols including the flavonoid polyphenols. Onions have anti-biotic, antiseptic, antimicrobial and carminative properties that fight all infections.

Onion is valued for it bulbs which are suited for storage for a long time and long distance transport according to Gopalakrishman (2007). Bulb formation and growth of onion is influenced by temperature and photoperiod, however if two parameters are compromised there will be a failure of plants to initiate bulbing thus causing quality defects such as double bulbs, thick necked bulbs and bolters. Onion bulbing is promoted by long days and high temperatures. Night temperature and far-red light in the induction of bulbing in phytotron-grown plants are necessary (Lancaster, 1996). In South Africa, onions that are mostly sown are intermediate cultivars however a new onion cultivars (short, early and mid-intermediate) were released due to a market turnaround strategy, thus the sowing season would be lengthened from February until the end of June in the central areas of South Africa ( Bosekeng,2012).if

In New Zealand onions are sown at low densities so that light quality is not a limiting factor. Clearly, many factors other than temperature and photoperiod affect bulb growth e.g. irrigation, fertilizer application, weed competition and planting density (Lancaster, 1996). However field experiments described that weed competition, density, fertilizer and water were non-limiting. Although temperature and photoperiod are known to interact to induce bulbing there has been little work in which the photothermal requirements for bulbing in the field have been specified.

### 1.2. Problem Statement

It has been discovered that there is a lack of understanding the suitable level of day/night temperature and daylength (growing conditions) that gives the maximum yield of onion thus resulted in varying onion yields due to poor onset of onion bulbing in KZN. Growing conditions of onion seem to have an influence on different physiological stages of onion seedlings. Photoperiod and temperature had a noticeable influence in the bulbing responses of all cultivars. However, no published evidence on the role of night temperature on bulbing of onions, although Heath and Holdsworth (1948) stated that high night temperature was more effective in accelerating bulbing than high day temperature.

### 1.3. Research objectives

The goal of this study was to determine the combined effects of daylength and temperature in terms of the suitable levels of day/night temperatures that would give best bulbing and bulb yield. Production constraints and opportunities to increase productivity of the onion crop in the smallholder sector were addressed in the study.

The specific objectives of the study were:

- To investigate the bulbing response of common onion varieties to photoperiod and temperature interaction.
- To determine the effect of different growing conditions ( photoperiod and temperature) of onion seedlings on the growth ,biomass yield and fresh bulb yield of onion

1.3.1 Research questions

- Which level of day/night temperature and, suitable day length that would give best on the onset of onion bulbing?
- What are the suitable growing conditions that would result in good growth bulb yield and bulb quality of onion

1.3.2 Research Hypotheses

1.

**Ho**: Daylengths (11.5 h, 12 h, and 12.5 h) and temperatures (25/12 °C, 30/15 °C, and 35/18 $^0$C) which, each and in combination, do not have an impact in determining onion growth and development.

**Ha**: Daylengths (11.5 h, 12 h, and 12.5 h) and temperatures (25/12 $^0$C, 30/15 $^0$C, and 35/18 $^0$C) which, each and in combination, have an impact in determining onion growth and development.

2.

**Ho**: On onion seedlings grown under different growing conditions have no effect on the growth, biomass yield and fresh bulb yield of onion.

**Ha**: Onion seedlings grown under different growing conditions have an effect on the growth, biomass yield and fresh bulb yield.

## CHAPTER TWO: LITERATURE REVIEW

This chapter is aimed at the literature review of onion origin, production, morphology and bulb quality. It also highlight the impact of temperature and photoperiod on onion bulbing and yield quality. The chapter also looks at the climatic requirements of onions and how it affect the onion production,

### 2.1 ONIONS, THEIR GEOGRAPHICAL ORIGIN AND USES

#### 2.1.2 The Onion Geographical Origin and Related Species

The onion (*Allium* cepa L.) which belongs to the family Alliaceae is a biennial plant and the bulb is a vegetative hibernating stage in the life cycle of the plant. It is distributed from the mountains within the subtropical and tropical regions. A region of high species stretches from the Mediterranean basin to central Asia comprising Parkistan, Afganistan and North Iran (Hazra et al, 2011). There are several closely related other species that look similar to onion and share common morphological features and geographical differences, *A. oschaninii* (sister group to A Cepa), *A. Altaicum A. vavilovii*, and *A. galatinum* (Rabinowitch, 2002) the other vegetatively propagated variants of *A.cepa*, are shallots, tree onion and multiplier onions. Added to this there is also a perennial bunching species, A fistulosum is common in China and Japan which is grown for its edible tops and leaf bases.

The onion plant is composed of leaves which arise alternately from a small flattened stem so that older leaves are on the outside and younger leaves on the inside of the stem (Khan et al. 2002). Each leaf is composed of a photosynthetic leaf blade and a non-photosynthetic storage leaf base (scale). During the growth of the plant the leaf scales thicken and form the characteristic bulb. Onions have a determinate growth habit. At the onset of bulbing, leaf sheaths swell, bladeless bulb scales are initiated and these swell to form the central storage tissue of the bulb. Mature onion bulbs can range in size from 5 mm to over 100 mm bulb.

### 2.1 DOMESTICATION, IMPORTANCE, UTILISATION OF ONION

Almost all plant parts of *allium*s are consumed by humans and many wild species are exploited by the local inhabitants through over collection which results in a decline of these wild species (Smith et al. 2016). However the transfer of plants to the garden plot may have been important at the initial stages of domestication. Human and natural selection led to the development of different plant types present in several cultivated species according to (Rabinowitch et al, 2002). Selection for faster growth leading to biennial rather than a longer life cycle and larger bulbs is recommended. There is a great diversity in adaptation of many onion cultivars to photoperiod and temperatures in bulb storage life. Huge range of cultivars and landraces developed over the centuries to fit the diverse climates (Kedebe et al. 2014). Gene banks were established to preserve the potentially valuable and adaptive genes in the seed. Several phases of cultivars were developed for the domestication of wild species. The onion seed spread through travel and trade and slowly became adapted to each region (Brewster, 2008).

The combined effects of photoperiod and temperature influence bulb development and flowering, however photoperiod is more important for bulb formation and temperature for flowering (Hazra et al, 2011) these result to a reduced number of onion varieties that can adapt to both conditions. Long-day varieties do not bulb under short day conditions whereas short-long-day varieties if grown under long day condition will develop early bulbs. Varieties also vary in their susceptibility to floral induction (bolting), which is induced by low temperatures at the vegetative phase. Cultural adjustments such as date of planting, altitude, plant density and type of propagating material, may assist in attaining successful production of varieties. To ascertain varieties growing conditions or environment, it is of good importance to carefully test under local conditions (Hazra et al, 2011).

Onion cultivars range in size, color, and taste depending upon their variety. There are generally two types of large, globe-shaped onions, classified as spring/summer or storage onions. Storage onions are grown in colder weather climates and, after harvesting, are dried out for a period of several months, which allows them to attain dry, crisp skins (Rodrigues et al 2009). They generally have a more pungent flavor and are usually named by their color: white, yellow or red. Sowing dates for different cultivars (Table 1) vary with locality and soil type (Khan et al. 2002). Short day cultivars are used in the Northern and central areas of South Africa with intermediate day length cultivars used in central and Southern regions.

**TABLE 1: seasons for onion cultivation in Northern KwaZulu-Natal: Starkeayres (2014)**

| Onion cultivars | Time of sowing period | Time of harvest | Risk |
|---|---|---|---|
| Madalyn | March | July-August | September |
| STAR 5516 | Feb-March | July-Sept | Sept-Oct |
| Cristalina | Feb-March | July-Sept | Apr &Sept |
| Soberana | March-April | September | Apr, Aug & mid-Sept |
| STAR 5517 | Jan | June | May |
| Annika | Feb-March | Jun-July | Early June & end July |
| Mata Hari | March | Aug | Feb & end March |
| Rasta | March | Aug | Late Feb & end March |

## 2.2 MORPHOLOGY AND PROPAGATION OF ONION

### 2. 2.1 Distinguishing Characteristics of Onions

Onion plant is valued for its bulbs having characteristic odour, flavour and pungency. Varieties differ in size (small, medium, large), colour of skin (white, yellow or red), shape (flattened, round, or globular), texture (fine or coarse), maturation and pungency (Smith et al. 2016). Large sized bulbs are mild in pungency and sweet in taste compared to small sized onion. Red coloured varieties are more pungent than white skinned varieties and keep better in storage (Gopalakrishnan, 2007).The onion species are characterized by the distichous leaves and bulbs which are composed of several leaf bases and covered by membranous skins (Khan et al. 2002). The pseudostem is formed by the sheath part of the leaves. As the stem grows upwards, it also broadens, as is shown by the divergent arrows in Figure 2.1.

The plant is biennial; with fleshy bulbs develop the first season, and seed stalks developing during the following season. The leaves develop from a short flattened stem at the base of the bulb. They consist of two parts: the blade and sheath (Rodrigues et al. 2009). The sheaths are fleshy and surround the younger leaves within them. Each leaf is composed of a photosynthetic leaf blade and a non-photosynthetic storage leaf base. The onion is a biennial herb usually grown as an annual. All parts produce a strong onion odour when crushed.

### 2.2.2 Morphology

Each leaf consists of blade and sheath; the sheath develops to completely surround the growing point and forms a tube which encloses younger leaves and the shoot apex Figure 2.1. The pseudo stem formed from concentric leaf sheaths and the young leaf blade growing up the centre of the older surrounding sheaths. There is pore where blade and the sheath joins together to allow the next tip of the younger leaf to be seen.(Brewster, 2008) Eventually, the blade of the younger leaf will elongate and emerge through this pore. When the leaf is fully elongated the pore becomes visible at the top of the pseudostem with younger green blades growing through it. The older sheath bases get pushed away from the apex as the new leaves expand near the shoot apex enduring lateral expansion of the disc-like stem.

All additional roots are adventitious and arise from root initials above nodes on the compressed stem disc (Figure 2.1). Root diameter is 1 to 2mm with no subsequent increase in thickness; primary branches may be produced, but these seldom re-branch. New adventitious roots are initiated as the plant top enlarges and older roots may die as the plant ages

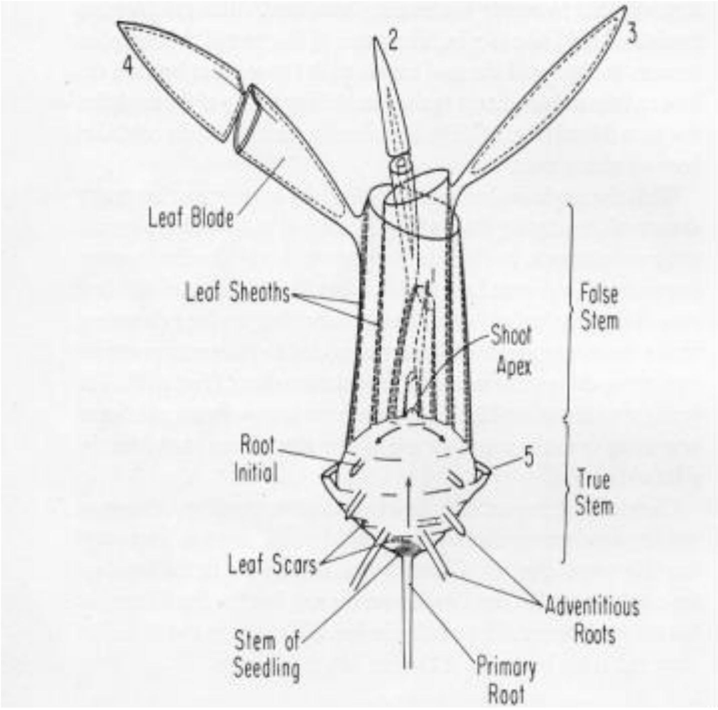


**Figure 2.1 A young plant structure of the common onion in the development of the stem, leaves, and roots, (Brewster, 2008)**

A very short flattened stem is produced at the base of the leaves, which increases in diameter as growth continue, producing the shape of an inverted cone. New leaves are produced by the apical meristem; the later eventually grows out to produce the inflorescence axis, which pushes up through the pseudostem formed by the sheathed leaf bases. Short-stemmed branches or buds may rise singly at the base of, and within the leaf sheathes.

In Japanese bunching onion, bulbs do not form it's only the thickened basal sheaths that act as food reserves during winter dormancy but with leek and kurrat bulbs are formed. The early stages of bulb development in onion involve the swelling of leaf sheaths. During bulbing the young developing leaves stop to form blades but developed into swollen bladeless called bulb scales, so leaf ratio (blade length/sheath length) of any developing leaf is characteristic of bulbing. Bulbing ratio (maximum bulb diameter/maximum pseudostem diameter) characterizes bulbing (Brewster, 2008). Initial increases in bulbing ratio depend on the extent of swelling in the sheaths of bladed leaves, and this increases with light intensity and nitrogen deficiency. Hence decreases in leaf ratio are a more reliable measure of bulb initiation that increases in the bulbing ratio. The outermost sheaths develop into thin dry protective skin and the sheath tissues in the middle region of the neck soften and lose turgidity, eventually causing the foliage to fall. This foliar fall-over is an indication of bulb maturity.

2.2.3 Propagation

Onion plants can be propagated from seed (direct sowing), transplants and/or dry sets. In directly sowing onion crops are normally drilled at a depth of about 2cm. In row seeding they are drilled at about 30cm apart, with a seed rate of 4 − 5kg $ha^{-1}$ and later thinned to about 75mm apart within rows. Improved emergency and shorter time spread of emergence, leading to higher yields and uniform sized bulbs can be obtained using a dibber drill (Gray et al, 1993). According to Brewster (2008) it is recommended to prepare the seedbed for the seed to be sown on to a moist firm underlying layer that will allow the seed the good capillary conductivity of water rising to the imbibing seeds. As seeds emergence depends on temperature and moisture availability.

Bulb onions are best sown under protection and transplanted after six weeks when the stem diameter is about 4 − 5mm particularly in cool temperate regions to lengthened the growing season (Brewster, 2008). When transplants are about to reach the proper size, one week hardening is recommended and then transplanted. To ease handling during transplanting, shoots and roots can be trimmed to a length of 10-15cm with knife or shears and excess tops are cut. Some farmers experienced a slightly reduced of yield because of improper trimming of the roots in particular. Transplants are planted with the base of the seedling about 2.5cm below the soil surface, when planted deeper at 5 or 10cm larger bulb which do not have splits inside are produced. In most places transplanting is still done by hand as transplanting machines may cause yields to be reduced due to the plants not planted upright. Premature bulbing of transplant should be avoided.

Sets are produced by growing a crop from seed at a very high density of 1000-2000 plants $m^2$. They are the small bulbs weigh 2-3g fresh and less than 25mm diameter and are planted to develop into larger bulbs. Growers used sets because have a shorter growing season than plants from seeds. The crop is grown with a low level of nitrogen fertilizer (40kg/ha) or less to encourage hard growth (Brewster, 2008). The small plants are then stored under high temperature of about $28^0$C to ensure that they do not bolt after planting out. Larger sets greater than 20mm diameter needs a warm storage to prevent bolting. Set planting densities 30-80 $m^{-2}$, it should planted upright and covered with soil. In South Africa transplants are the best method that are used so far due to its ease handling during transplanting although it is laborious as it is transplanted by hand .

### 2.2.4 Sexual Propagation

Hybrids can be produced from the crossing of widely different onion populations which can exceed either parent in vigour thus the fixing of genotypes shows the vigour in F1 hybrid cultivars. The advantage of F1 hybrid is that they will not breed true from the seed but produces new every generation from appropriate parent line that remains under the control of the breeder. Male sterile plant was discovered when the bubils that were produced in the flower head cultivars, instead of the seed, crossed with other onion (Pike, 1986; Khan et al. 2002). Pollen fails to develop in these plants; they become incapable of self-pollination. Hence, seed produced results from cross pollination. It was then exploited in hybrid breeding in other crops and breeders are always vigilant for such plants among their selections (Ayyachamy et al. 2007). It has shown the dependence of the combined effects of a nuclear gene and cytoplasmic factor; however the combination of genetic and various cytoplasmic factors provide sterility and fertility. Fertile cytoplasmic factor cannot be transferred to the female during the cross thus provided the normal fertility in male line known as maintainer line. Both male-sterile and maintainer lines produced good hybrids. For commercial production male sterile plants are commonly used (Tesfay, 2005).

There are factors that determine bulb onion yields which include, cultivar, sowing date and plant density (Brewster, 2008).Bulb onion yield increases with plant density and correlates with the percentage light interception by the leaf canopy. Later sown plants switched from leaf blade to bulb production while leaf Area Index and the leaf canopy light interception is lower than the earlier sown plants. Clearly, high bulb yield is dependent on a high percentage light interception by leaf canopy. Cooler temperatures causes longer duration of bulbing thus give slower bulb ripening and leaf senescence. Mean temperatures during bulbing is 13 -17.5 °C, depending on the growing season. The bulb size that is acceptable to most of the markets is 5-7cm in diameter, to achieve this, cultivars with the capability of producing sufficient leaf area to intercept a high proportion of light about 60% or greater must be sown at an appropriate time (Brewster, 2008).

## 2.3 GROWTH AND VEGETATIVE DEVELOPMENT OF ONIONS

### 2.3.1 Growth stages of bulb onion

There is a curled embryo within an onion seed which consist of hypocotyl (short root) with shoot apex and cotyledon. After imbibition has occurred the cotyledon ends in a haustorium like structure which absorbs nutrients from the endosperm (Currah and Proctor, 1990). During germination, the radicle appears then the cotyledon elongates and root emerges. As cotyledon elongates, mitosis occur, causing the primary root to grow downwards and a developed U shaped bend in the slit containing apical meristem. The cotyledon emerges from the soil forming a looped structure, which break the surface of the ground while the seed is still below the ground. The cotyledon continues to elongate at the base until eventually the remains of the seed coat from which it has grown is carried up above the ground level, still attached to the tip of the cotyledon. The meristematic growing point of the seedling remains below the ground, within the area where the cotyledon joins the radicle. This zone is crucial to the organization of the onion plant throughout its life. From the apical meristem the seedling develops a succession of leaves, which grow from the flattened stem or base plate, which forms around the meristem. Each foliage leaf is made up of a hollow photosynthetic blade and a cylindrical sheath, which connects the blade to the base-plate shaped stem. Cell division takes place near the base of the leaf blade and the sheath, so that the oldest part of each leaf is the tip, and the youngest part is the base of the leaf sheath and leaf blade. Each new leaf is produced inside the encircling leaf sheaths of older ones and grows up through them, so that a neck or 'pseudostem' is formed from the concentric leaf sheaths. Each new leaf blade emerges through a small hole or pore at the junction of the blade and sheath of the previous leaf. The hollow tapering leaf blades are carried in rows arranged opposite to each other.

Currah and Proctor (1990) reported that adventitious roots are also produced from the base plate. New roots form in irregular rings above and around the older ones and emerge through the corky outer tissue. Each successive ring contains more roots than the previous one throughout the time that active vegetative growth continues. The leafy plant eventually ceases to form leaf blades (Ayyachamy et al. 2007). Instead, the apex begins to initiate a number of bladeless, concentric, thickened leaf sheathes; these form the bulb scales. Together with the swollen lower leaf sheathes of the older leaves, they make up fleshy part of the onion bulb. Studies on the movement of assimilates during bulbing have shown the most of the dry matter in the green leaves is transferred down to the bulb at this stage, contributing to both the swollen leaf sheaths and to the bladeless fleshy scales. The papery outer bulb scales are formed from the expanded dried out bases of the older leaf sheaths.

When no leaf blades are produced to support the plant from the inside, the onion’s neck becomes hollow, and the top of the plant falls down under the weight of the leafy blades. The green blades gradually senesce and die, but during this period nutrients from the leaf blades are still exported into the bulb, which continues to store them.  When this process is complete, the onion ceases to grow and is ready for harvest.  If it remains in the ground, the plant may root again and re-growth may start, particularly if the soil is wet.

### 2.3.2 Climate and Cultural Requirements

Onions can be grown under variety climatic conditions according to Smith (2006), but it is essentially a cool season crop, thrive best in a mild climate without extreme rainfall, heat or cold. They are not suited to regions with heavy rainfall in the lowland humid tropics. In South Africa onions are planted all year round with cool conditions during vegetative growth and hot, dry conditions nearing maturity, in early summer. Rainy spells in late spring and early summer reduce quality, particularly keeping quality. They can be grown on a variety of soils, but, sandy to clay soils are suitable. The soil should have good total available moisture (TAM), be non-packing and friable; good fertile loam usually gives the best results. The optimum soil pH ranges from 5.0 to 6.0. Onions succeed best on highly fertile, slightly acid, well-drained sandy loams. Normal formation of the bulb is permitted by these soils, and has adequate water holding capacity (Smith, 2006).

### 2.3.3 The Effect of Photoperiod, Temperature and Radiant Flux on Bulbing

Physiologically onion is categorized as a long day crop. This means that a certain length of the day must be attained for a particular onion population before bulbing take place regardless of all the environmental conditions (Currah and Proctor, 1990). Factors such as temperature, nutrition and spacing play a vital role in accelerating or slowing down the bulbing process. Onions that are a adapted to latitudes that are far away from the equator start to initiate bulbing when day lengths of 14 to 16 hours are reached and they are commonly referred as long-day cultivars, however in tropic regions the variations of day length is approximately 11 to 13 hours and the onions that can grow in such regions are referred as short day.

Bulbing is promoted by the photoperiod, in dry soil conditions it is accentuated (Brewster, 2008) the stimulus being received through the leaves. The plants form new leaves indeterminately under a very short daylength, without bulbing. The critical daylength varies from 11 to 16 hours, depending on the cultivars. In temperate regions, long-day cultivars will not form bulbs in the shorter days of the tropics only short-day cultivars are required. Temperature also plays an important role in bulbing .It takes place more quickly at warm than at cool temperatures, provided that the minimum photoperiod for the cultivars has been reached. Plant size also has some effect and good vegetative growth should be obtained before the bulbing stage is reached. Onions mature quickly when planted closely. High soil temperatures contribute to the occurrence of bottle or cigar shaped onion bulbs reported from hot regions (Currah and Proctor, 1990).

#### 2.3.3.1 Induction of bulbing and bulb development

A change in onion leaf morphology caused by the exposure to a critical day length results in bulbing, not only day length has an influence in bulbing but also the temperature do influence bulbing. Each onion cultivar has a critical daylenght for the induction of bulbing (Welbaum, 2015). Plant growth and development changes of onion are strictly adjusted to seasonal changes throughout the year. All cultivars are long day plants with respect to bulbing due to the fact that they bulb in response to increasing rather than decreasing daylength. This is most noticeable in the timing of the onset of bulbing or flowering. Dual photoperiodic requirements have been observed in onion plant. Bulb formation is promoted by long days. Short-day conditions (non-inductive) are unfavorable for bulbing; responses of plants to inductive temperature results in flower initiation, while after that, long day conditions usually accelerate flower stalk emergence. Genotypic variation in photoperiodic sensitivity appears to be determined by several factors such as critical day length, duration of immature phase, and responsiveness to the ratio of red: far-red light enhancement during the twilight period. Bulbing is photoperiod dependent from the initiation stage to maturity (Welbaum, 2015).

Physiologically, the bulbing process of onion is classified as quantitative long day plant. This concept means that for a particular onion population, a certain length on day can be determined which must be attained before bulbing takes place. Regardless of the other environmental conditions within this concept, factors such as temperature, nutrition and spacing play important parts in accelerating or slowing down bulbing process. Internal factors such as plant age or size also have a strong influence on the readiness of onion plants to respond to external stimuli (Currah and Proctor, 1990).

In the tropics, well adapted onion populations are found where day length varies very little or not at all, according to Currah et al, (1990).The onion plant is very responsive to two effects i.e. temperature and photoperiod, these effects have been confirmed by many studies (Brewster, 2008). The critical minimum daylength for bulbing varies among cultivars but, within the tropics variation over a year in day length normally takes between 11 and 13 hours. Even if the photoperiod is adequate, minimum temperature must be met, or bulbing is delayed. The ideal climate would be cool weather early in the season with increasing temperature as maturity approaches. The lengths of day to which particular onion cultivars respond by forming bulbs varies greatly. Onions adapted to high latitudes start to initiate bulbing when daylength of 14 to 16 hours are reached, and often complete the bulbing process under declining day lengths in the autumn. The onion cultivars, mostly planted as sets are adapted to these regions are commonly referred to as long- day onions.

As reported by Brewster, 1990, bulb maturity is accelerated by higher density planting associated with high Leaf Area Index (LAI). High plant density or use of fertilizer increases LAI which in turn accelerate bulb maturity. Early maturity date caused by an early initiation of bulb scales. The red: far-red ratio plays an important role in the developmental processes of plants ranging from seed germination to stem elongation but it becomes low when the light passes through leaf canopies due to the fact that leaves absorb red wavelengths strongly than far-red. In onions, Bulbing and crop maturity is accelerated by the decreased in red: far-red in the incident light. Increase in both crop plant density and weed competition increase LAI and accelerate bulbing.

#### 2.3.3.2 Photoperiod

Onion bulbing is photoperiod dependent; it is controlled by photoperiod and is promoted by long day, Peter (2009) .The principal carbohydrate, sucrose is translocate to the storage organ due to stimulus photoperiod. The stimulus is perceived by the leaves and translocated downwards to responding organ. The stimuli photoperiod, are the different plant hormones that play a role in development and regulation of storage organs. Auxin is also associated with onion bulbing. Long day stimulate the formation and the development of onion. In onion, responses of photoperiod differ with onion cultivars, The study conducted in India for the behaviour of onion cultivars planted during December to May, shown that cultivars require 12-13 h daylength for bulb formation and development whereas onion grown in Maharashtra require 10-11h.daylength for bulb formation and development. In European countries the long day cultivars require 13-14 h day length for bulb formation and development. Conditions become unfavourable for them to bulb in short days (Peter, 2009).

According to Bosekeng (2012) Intermediate day cultivars such as Jaquar and Python and short day cultivars such as Charlize can be planted in South Africa, due to the fact that South Africa receive about 14.33h day length in average Table 2.1 is a summary of different onion cultivars indicating their day length requirement and sowing dates for specific areas in South Africa.

Table 2.1 Onion cultivars classified according to their day length requirement for bulbing, cultivar type and sowing date for specific areas in South Africa (Comrie, 1997; Joubert & Van Niekerk, 1997; Messiaen & Rouamba, 2004; Hygrotech, 2009a & b) cited by Bosekeng, 2012.

| **Cultivars** | **Type** | **Required Daylength (Hours)** | **Sowing Date** | **Province** |
|---|---|---|---|---|
| **Charlize** | Short | < 12 | February-March | Limpopo& Northern |
| **Pyramid** | Early-Short | < 12 | March-April | Gauteng |
| **Hojem** | Late-Short | < 12 | March – April | FreeState& Northen Cape |
| **Python** | Early-intermediate | 12-14 | May | Northern Cape |
| **Ceres Gold** | Mid-Intermediate | 12-14 | Late May-June | Northern Cape |
| **Australian Brown** | Late- intermediate | 12-14 | May | Free State & Northern Cape |
| **Caledon Globe** | Late-intermediate | 12-14 | May | Free State &Northern Cape |

Photoperiod and temperature are the two most significant climatic factors in determining the adaptability of onion cultivars. Time taken for the onion plant to start bulbing is determined by the photoperiod not the age of the plant. Early maturity effects from the ability of the plant to start bulb formation at short photoperiods and then develop rapidly (Raisz, 2004). To obtain the good yields or large bulbs it is vital to sow the early cultivars seed in greenhouse or hot bed instead of sowing direct in the field, so , large plants will be transplanted before the minimum photoperiod for bulbing to occur. Late cultivars mature late due to long photoperiod requirements. They develop at a very slow rate after bulbing has started (Raisz, 2004).

According to Yamasaki (2000) Long day (LD) photoperiod given before vernalization inhibits flower initiation compared to short day (SD photoperiod. At low temperature ($3^0$C) LD does not affect flower initiation, but inhibit flower initiation at $7^0$C,$11^0$C, and $15^0$C. In other cultivars, LD photoperiod inhibit flower initiation under all temperature conditions. Therefore Japanese bunching onion require short day photoperiod to initiates flowering, so the induction of flowering should complement low temperature and short day photoperiod. Low Nitrogen promotes flower initiation and lead to swelling of the leaf sheaths. Development of inflorescence to floret initiation stage causes long photoperiods to increase scape elongation. High temperatures about $35^0$C devernalize and suppress inflorescence development .Bolting was prevented by growing plant from mid-December to mid-April in plastic tunnels where temperatures were 35-$40^0$C and extension of photoperiod in other cultivars investigated by Yamasaki et al, (Brewster,2008).

As reported by Wright and Sobeih (1986), cited by Tesfay (2005). High level of photosynthetically active radiation (PAR) combined with a long photoperiod accelerated both bulbing and final bulb size in onion (Figure 2.2) Plants grown under a short photoperiod with a low level of irradiance produced bulbs earlier when transferred to a long photoperiod with high radiance than did plants that received a short photoperiod with a high irradiance level and were then moved to long photoperiod with low irradiance. Along photoperiod with a high irradiance level showed a rapid in leaf numbers due to bulb formation. This was suggested to be caused by the cessation of new leaf growth and the senescence of older leaves. An experiment was conducted in order to examine the relationship between photoperiod, photon flux density (in the region 400-700nm) and bulb development. Each compartment had the following different light environment (Tesfay, 2005):

1. Long photoperiod (LD) with high irradiance (HI): 16h light at 135 $Em^{-2}s^{-1}$ of photosynthetically active radiation (PAR).
2. Long photoperiod (LD) with low irradiance (LI): 16h light at 67.50 $Em^{-2}s^{-1}$ PAR.
3. Short photoperiod (SD) with high irradiance (HI): 8h light at 135 $Em^{-2}s^{-1}$ PAR.
4. Short photoperiod (SD) with low irradiance (LI): 8h light at 67.50 $Em^{-2}s^{-1}$ PAR.

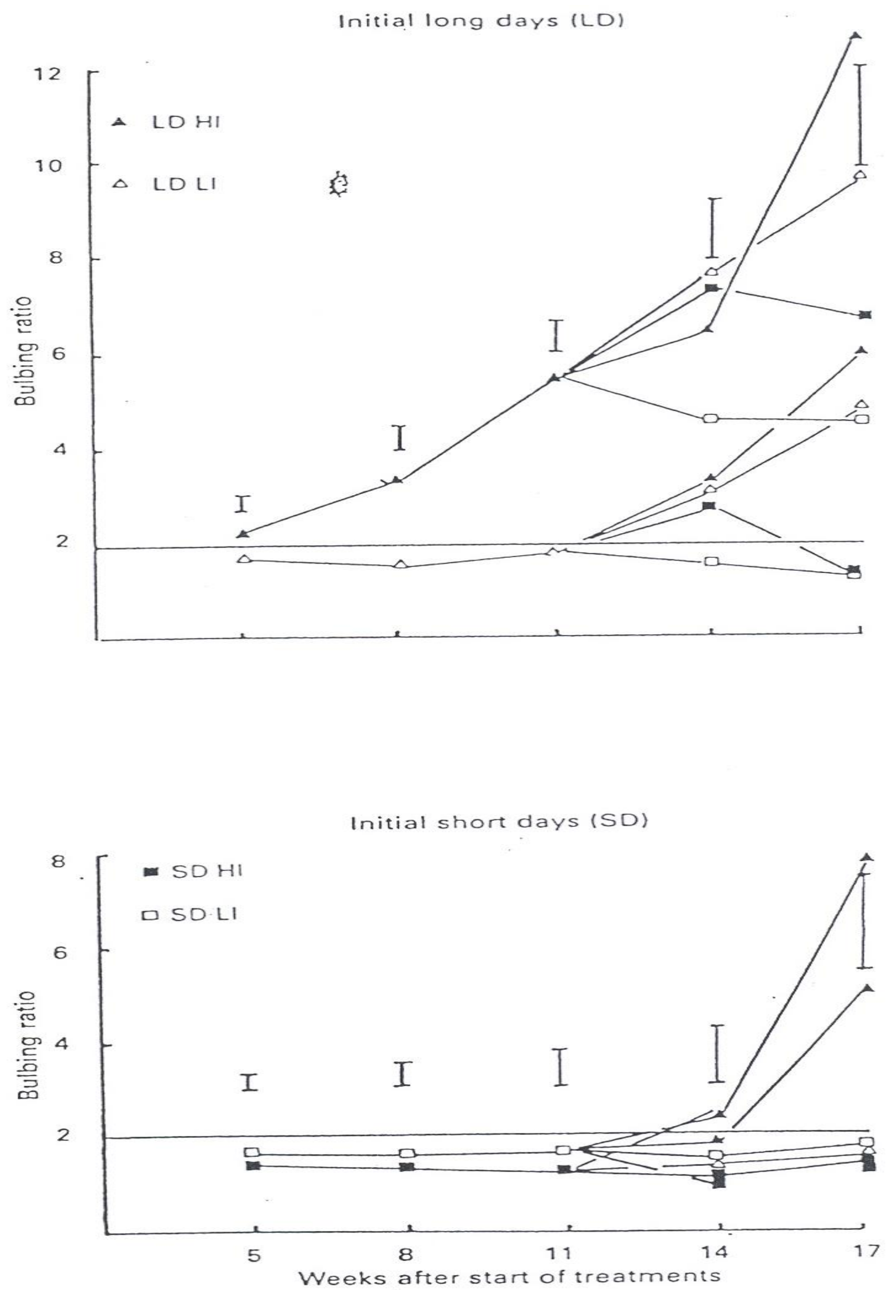


**Figure 2.2 Effect of radiance level and daylength on bulbing ratio in onion cv Rocket. Bars Represent LSD at P=0.05**

Defoliation techniques used, had shown that bulbing in onions relies on the perception of the long day stimulus by young developing leaves. Bulbs constantly grow more rapidly in older plants, and young plants would only bulb when they have approximately four foliage leave (Tesfay, 2005).

Leaves have been shown to be the site of daylength response in many long- and short-day plants, as several researchers have also shown that the sensitivity to daylength changes with the age of the leaf (Tesfay, 2005). .The reports revealed that the position of the leaf had effect on the time of bulb formation .A decline in photoperiodic sensitivity of old leaves may result from the decline in metabolic activity due to changes in their mineral nutrition, protein and chlorophyll contents as they age, however they could be induced to bulb in 11 h. Expansion of young leaves hastens the onset of bulbing and the most rapidly expanding leaf is the most sensitive to photoperiodic induction (Tesfay, 2005).

2.3.3.3. Temperature

Onions grow optimally at temperatures ranging from 12 to 24°C, seeds can germinate from 7°C to 29°C, but do best at about 18°C (Smith,2006). Onions require cool temperatures during the seedling stage and moderately high temperature during bulbing, however temperatures above or below the optimum for photosynthesis efficiency will be reduced i.e. the conversion of absorbed light to primary photosynthetic products (Brewster, 1994).More over a high temperature between 25 $^0$C-27 $^0$C enhance bulb formation and maturity. For the onion plant to initiate bulbs it must first accumulate a thermal time (growing degree days above 5 $^0$C) of about 600 degree days from emergence (Lancaster et al., 1996), cited by (Bosekeng, 2012).Plants may reach 600 degree days thermal time before the required day length is reached causing bulb initiation to start earlier. The calculation to determine thermal time (D) is:

$$\boldsymbol{D = \sum_{t=1}^{n} \frac{T\,\mathrm{max} + T\,min}{2} - T\text{--}b}$$

Where: D = thermal time

T*max* and T*min* = daily maximum and minimum temperature

T$b$ = base temperature

$n$ = number of days between emergence and bulb initiation

Base temperature = 5°C

The plus sign indicates that the summation only included days when temperature surpassed the base temperature. The literature above reports that onions will only form bulbs if the day length and temperature requirements of the plant are met. Larger plants and warmer temperatures cause onion plants to start forming bulbs earlier. Bolting is caused by temperatures between 7.2 – $10^0$C according to Albert. (2013) seed set and bulb development cease sending up flower stalk. Flowering causes a decrease in bulb size. Young bulb onion should be protected from freezing temperatures because that can kill the plants if not the plant is likely to bolt as soon as temperature rises.

The effect of soil temperature on bulb shape was remarkably found by Ymaguchi et al. (1975) in glass-house in California, using three white onion cultivars, two of which were grown for dehydration. Comparisons were made at soil temperatures of 13°C, 18°C, 24°C and 29°C and it was found that the higher the soil temperature, the more elongated was the resulting bulb, cited by, Currah and Proctor, 1990).The height of bulb increased while the diameter remained the same, except at the highest soil temperature, 29°C at which bulb diameter was slightly reduced. High soil temperatures may therefore contribute to the occurrence of bottle or cigar shaped onion. A rise in soil temperature significantly increases onion pungency and flavour volatiles (Currah and Proctor, 1990).

The number of days from sowing to the start of bulbing decreased with increasing night temperature. The rate of bulbing increased with increasing night temperature. Photoperiod and temperature had a marked influence in the bulbing responses of all cultivars. There is no extensive published evidence on the role of night temperature on bulbing of onions, although Heath and Holdsworth (1948) stated that high night temperature was more effective in accelerating bulbing than high day temperature. High temperatures and low humidity are advantageous during bulbing and curing.

As reported by Tesfay (2005), onion bulbing may be divided in to two phases with respect to the influence of environmental factors: the time of initiation of bulbing and the rate of bulb development after initiation. The bulbing ratio of 2.0 was obtained by extrapolation of the bulbing ratio data, and the rates of bulbing were obtained from the period of most rapid bulbing in each treatment. There were three daylengths (13, 14, 15 h); three day temperatures (22°C, 26°C, 30°C) and night temperature drop of 5°C or 15°C from each day temperature.

### 2.3.3.4 Reversibility of Bulbing and Sensitivity to Photoperiod

According to Tesfay, (2005) Onions require a certain minimum length of day for the completion of bulb development and maturation process. The transfer of bulbing plants from inductive photoperiod to non-inductive photoperiod conditions can reverse bulb development process and renewal of vegetative growth (Smittle, 1993). The reversibility of bulbing can thus be used to test and evaluate the relative sensitivity of onion cultivars to photoperiod during the bulbing process (Figure 2.3).

As illustrated in Figure 2.4 by Kedar et al., (1975), plants were grown in a glasshouse with 18h supplementary light until reaching a bulbing ratio of 3.5, whereupon transferred to naturally decreasing daylength. As shown Figure 2.3, the increase in bulbing ratio continued for some time after transfer to decreasing daylength conditions. After the first date of sowing Beta Alpha and the other two early cultivars managed to mature before natural daylength decreased below 11h and 42min. The two late cultivars, whose bulbing ratio increased more slowly, were influenced by decreasing daylength; bulbing stopped and they reverted to vegetative growth, as indicted by the decreasing bulbing ratio. In the experiment of Figure 2.3, Beta Alpha responded as the other cultivars. Bulbing stopped when daylength decreased below 11h and 3min. and bulbing ratio decreased gradually thereafter in all three cultivars. In the two cultivars, Riverside and Zittau Giant Yellow, the bulbing ratio decreased later and it seems that their response to changes in daylength was delayed in comparison with that of Beta Alpha.

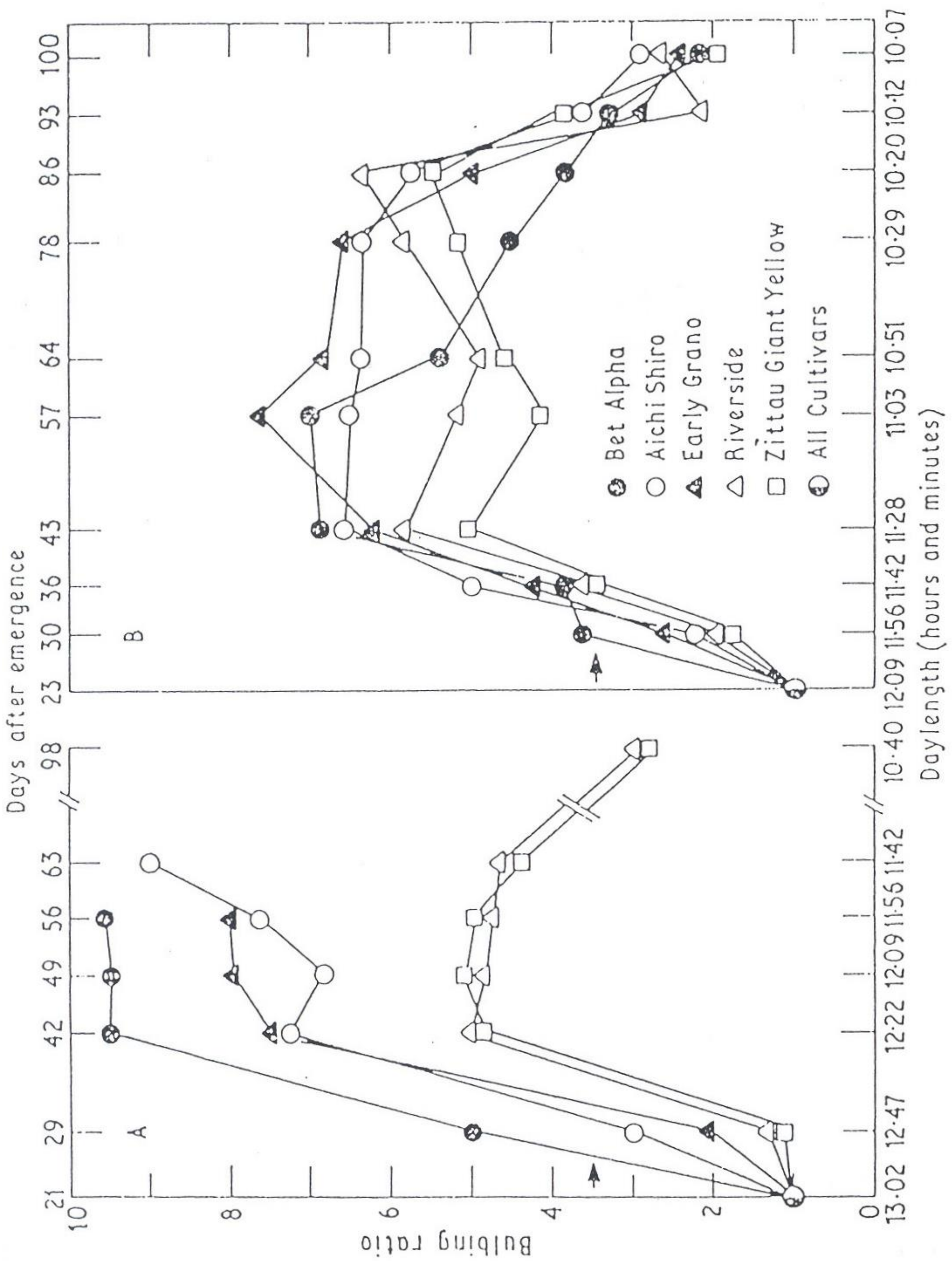


**Figure 2.3 Reversibility and bulbing ratio of 5 onion cultivars grown under long-day conditions (18h supplementary light by 100W incandescent lamps, light intensity 18fc), and transferred to a glasshouse compartment with natural decreasing daylength after reaching a bulb ratio of 3.5 (indicated by arrows). Each point is the mean of 5 replications, in each replication there were 5 plants.**

It is known that reversion to leaf blade production is possible near bulb maturity (Smittle, 1993). It could be argued, however, that once the bulbing process has reached an advanced stage, bulbing could be completed even under non-inductive photoperiods.

### 2.3.4 Carbon Assimilation in the Development of Onion Bulb

Onion plant is different from other crops due to several qualities the crop has. It is a bulb crop with unusual leaf morphology, and phytochemicals (Peffley et al, 1999).In most cases onion production is influenced by the time of onset of bulbing and the duration of bulb growth. Bulb development is complex with the onset of bulb formation, leaf productivity ceases as photosynthates are reallocated to the bulb, lowering the production of new shoots and ultimately crop canopy. Onion has high productivity of edible biomass and is excellent model plant to assess the role of source-sink relationship with elevated Carbon dioxide ($CO_2$) and changes in light and nutrient conditions. According to Tesfay (2005), yield increases of root crops grown at elevated atmospheric concentration of $CO_2$ are often greater than average, possibly because the harvested portion of the plant is larger sink for photosynthetic assimilates (Clough et al., 1981).

A study was done by Peffley et al, 1999 to evaluate the environmental conditions such as Photoperiod, temperature, nutrient solution composition, pH and $CO_2$ levels. They only focused on red- pigmented onion cultivars as they contain high levels of flavonols as an important aspect of phytochemicals. Plants grown under long day (16h) produced more biomass compared to plants grown under short days (11h) and elevated (2000 ppm) rather than ambient (370 ppm) $CO_2$.levels of N, Ca and Mg decreased as plant matures but Flavonols increases. An increased source activity (photosynthesis) relative to sink activity (growth) may increase carbohydrate accumulation, initiating a carbohydrate feedback effect resulting in down-regulation of photosynthesis.

Distinction of bulb size and time to maturity depend on the physiological processes regulating the development of bulbs according to Tesfay 2005. The production of leaves after bulbing is considered to be central to the process of bulb development since they are key suppliers of assimilates for bulb expansion.

### 2.3.5. Onion Bulb Quality.

2.3.5.1 Bulb and Neck diameter

Onion is regarded as the high value crop in most countries so high yield and quality are the important economic consideration. Bulb size, neck diameter (appearance), susceptibility to sprouting and decay in storage are the components of bulb quality including the nutrients management. Bulb size and diameter are also influenced by how plant density is managed. Relationship between plant population (20, 30, and 40 $m^2$) and bulb diameter was studied by Farooq-Ch et al, 1990 in Pakistan. They reported that as plant density increases in a square meters, bulb diameter decreases, however the difference was not significant. The lesser the plant density in a square meter the larger space for the bulb formation (Bosekeng, 2012).

Bosekeng, 2012 cited, another experiment was conducted in Peshawer during 2003, to study the influence of plant density (40, 60 and 80 plants $m^{-2}$) on the neck diameter of onions (Dawar et al., 2005). According to the authors reports that when the plant density increased from 40 to 80 plants $m^2$ onion neck diameter reduced significantly from 20.9 to 18.3 mm. The thickest necks (20.9 mm) were produced by plants planted at a population of 40 plants m-2, followed by the medium plant population of 60 plants $m^{-2}$ (19.3 mm), while the thinnest necks (18.3 mm) were measured at the highest plant density (80 plants $m^{-2}$). Bulb necks become thinner as plant density increased because of the small plants attained at high plant population. Plant density has an impact on marketable bulb size and the higher the plant density the smaller the marketable size Seck et al, 2009 cited Kahsayl, 2013.

2.3.5.2 Bulb Shape

An important quality characteristic for both market acceptability for appearance and ease packaging is not only the bulb size but the bulb shape (Bosekeng, 2012). Consumers prefer a round or globe shaped onion hence the onion shape is influenced by both genetic and environmental factors. Genetic variations range from flat to oblong or torpedo types, and bulb shape modified by environmental conditions such as sowing time, plant density and sowing depth. As plant density increased from 50 to 100 plants $m^{2,}$ the percentage bulbs rejected on their shape increased from 7.9 to 15.3%. more the same trend were noticed when plant density increased from 65 to 130 plants $m^2$, bulbs rejected also increased from 9.1 to 14.2% (Grant & Carter, 1997). The higher the plant density results in an elongated bulb with a shape index greater than 1.2 which is not considered as having desired shape by consumers (Eksteen et al., 1997). McGeary (1985) investigated the effect of plant population (178, 400, 625, 816, 1 111 and 1 600 plants $m^2$) on bulb shape of pickled onions for the market in Australia. Pickled market onions should be small in sizes (25-45 mm) and round. The results revealed that as plant density increases, the more irregular shaped bulbs obtained. The percentage of round bulbs declined by 13.3% as plant density increased from 178 to 1 600 plants $m^2$.Different cultural practices and growing environments influence bulb size, shape and yield

2.3.5.2 Bolting

Bolting is the emergence of a seed stalk prior to time of maturation, it adversely affects the formation and the development of bulb .It may be important for onion seed production but not bulb production (Voss et al., 1999). Bolting reduce the marketable yield of onion bulbs. Onion bolt when it is exposed to low temperatures (8-13°C), preparing to start forming bulbs. The number of leaves has been used to determine a critical plant size at which bolting will be induced under low temperature conditions. According to Khokhar et al. (2007) cited by Bosekeng, 2012, the sensitive plant size is when 7 to 10 leaves have formed. Transplanting too early in the season (August) and late (end of December to January), the onion plant will reach the minimum plant size for bulbing when temperatures are still low and that can induce bolting instead of forming bulbs. Correct transplanting or sowing date should therefore be practised to prevent plants receiving a cold spell when reaching a minimum plant size resulting in bolting instead of bulbing. more, cultivar selection and sowing date are important production factors that need to be taken in to consideration in preventing bolting to occur.

**2.3.5 Maturation**

Most onion varieties begin to form bulbs when they meet certain temperatures and daylight levels .Some bulbs are regarded as long day bulbs (14-16 h) and short day bulbs (12-14h).Onions take about 180-230 days from sowing to maturation depending on the variety planted (Smith. 2006).However the timing of maturation or harvest should depend on market opportunities according to Sullivan et al. (2001).Maturation can be evaluated by the percentage of tops falling down and dry leaves probably 60-70%. High quality onions for storage can be achieved by proper degree of maturation prior to harvest. Both environmental and crop management factors have an influence in poor maturation and decay during storage.

**2.3.6 Growth Substances in Stored Onions**

Brewster. (2008),Sharma et al.(2015) summarized that onion bulbs undergo three phases in relation to the effect of warm temperature on sprouting, immediately after harvest, dormancy is reduced at 25-35$^0$C and results in earlier sprouting. Successively, long term storage at 25-30$^0$C retards sprouting. Once bulbs grow and develop roots, such temperatures are optimal for sprout growth and typical of vegetative growth process in onion. Priya et al. (2014) reviewed studies on the spray chemicals of stored onions and their changes throughout dormancy. They explained the pre-harvest chemicals that prolong the shelf life of onions. Maleic hydrazide (MH, 1,2-dihydropyridazine-3-6-dione) depends on its translocation into the inner meristem or in its point of growth to inhibit sprouting. It is applied 2 to 3 weeks prior to harvest when the crop has its green foliage for effective absorption and translocation. However other Authors reported that Maleic hydrazide does not have worldwide permission so ethephon (2-chloroethyl phosphonic acid) may be used as an alternate to keep bulbs dormant for a longer period, and effective when used2 weeks prior to harvest to reduce sprout incidence by 5% after 32 weeks of storage at 0$^0$C.Ethelene was also reported as an suppresser for sprout growth. Priya et al, 2014 studied the effect of ethylene ($L^{-1}$) and ethylene binding inhibitor 1-methylcylopropene (1-MCP), where onions were treated with 10 mL $L^{-1}$ ethylene or 1mL $L^{-1}$MCP individually or in combination for 24 h at 20$^0$C prior or after curing (6 weeks) at 20$^0$C and then stored at 1$^0$C.the results showed that sprout growth was reduced in onions treated with both chemicals after curing for 24h compared to the control after 25 weeks harvest.

Sprouting is controlled by the amount of growth inhibitors (Grevsen & Sorensen, 2004) formed in the leaves. Concentration of growth inhibitors or promoters rise or fall as dormancy storage of onion proceed , however dormancy in plants is controlled by aggressive action of promoting hormones such as gibberellins (Gas) and cytokinins as the inhibitory hormones abscisic acid (ABA).Investigation was done by many researchers concerning the correlation between sprouting and changes in endogenous growth substances (Auxin, GAs ,cytokinins and ABA levels in onion according to Sharma et al,(2015).Tesfay ,(2005) reported that Auxin decline in foliage leaves and bulb aspices during the final stages or green leaf decline and bulb expansion prior to harvest. The significant amount of growth inhibitor abscisic acid (ABA) is found in the leaves when the onions tops have fallen over and translocated to the bulb apex throughout the growth period as the levels of auxins, cytokinins and gibberellins and a high level of inhibitor. Defoliation of onion plants prematurely results to an increase of bulb sprouting during storage. Bioassays data indicated that more auxin is found in early stages of sprouting compared to a fully sprouted bulb. more, according to the study conducted in KZN reported by Tesfay (2005), bioassays during the winter months indicated a decline in inhibitor to a low level by February, while in December gibberellins increased to a maximum i.e. after sprouting, followed by cytokinins, and then by auxins Gibberellins peak took place at sprouting period and increased by the cold treatment in the bulb, that the rise in cytokinins signalled the resumption of active cell division; and that the auxins peak was connected with shoot growth.

# CHAPTER THREE: THE COMBINED EFFECTS OF DAYLENGTH AND TEMPERATURE ON STIMULATING BULBING OF ONIONS

## 3.1 Abstract

Onset of onion bulbing determines plant bulb development, final yield as well as its quality. This study was conducted on three onion cultivars, investigating the combined effects of growth conditions mainly day length and temperature on the onion bulbing. Three cultivars Red Creole (V1), (Star 5516(V2), Star 5517 (V3) were selected for the experiment. Plants were grown in growth rooms under combinations of photoperiod (11.5, 12 and 12.5 h) and day/night temperatures (25/12, 30/15 and 35/18 $^{0}$C). Responses of the onion to photoperiod and temperature on onset of bulbing were compared, and plant measurements for the plant height, leaf number and bulb ratio were measured fortnightly. more, plant carbohydrates was determined using HPLC-RID as well as invertase and sucrose synthase enzyme activities were also determined using spectrophotometer (Shimadzu UVprobe-1800).The results revealed that the interaction effects of daylengths at 12h,12.5h and temperatures levels of 25/12$^{0}$C,30/15$^{0}$C significantly increase the onset of onion bulbing. To these temperatures, overall the plants recorded plant height (583 and 640 mm),leaf number (8.4,9.8) and bulb ratio (2.2,2.7).Interestingly, plant carbohydrates, mainly fructose (14-16mg/g dw) and glucose (10-14 mg/d dw) increased for the daylengths 12h,12.5h and temperatures 25/12$^{0}$C,30/15$^{0}$C.and sucrose synthase (3-8 U) activities also increased.

In conclusion, the onions grow well in a conducive environment with optimum daylength 12 h and temperature combinations 25/12$^{0}$C, results in timely ‘onset of bulbing’ and this progressing for bulb development, which eventually produces quality bulbs

Keywords: Onions, Bulbing, temperatures, photoperiod, carbohydrates, enzymes

### 3.2 Introduction

Bulb onions (*Allium* Cepa L. var cepa) originated in Southwest Asia and the Mediterranean region. Onions have been used as a condiment in the cuisines of ancient China, India, and Egypt for well over 4000 years. Although its main role in cooking is to provide flavour, onion is a significant source of Vitamin C and Potassium. It contains about 60 calories in a medium-sized bulb, and has very low sodium content (Hamasaki et al, 1999)

The environment and growing conditions govern the development rate of onions, which then influences the earliness of the crop. This, in turn can influence the quality of the bulbs. The most important characteristic of development is bulbing, which occurs when the plants no longer form green leaf blades but bladeless bulb scales (Brewster,1990).therefore, it was vital to look at the growth components in response to daylengths and temperatures which, each and in combination, have an impact in determining onion growth and development.

Physiologically, according to the bulbing process, the onion is classed as being a quantitative long day response. This concept means that plants must be exposed to a number of days longer than a certain length of the day for a particular onion population before bulbing takes place. Regardless of the other environmental, factors conditions within this concept, factors such as temperature, and nutrition and spacing play important parts in accelerating or slowing down the bulbing process. Internal factors such as plant age or size also have a strong influence on the readiness of onion plants to respond to external stimuli (Jones and Mann, 1963). Moreover there is scant information on the environmental influence on onion bulbing, therefore the current study investigate the bulbing response of common onion varieties to photoperiod and temperature interaction.

### 3.3 Material and Method

3.3.3 Plant materials and treatment combinations

***Preparation of seedlings***

Seeds were sown into polystyrene trays with 200 cells (each cell 28x28x36mm). Three seeds per cell were sown and thinned to leave the strongest plant 2-3 weeks after sowing. Seedlings were grown under 18 h light and day/night temperature of 24/17 $^{0}$C in a growth room to prevent bulbing prior to application of the temperature/daylength treatments. After eight weeks of growth, three uniform seedlings were transferred to plastic pots of 200 mm diameter. Before the imposition of treatments; the potted plants were conditioned for one week under the same environmental conditions of the seedlings to allow them to adjust from transplanting-shock.

***Experimental design***

Three cultivars (Red Creole, Star 5516 and Star 5517) plants were nine weeks (stage 4 leaf growth stage) old at the start of the experiment. The experimental combinations were, Cultivars (V1, V2 & V3) Day lengths (11.5, 12, 12.5 h), day/night temperatures (25/12$^{0}$C, 30/15 $^{0}$C, 35/18 $^{0}$C). ). A total of 48 pots of all cultivars per treatment of nine treatment combinations (three levels of photoperiod, three levels of temperatures) were transferred to each growth room treatment following the week of transplant adjustment. Three seedlings within each pot, a total of 1296 seedlings in 432 pots were used throughout the experiment.

**Table 3.1 The factorial treatment arrangement with three levels of photoperiod and three IeveIs of temperature**

| | | | |
|---|---|---|---|
| Red Creole (V1) | 11.5h X25/12$^{0}$C | 12h X 25/12$^{0}$C | 12.5h X25/12$^{0}$C |
| | 11.5h X30/15 $^{0}$C | 12h X 30/15 $^{0}$C | 12.5 hX30/15 $^{0}$C |
| | 11.5 h X 35/18 $^{0}$C | 12h X 35/18 $^{0}$C | 12.5h X35/18 $^{0}$C |
| Star 5516 (V2) | | | |
| | 11.5h X25/12$^{0}$C | 12h X 25/12$^{0}$C | 12.5h X25/12$^{0}$C |
| | 11.5h X30/15 $^{0}$C | 12h X 30/15 $^{0}$C | 12.5 hX30/15 $^{0}$C |
| | 11.5 h X 35/18 $^{0}$C | 12h X 35/18 $^{0}$C | 12.5h X35/18 $^{0}$C |
| Star 5517(V3) | | | |
| | 11.5h X25/12$^{0}$C | 12h X 25/12$^{0}$C | 12.5h X25/12$^{0}$C |
| | 11.5h X30/15 $^{0}$C | 12h X 30/15 $^{0}$C | 12.5 hX30/15 $^{0}$C |
| | 11.5 h X 35/18 $^{0}$C | 12h X 35/18 $^{0}$C | 12.5h X35/18 $^{0}$C |

**Table 3.2 Example of 'Layout' of the pots for each growth room.**

| Rep I | | | | Rep III | | | |
|---|---|---|---|---|---|---|---|
| P1STR1 | P1STR1 | P1STR1 | P1STR1 | P3STR1 | P3STR1 | P3STR1 | P3STR1 |
| PISTR2 | PISTR2 | PISTR2 | PISTR2 | P3STR2 | P3STR2 | P3STR2 | P3STR2 |
| P1RC | P1RC | P1RC | P1RC | P3RC | P3RC | P3RC | P3RC |
| Rep II | | | | Rep IV | | | |
| P2STR1 | P2STR1 | P2STR1 | P2STR1 | P4STR1 | P4STR1 | P4STR1 | P4STR1 |
| P2STR2 | P2STR2 | P2STR2 | P2STR2 | P4STR2 | P4STR2 | P4STR2 | P4STR2 |
| P2RC | P2RC | P2RC | P2RC | P4RC | P4RC | P4RC | P4RC |

Cultivars: STR 1: Star5516; STR2: Star5517; RC-Red Creole; Rep: replication.
PI - P4 = numbering of pots according to replications

### 3.3.4 Measurements and terminology

***Bulb ratio***

Bulb ration defined as the ratio of maximum bulb diameter to minimum pseudostem (neck) diameter (Clark and Heath, 1962) was used as a measure of bulbing. Bulbing ratios of two (2.0) characterize the onset of bulbing.

***Leaf emergence***

Leaf emergence was recorded by counting the number of leaves above pseudostem. In onion, leaves are arranged alternately and emerge through the pore of the proceeding leaf (Brewster, 2008)

***Plant height and leaf area***

The plant height was taken as the distance from the base of the pseudostem to the tip of the longest leaf. For the destructive measurement of leaf area, leaves were split and opened. The spread leaf blades were measured using a portable meter (LI-COR, L!-3000).

Total protein assay for determination of enzyme activity

The Bradford microassay was used to determine the protein content of the samples (Bradford, 1976). Bradford dye reagent was added to test tubes containing 20µL sample extract, mixed and incubated at room temperature for 5 min. Samples were then read spectrophotometric ally at 595 nm and the protein concentration determined by comparing results with standard curve constructed using bovine serum albumin.

The activity of soluble invertase, sucrose synthase and non-structural carbohydrates in onion bulbs

***Invertase assay***

Onion bulb was used for soluble invertase which was extracted according to the method of van den Ende et al. (2000), with slight modification. Briefly, the enzymatic reaction was carried out in a total volume of 0.4 ml containing sodium acetate buffer (pH 5) containing 0.02% (w/v) Na-azide. Invertase activity was assayed by incubating an aliquot of enzymatic extract (0.1ml) in 50mM sodium acetate buffer (0.1 ml) and substrate solution containing 200 mM sucrose (0.2 ml). The reaction mixture was incubated at $30^0$C for 2 h, and stopped by heating in a boiling bath for 5 min. The fructose content formed was determined by high-performance anion exchange chromatography (phenomenex, city, country) as described later. One unit of invertase is defined as the amount of invertase that releases one micromole of fructose per minute under the assay condition.

***Sucrose synthase***

Sucrose synthase was determined by measuring sucrose-6-phosphate produced from substrates, UDP-glucose and fructose-6-phosphate (Robbins and Pharr, 1987).Briefly, 100µl of desalted protein extract added into a reaction mixture containing 25mM UDP-glucose, 8mM fructose-6-phosphate, 5mM MgCl2 was incubated at $25^0$C for 1hr and terminated by adding 100µl of 1 N NaOH.sucrose-6-phosphate formed during the reaction was determined by reacting with 0.25ml resorcinol solution and quantified by a spectrophotometer 520nm wavelength

***Non-structural carbohydrates***

Sugars were determined using HPLC-RID according to Liu and Li (2000), with slight modifications. Concisely, freeze-dried material (0.05 to 0.10 g) was mixed with10mL 80%

(v/v) ethanol and homogenized for 1 min. Thereafter, the mixture was incubated in an $80^0C$ water bath for 60 min to extract the soluble sugars. Subsequently the mixture was kept at $4^0C$ overnight. After centrifugation at 12000 g for 15 min at $4^0C$, the supernatant was filtered through glass wool and taken to dryness in a vacuum concentrator. Dried samples were re suspended in 2 mL ultra-pure water, filtered through a 0.45 µm nylon filter and analysed using an isocratic HPLC system equipped with a refractive detector (RID) on a phenomene(R) column (Rezex RCM-Monosaccharide).The concentration of individual sugars was determined by comparison with authentic sugar standards.

***Data analysis***

Data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical package 17. Differences among treatment were separated using the least significant different (LSD) at the 5% significance level according to Fisher's LSD test. All the cultivars which were grown under 11.5 h daylengths at all temperatures treatments started 'onset of bulbing' (bulb ration ≥2.0) at 123 days (which was 15 days later than in the longer daylength) comparisons of developmental events on a time basis were confounded. Conventional statistical analyses were therefore only done on the data collected at one period of growth (108 days of plant age) to represent the same age of plants.

## 3.4 Results and discussion

### 3.4.1 Leaf number

Significant responses to daylength and temperature, and to the interactions between daylength and temperature, daylength and cultivar (Table 3.3) were observed. There was also a higher order significant interaction.

**Table 3.3 Analysis of variance table for measurements of leaf number at 108 days for three onion cultivars grown at three temperature regimes and daylengths.**

| **Source of Variation** | F Prob. (5%) | LSD (5%) |
|---|---|---|
| Daylength | 0.002** | 0.2 |
| Temperature | <0.001 ** | 0.2 |
| Cultivar | 0.233 | NS |
| Daylength x temperature | <0.001 ** | 0.4 |
| Daylength x cultivar | 0.005** | 0.4 |
| Temperature x cultivar | 0.057 | NS |
| Daylength x temperature x cultivar | 0.012** | 0.7 |

**- highly significant; NS-not significant.

There was a significant interaction between daylength and temperature (Table 3.4).At an 11.5h daylength, and increase in day and night temperatures from 25/12$^0$C did not significantly decrease the leaf number. However, when the temperatures were increased to 35/18$^0$C, there was a significant decrease in leaf production. In 12 and 12.5h daylengths, the initial increase in temperatures from 25/12 $^0$C to 30/15$^0$C included an expected significant increase in the rate of leaf production. However, increase in temperature to 35/18$^0$C provided no significant increase in leaf number at 12.5h photoperiod, the day temperature of 35/18 $^0$C was supra-optimal (stress related), or that daylength- induced developmental processes were affected.

The significant cultivar and daylength interaction in Table 3.3 was generated by STR 2, producing significantly fewer leaves under 11.5 h daylength than at 12 h and 12.5 h daylengths, whereas the other two cultivars produced similar numbers of leaves at each daylength treatment. However, STR 2 in the 11.5 h was affected in the growth room by a fungal disease (downy Mildew) during the experiment and therefore the apparent reduction in leaf number at 11.5 h daylength in the cultivar may be due to this factor. Obviously then, the apparent interaction is an invention of the experimental process rather than treatment effects .It can be expected that two cultivars (STR 1 and STR 2), being fairly closely genetically related, to respond in a similar manner to environmental conditions. It is interesting that the RC responded similarly to the other two cultivars.

**Table 3.4 The combined interaction effects of daylength and temperature on leaf number of Red Creole (RC), Star 5516 (STR1) and Star 5517 (STR2) at 108 days when grown at different temperatures and daylengths.**

| **Growth rooms Daylength** | **Temperatures** | **Red Creole** | **Star 5516** | **Star 5517** | **Mean** |
|---|---|---|---|---|---|
| 11.50h | 25/12$^0$C | 7.6 | 7.8 | 8.0 | 7.8 |
| | 30/15$^0$C | 8.5 | 6.9 | 8.0 | 7.8 |
| | 35/18$^0$C | 7.0 | 6.7 | 7.0 | 6.9 |
| 11.50h Mean | | 7.8 | 7.1 | 7.7 | $7.5^{B}$ |
| 12.00 h | 25/12$^0$C | 6.3 | 6.9 | 6.6 | 6.6 |
| | 30/15$^0$C | 8.5 | 8.8 | 7.9 | 8.4 |
| | 35/18$^0$C | 9.0 | 8.8 | 8.3 | 8.7 |
| 12.00h Mean | | 7.9 | 8.1 | 7.6 | $7.9^{A}$ |
| 12.50 h | 25/12$^0$C | 6.6 | 7 | 6.2 | 6.6 |
| | 30/15$^0$C | 10.0 | 10.1 | 9.3 | 9.8 |
| | 35/18$^0$C | 7.4 | 7.1 | 7.7 | 7.4 |
| 12.50 h Mean | | 8.0 | 8.1 | 7.7 | $8.0^{A}$ |
| Temp. Mean | 25/12$^0$C Mean 6.9 | 7.2 | 6.9 | $7.0^{C}$ | |
| | 30/15$^0$CMean 8.9 | 8.5 | 8.4 | $8.6^{A}$ | |
| | 35/18$^0$CMean 7.8 | 7.6 | 7.7 | $7.7^{B}$ | |
| Cultivar Mean | | $7.9^{A}$ | $7.8^{A}$ | $7.7^{A}$ | |

L.S.D (0.05) marginal means = 0.2

L.S.D (0.05) two-way interaction means = 0.4

L.S.D (0.05) three-way interaction means =0.7

### 3.4.2 Height of uppermost leaf

There were significant responses to daylength, temperature and cultivars, and to the interaction between daylength and temperature (Table 3.5).A significant interaction between daylength and temperature suggested that the growth in terms of plant height may show a significant response to the growth factors over the progression of the experiment.

**Table 3.5 Analysis of variance table for measurements of plant height at 108 days for three onion cultivars grown at three temperature regimes and daylengths.**

| **Source of Variation** | F Prob. (5%) | LSD (5%) |
|---|---|---|
| Daylength | <0.001 ** | 18 |
| Temperature | <0.001 ** | 18 |
| Cultivar | 0.002** | 18 |
| Daylength x temperature | <0.001 ** | 31 |
| Daylength x cultivar | 0.066 | NS |
| Temperature x cultivar | 0.355 | NS |
| Daylength x temperature x cultivar | 0.257 | NS |

**- highly significant; NS-not significant.

Plant height significantly increased with each increment in daylength (512.0,547.0 and 594.0 mm at 11.5, 12 and 12.5 h daylength, respectively) (Table 3.5).There was a significant interaction between daylength and temperature (Table 3.6) at an 11.5 h daylength, an increase in temperature from 25/12$^0$C to 35/18$^0$C significantly and gradually decreased the plant height. Under 12 and 12.5h daylength, the initial increase in temperature from 25/12 $^0$C to 30/15 $^0$C did not cause any significant decrease in plant height in the 12h photoperiod. In both these cases, the day temperature in excess of 30/15$^0$ C appears to be supra-optimal (stress related), or alternatively, daylength-induced developmental processes were affected.

The significantly highest plant height was recorded at temperature treatments of 30/15°C (571.0 mm) and 25/12°C (560.0 mm) and shortest at 35/18°C (522.0 mm). While the shift from 25/12°C to 30115°C had a positive influence on plant height, a further increase to 35/18°C led to a reduction in plant height. Two cultivars, STR 1 (561.0 mm) and STR 2 (560.0 mm), were also found significantly taller than Red Creole (532.0 mm). However, no significant differences were observed between the two cultivars (STR1 and STR2).

**Table 3.6 The combined interaction effects of daylength and temperature on Plant height (mm) of Red Creole (RC), Star 5516 (STR1) and Star 5517 (STR2) at 108 days when grown at different temperatures and daylengths.**

| Growth rooms | | Red Creole | Star 5516 | Star 5517 | Mean |
|---|---|---|---|---|---|
| **Daylength** | **Temperatures** | | | | |
| 11.50h | 25/12$^0$C | 675.0 | 657.0 | 633.0 | 655.0 |
| | 30/15$^0$C | 543.0 | 475.0 | 449.0 | 489.0 |
| | 35/18$^0$C | 409.0 | 398.0 | 366.0 | 391.0 |
| 11.50hMean | | 542.0 | 510.0 | 483.0 | 512.0$^C$ |
| 12.00 h | 25/12$^0$C | 495.0 | 493.0 | 499.0 | 484.0 |
| | 30/15$^0$C | 595.0 | 627.0 | 532.0 | 583.0 |
| | 35/18$^0$C | 582.0 | 588.0 | 548.0 | 8573.0 |
| 12.00 Mean | | 545.0 | 569.0 | 526.0 | 547.0$^B$ |
| 12.50 h | 25/12$^0$C | 537.0 | 560.0 | 524.0 | 540.0 |
| | 30/15$^0$C | 638.0 | 643.0 | 640.0 | 640.0 |
| | 35/18$^0$C | 613.0 | 601.0 | 595.0 | 603.0 |
| 12.50 h Mean | | 596.0 | 601.0 | 586.0 | 594.0$^A$ |
| Temp. Mean | 25/12$^0$C Mean | 557.0 | 570.0 | 552.0 | 560.0$^A$ |
| | 30/15$^0$CMean | 592.0 | 582.0 | 540.0 | 571.0$^A$ |
| | 35/18$^0$CMean | 534.0 | 529.0 | 503.0 | 522.0$^B$ |
| Cultivar Mean | | 561.0$^A$ | 560.0$^A$ | 532.0$^B$ | |

L.S.D (0.05) marginal means = 18.0

L.S.D (0.05) two-way interaction means = 31.0

L.S.D (0.05) three-way interaction means =54.0

There was a significant interaction between daylength and temperature (Table 3.5). At a 11.5 h daylength, an increase in temperature from 25/12°C to 35/18°C significantly and incrementally decreased the plant height. A significant decrease in the plant height indicated that day temperatures in excess of 25°C are greater, inducing stress on the plant. Alternatively, the 11.5 h daylength may also have induced physiological changes to the plant developmental processes at the higher temperatures. Under 12 and 12.5 h daylengths, the initial increase in temperature from 25/12°C to 30/15°C induced an expected significant increase in plant height. However, further increase in temperature to 35/18°C provided no further significant change in plant height in the 12 h photoperiodic treatment, but it decreased plant height significantly at the 12.5 h photoperiod. In both cases, the day temperature in excess of 30°C appears to be greater (stress related), or alternatively, daylength induced developmental processes were affected.

3.4.3 Leaf area

There were significant responses to daylength and temperature and to the interaction between daylength and temperature (Table 3.7). A significant interaction between daylength and temperature suggested that the leaf area was affected by the growth factors over the course of the experiment.

**Table 3.7 Analysis of variance table for measurements of leaf area at 108 days of three onion cultivars grown at three temperature regimes and daylengths.**

| **Source of Variation** | F Prob. (5%) | LSD (5%) |
|---|---|---|
| Daylength | <0.001 ** | 63.3 |
| Temperature | 0.005** | 63.3 |
| Cultivar | 0.111 | NS |
| Daylength x temperature | 0.001 ** | 109.7 |
| Daylength x cultivar | 0.418 | NS |
| Temperature x cultivar | 0.406 | NS |
| Daylength x temperature x cultivar | 0.275 | NS |

**- highly significant; NS-not significant.

The significant interaction between daylength and temperature for leaf area was similar in nature to that of the leaf number (Table 3.4).At a 11.5h daylength, an increase in temperature from 25/12$^0$C to 30/15$^0$C significantly decreased the leaf area. However, when the temperature was increased to 35/18$^0$C,there was no significant decrease in leaf area (Table 3.8).At 12 and 12.5 h daylengths the initial increase in temperature from 25/12$^0$ C to 30/15 $^0$C induced an expected significant increase in leaf area. However, increase in temperature to 35/18 $^0$C provided no significant increase in leaf area at the 12.5h photoperiod, in both these cases, it appears that as happened in the 11.5 h photoperiod, the day temperature of 35/18 $^0$C was greater (stress related),or that daylength-induced developmental processes were affected. The leaf area data mirror the plant height data indicating that the changes in leaf area were more a consequence of leaf elongation responses to the treatments than of leaf number.

**Table 3.8 The combined interaction effects of daylength and temperature on leaf Area unit of Red Creole (RC), Star 5516 (STR 1) and Star 5517 (STR 2)' at 108 days when grown at different temperatures and daylengths.**

| Growth rooms Daylength | Temperatures | Red Creole | Star 5516 | Star 5517 | Mean |
|---|---|---|---|---|---|
| 11.50h | 25/12$^0$C | 585.0 | 485.0 | 633.0 | 655.0 |
| | 30/15$^0$C | 282.0 | 116.0 | 449.0 | 489.0 |
| | 35/18$^0$C | 136.0 | 118.0 | 366.0 | 391.0 |
| 11.50hMean | | 334.0 | 240.0 | 483.0 | 512.0$^C$ |
| 12.00 h | 25/12$^0$C | 207.0 | 235.0 | 499.0 | 484.0 |
| | 30/15$^0$C | 471.0 | 465.0 | 532.0 | 583.0 |
| | 35/18$^0$C | 515.0 | 525.0 | 548.0 | 8573.0 |
| 12.00 Mean | | 398.0 | 408.0 | 526.0 | 547.0$^B$ |
| 12.50 h | 25/12$^0$C | 341.0 | 541.0 | 397.0 | 426.0 |
| | 30/15$^0$C | 904.0 | 786.0 | 371.0 | 807.0 |
| | 35/18$^0$C | 515.0 | 532.0 | 613.0 | 553.0 |
| 12.50 h Mean | | 587.0 | 620.0 | 580.3 | 596.0$^A$ |
| Temp. Mean | 25/12$^0$C Mean | 378.0 | 420.0 | 355.0 | 380.0$^B$ |
| | 30/15$^0$CMean | 552.3 | 456.0 | 415.0 | 474.0$^A$ |
| | 35/18$^0$CMean | 389.0 | 392.0 | 352.0 | 377.0$^B$ |
| Cultivar Mean | | 440.0$^A$ | 423.0$^{AB}$ | 532.0$^B$ | |

L.S.D (0.05) marginal means = 63.3

L.S.D (0.05) two-way interaction means = 109.7

L.S.D (0.05) three-way interaction means =190.0

3.4.4 Bulbing ratio

There were significant responses to daylength, temperature and all the interactions between daylength, temperature and cultivar (Table 3.9).As for the length of photoperiod, all treatment means differed significantly from each other. The highest bulb ratio was recorded at 12 h (2.5), followed by 12.5 h (2.2) and then the lowest at 11.5 h (1.6). The data showed that the 12 h daylength induced bulbing earlier than the 11.5 and 12.5 h daylengths (Table 3.10).

**Table 3.9 Analysis of variance table for measurements of bulb ratio at 108 days of three onion cultivars grown at three temperature regimes and daylengths.**

| **Source of Variation** | F Prob. (5%) | LSD (5%) |
|---|---|---|
| Daylength | <0.001 ** | 0.1 |
| Temperature | <0.001 ** | 0.1 |
| Cultivar | <0.005 ** | 0.1 |
| Daylength x temperature | <0.001 ** | 0.2 |
| Daylength x cultivar | <0.001 ** | 0.2 |
| Temperature x cultivar | <0.011 ** | 0.2 |
| Daylength x temperature x cultivar | 0.040** | 0.3 |

**- highly significant; NS-not significant.

In terms of temperature treatments, all treatment means differed significantly from each other. The highest bulb ratio recorded at 35/18°C (2.2), followed by 25/12°C (2.1) and then at 30/15°C (2.0) (Table 3.10). In terms of cultivar response, there was no significant difference between STR 1 and STR 2, but they bulbed significantly earlier than Red Creole (Table 3.10).

At an 11.5h daylength, and increase in temperature from $25/12^{0}$ C to $35/15^{0}$ C did not affect the rate of the bulb growth. Temperature does not seem to have any effect on bulb development under 11.5h daylength. Instead; it might increase the vegetative growth of the plant. However, in the current study, under a 12 h daylength, an increase in temperature from $25/12^{0}$C to $30/15^{0}$ C significantly decrease the bulb ratio, but when the temperature increased to $35/18^{0}$ C, there was a significant increase in bulb ratio. As daylength lengthened to 12.5 h an increase of temperature from 25/12$^0$C to 30/15$^0$C significantly increased bulb ratio and increase of temperature to 35/18$^0$C did not significantly increases bulb ratio.

**Table 3.10 The combined interaction effects of daylength and temperature on bulb ratio of Red Creole (V1), Star 5516 (V2) and Star 5517 (V3) at 108 days when grown at different temperatures and daylengths.**

| **Growth rooms** | | **Red Creole** | **Star 5516** | **Star 5517** | **Mean** |
|---|---|---|---|---|---|
| **Daylength** | **Temperatures** | | | | |
| 11.50h | 25/12$^0$C | 1.7 | 1.5 | 1.6 | 1.6 |
| | 30/15$^0$C | 1.5 | 1.7 | 1.6 | 1.6 |
| | 35/18$^0$C | 1.7 | 1.5 | 1.6 | 1.6 |
| 11.50hMean | | 1.6 | 1.6 | 1.6 | 1.6$^C$ |
| 12.00 h | 25/12$^0$C | 3.0 | 3.0 | 2.2 | 2.7 |
| | 30/15$^0$C | 2.2 | 2.2 | 2.2 | 2.2 |
| | 35/18$^0$C | 2.8 | 2.7 | 2.3 | 2.6 |
| 12.00 Mean | | 2.7 | 2.6 | 2.2 | 2.5$^A$ |
| 12.50 h | 25/12$^0$C | 2.1 | 1.9 | 1.9 | 2.0 |
| | 30/15$^0$C | 2.2 | 2.3 | 2.3 | 2.3 |
| | 35/18$^0$C | 2.3 | 2.3 | 2.5 | 2.4 |
| 12.50 h Mean | | 2.2 | 2.2 | 2.2 | 596.0$^A$ |
| Temp. Mean | 25/12$^0$C Mean | 2.3 | 2.1 | 1.9 | 2.1$^B$ |
| | 30/15$^0$CMean | 1.9 | 2.1 | 1.9 | 2.0$^C$ |
| | 35/18$^0$CMean | 2.3 | 2.2 | 2.1 | 2.2$^A$ |
| Cultivar Mean | | 2.2$^A$ | 2.1$^A$ | 1.9$^B$ | |

L.S.D (0.05) marginal means = 0.1

L.S.D (0.05) two-way interaction means = 0.2

L.S.D (0.05) three-way interaction means = 0.3

3.4.5 Plant carbohydrates

At 11.5h daylength, temperature had a significant effect on plant carbohydrate accumulations for all cultivars. In all cases, sucrose recorded the highest concentration and the fructose and glucose followed, respectively (Fig.3.1) Plants grown under 25/12$^0$C and 30/15$^0$C had a higher carbohydrate accumulation than 35/18$^0$C.

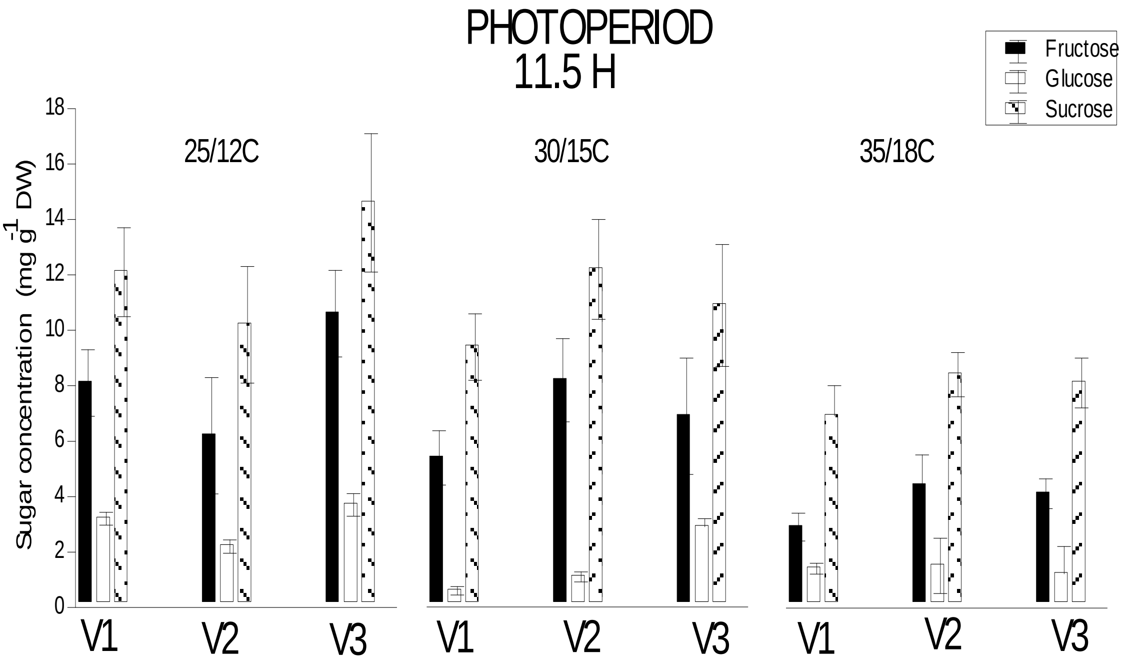


**Figure 3.1 The effect of three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C and 35/18$^0$C) on plant carbohydrates grown under 11.5h daylength. Vertical bars represent ±SE (n=5)**

At 12h daylength, temperature had a significant effect on plant carbohydrate accumulations for all cultivars.in all cases, fructose recorded the highest concentration and the glucose and sucrose followed, respectively (Fig.3.2) Plants grown under 25/12$^0$C and 30/15$^0$C had a higher carbohydrate accumulation than 35/18$^0$C.

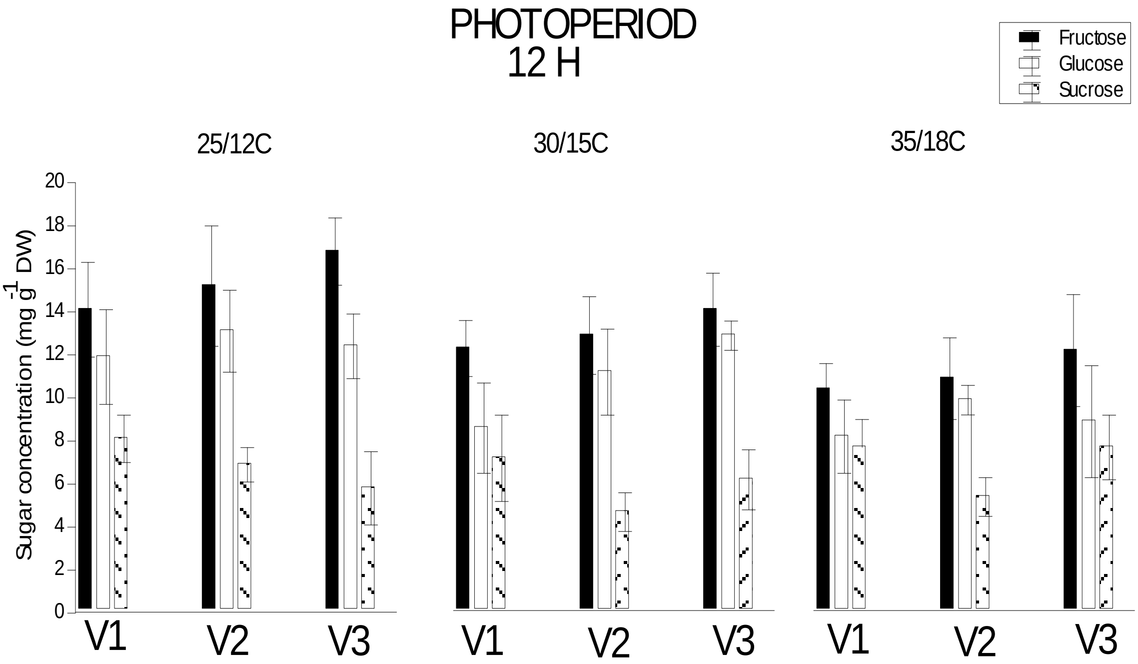


**Figure 3.2 The effect of three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C and 35/18$^0$C) on plant carbohydrates grown under 12h daylength. Vertical bars represent ±SE (n=5)**

Similarly at 12.5h daylength, temperature had a significant effect on plant carbohydrate accumulations for all cultivars.in all cases, fructose recorded the highest concentration and then glucose and sucrose followed, and respectively (Fig 3.3) .Plants grown under 25/12$^0$C and

30/15$^0$C had higher carbohydrate accumulation than 35/18$^0$C.

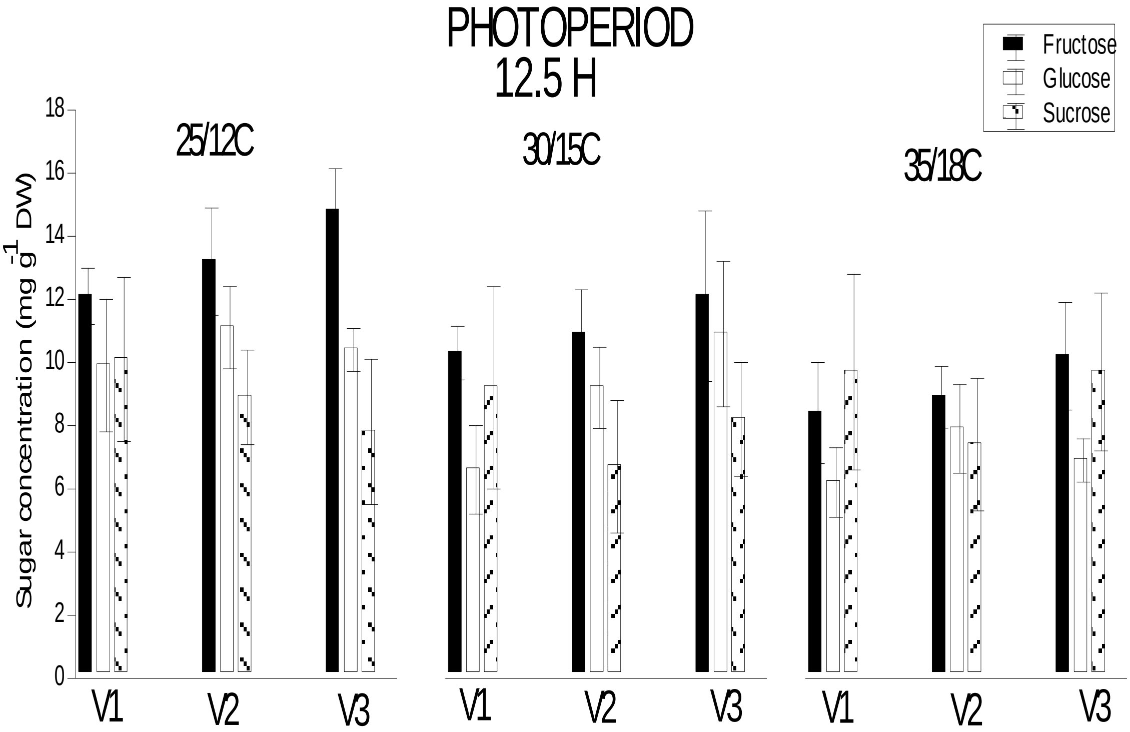


**Figure 3.3 The effect of three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C and 35/18$^0$C) on plant carbohydrates grown under 12.5h daylength. Vertical bars represent ±SE (n=5)**

3.4.6 Plant enzyme activity

Plant enzymatic protein analyses showed that temperatures had significant effect on invertase activity while grown under three daylengths (11.5h, 12h, 12.5h) (Fig 3.4).At 12h daylength. Plant invertase activity was the highest followed by 12.5h daylength, while the 11.5h daylength recorded the lowest activity. Plant enzymatic protein analysis showed that temperature had significant effect on sucrose synthase activity while grown under three daylengths (11.5h,12h,12.5h) (Fig 3.5). Seemingly, both 11.5h as well as 12h daylength had a higher activity than 12.5h daylength.

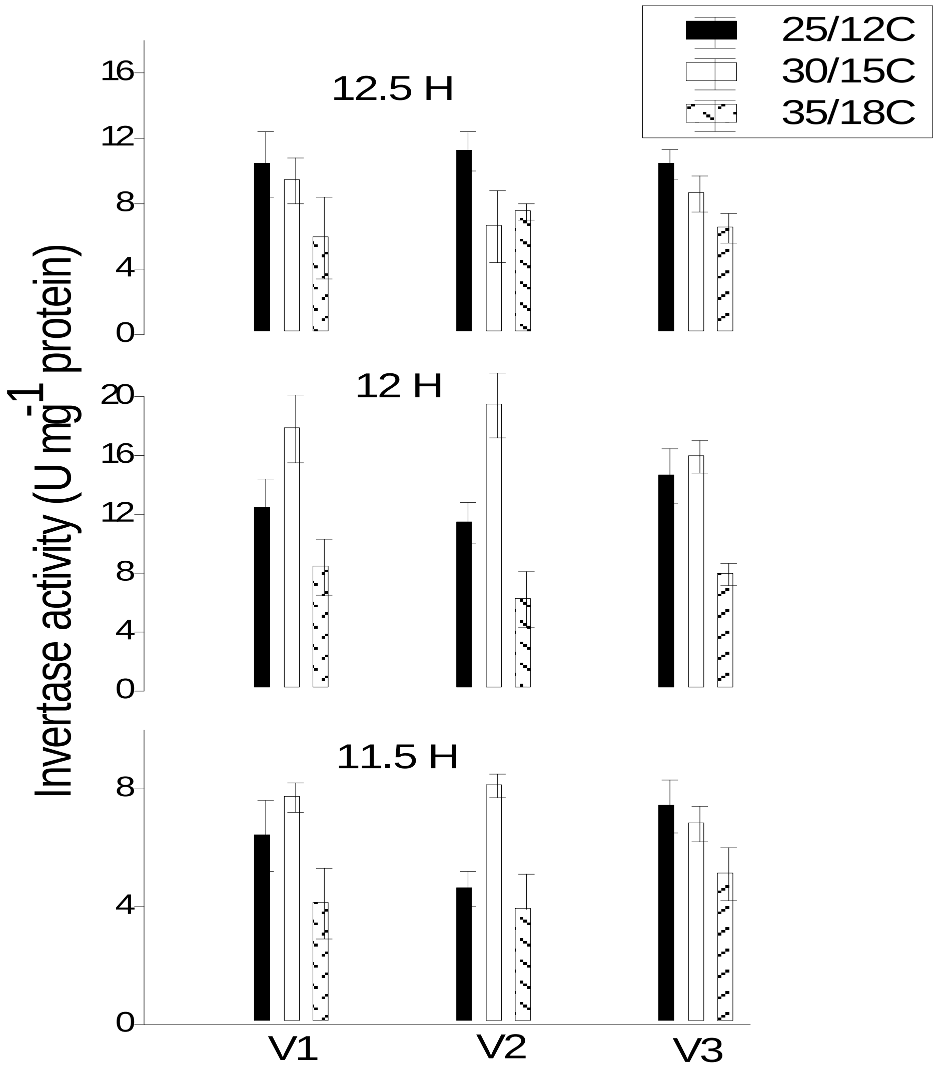


**Figure 3.4 The effect of three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C and 35/18$^0$C) on plant invertase activity grown under three levels of daylengths (11.5h, 12h and 12.5h.Vertical bars represent ±SE (n=5)**

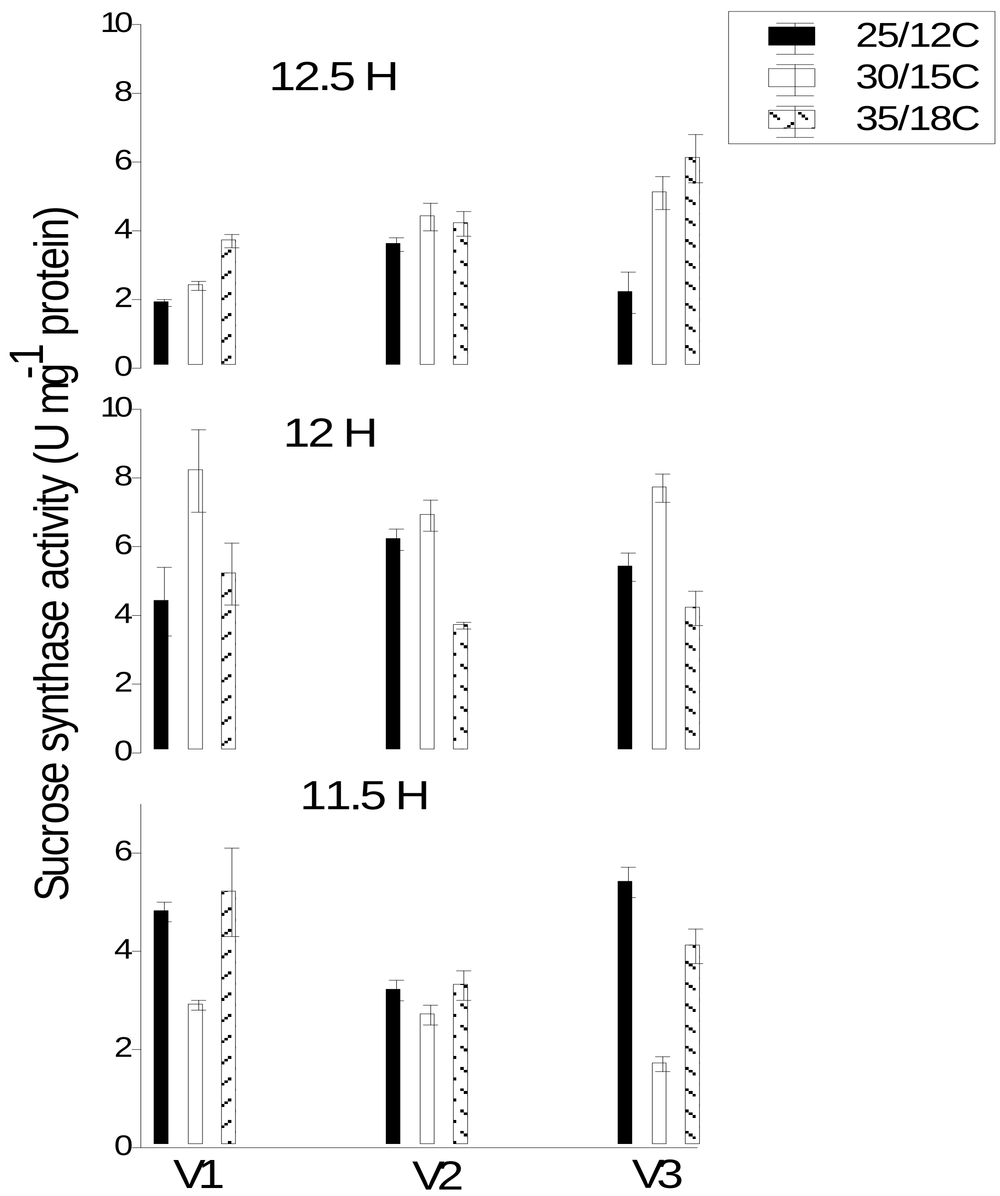


**Figure 3.5 The effect of three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C and 35/18$^0$C) on plant sucrose synthase activity grown under three levels of daylengths (11.5h, 12h and 12.5h.Vertical bars represent ±SE (n=5)**

The 11.5h photoperiod was a non-inductive environment for bulbing in all cultivars as the bulbing ratio (1.5 to 1.7) was well below the accepted ratio of 2.0 (Kedar et al.1975) (Table3. 4). This infers that growth responses were not inferred with the inductive physiological processes, so that photoperiodic and temperature responses can be interpreted as affecting vegetative growth only. At this daylength the temperature increment from 25/12$^0$C to 30/15$^0$C did not significantly reduced the leaf production, but the leaf production at 35/18$^0$C was reduced, indicating that plants were stressed at the high day temperature. However, there was a marked effect of each incremental temperature significantly reducing plant height and leaf area. It seems that the 11.5h daylength only facilitate more vegetative growth than bulbing at 25/12$^0$C (Kedar et al.1975). However, the increase in temperature in excess of 25/12$^0$C decreases vegetative growth under the short daylength without development of bulbing (Roberts et al.1988).he effect of temperature on growth components clearly indicated that the decreased in leaf number at 35/18$^0$C was likely a temperature stress factor. The leaf height and data show that the stress to leaf development already occurred at 30/15$^0$C, probably associated with the day temperature

At the 12 h photoperiod, an inductive environment for bulbing in all treatments. It was observed that growth responses were to some extent interfered with by interactive effects of daylength and temeperature .The 12 h daylength at the temperature 25/12$^0$C,which induced bulbing more strongly than any other increment, significantly reduced leaf number ,height, and leaf area in all cultivars in comparisons to plants grown at the same temperature in the non-inductive environment of 11.5h.The latter effects indicate that there was a marked effect of source-sink relationship which resulted in the cultivars producing the highest bulb ratio. The temperature increment from 25/12$^0$C to 35/18$^0$C increased leaf number at a 12h daylength, similarly to plants grown at a 11.5h daylength and also increased plant height and leaf area of the cultivars, particularly at 35/18$^0$C. In the case of Red Creole, a temperature increment did not affect the bulbing response at the 12h daylength, but the leaf number, plant height and leaf area increased with increased temperature .At the 12 h inductive daylength, the varieties (Star 5516 and Star 5517) showed a marked reduction in bulb initiation as the temperature increased from 25/12$^0$C to 30/15$^0$C.As expected, with the change in source-sink ratio. This was accompanied by an increase in leaf number, height and area .However, in contrast to this postulate of source-sink ratio effect, a increase in temperature to 35/18$^0$C in these varieties led to significantly increased rate of bulbing, but this was also accompanied by an increase in leaf number, height area. The higher the temperatures in this inductive environment which promoted leaf growth may also have played a part in temperature stress-related induction of bulbing. The plant size has also an effect on the time of onset of bulbing and development of bulbing (Mettananda & Fordham, 1999).at 12 h daylength, the two varieties (Star 5516 and Star 5517) responded in a similar way to Red Creole under increasing temperature. The higher numbers of leaves, leaf area were recorded particularly at 30/15$^0$C than 25/12$^0$C and this will be associated with increasing photosynthetic leaf area that led the cultivars to produce high production of onion. As the bulb ratio remained the same .The bulb growth at the 35/18$^0$C temperatures, probably temperatures stress related growth response. The receptor site for daylength response has been shown to be in the leaves in many long and short-day plants (Vince-Prue, 1975; Summerfield& Roberts, 1987).Several researchers have also shown that the sensitivity to daylength changes with the age of the leaf (Evans, 1969, Vince-Prue, 1975), as soon as the day length requirement is adequate, onion cultivars will form bulbs at more or less the same time even if they are sown on different dates. Given that the leaves receive the signals of solar radiation, sufficient leaf area index is therefore an important variable (Bull, 1968) Factors such as environmental conditions, nutrients, moisture (Hedge, 1986) and plant population influence the leaf area of a plant. The maximum projected leaf area per unit ground surface area is referred to as leaf area index (LAI) (Nock et al.2008). Photosynthesis is the production of sucrose when will be transported and stored in the structural and storage tissue of the plant. During bulb development, soluble invertase converts sucrose to reducing sugars namely, glucose and fructose.

In the onion, Health and Holdsworth (1948) have demonstrated that the leaves are the photoperiodic perception site for bulbing and it has been reported that the position of the leaf has an effect on the time of bulb formation (Terabun, 1971). A decline in photoperiodic sensitivity of old leaves may result from the decline in metabolic activity due to changes in their mineral nutrition, protein and chlorophyll contents as they age (moss and Peaslee,1965).The expansion of young leaves could be important in controlling bulbing. Salisbury (1955) demonstrated that the most rapidly expanding leaf is the most sensitive to photoperiodic induction.

The 12.5h daylength was inductive for bulbing in all treatments but temperature affected the rate of response. At 25/12 $^0$C where bulbing had just started to be induced (bulb ratio of 1.9 to 2.1), there was also a lower leaf number, plant height and leaf area of all the cultivars in comparisons to plants grown at the same temperature in the non-inductive environment of 11.5 plants, however, had higher plant height and leaf area as compared to those grown at the same temperature at a 12h daylength. The 11.5h non-inductive, cool temperature environment increased the vegetative growth of the cultivars and under this growth condition; the active plant growth might be related to the readiness of a plant to receive bulbing stimuli as a result of an inductive growth environment trigger (12.5h) for bulb initiation and growth. The increased leaf area and plant height under 12.5h daylength, as compared to 12 h daylength at

25/12$^0$C, might be related to increased availability of photo assimilates supplied to the apical meristem of a plant for bulb initiation and growth. The temperature increment from 25/12$^0$C to 30/15$^0$C increased leaf number, plant height and leaf area at 12.5h to that similar to plants grown at a 12h daylength. However, the increase in temperature to 35/18$^0$C decreases leaf number, plant height and leaf area at the 11.5h and 12.5 h daylengths. This might be associated with a temperature increment from 25/12$^0$C to 30/15$^0$C, but decreased at 35/18$^0$C.However at 12.5 h daylength, the 30/15$^0$C temperature was expected to produce the highest onion production as these plants had a larger leaf area. Such plants are able to produce greater leaf carbohydrates to be assimilated in a longer period of time from the plant canopy into a growing bulb and hence delay foliage collapse (Daymond et al., 1997). The 35/15$^0$C temperature appears to have induced bulbing due to temperature stress-related growth conditions. At a 12.5 h inductive daylength, the V1 and V2 showed no marked differences in bulb initiation as the leaf number, plant height and leaf area at temperatures from 25/12$^0$C to 30/15$^0$C.However, an increase in the temperature to 35/18$^0$C in these cultivars did not increase the bulbing response and this was also accompanied by a decrease in leaf number, plant height and leaf area as compared to the 30/15$^0$C temperature.

At the 12h and 12.5h daylengths, the varieties which were grown at 30/15$^0$C and 35/18$^0$C, produced larger leaf areas. The larger leaf area would be associated with the cultivars potential to have a higher assimilation rate and the supply of carbohydrates to the apical meristem would be more available. Carbohydrates photo assimilates in combination with a bulbing stimulus derived from other environmental triggers would be responsible for bulb scale initiation and growth (Mettananda &Fordham, 1999).

Onion carbohydrates study revealed that hexoses released from INV-or Sus-mediated sucrose degradation, or the cleavage reactions themselves, can serve as signals to modulate a variety of developmental processes, in this case most likely regulates source-sink gradients leading to bulbing. Daylength 11.5h interacted with the three temperature levels had significant effect in sugar concentration, in all temperatures sucrose was dominating, followed by fructose and glucose respectively. The three onion varieties responded to these temperatures in similar pattern, accumulating more sucrose, their accumulation is regulated by sucrose synthase. It is therefore, the onion growth more inclined vegetative, as this delays onset of bulbing, could be affected by short-day length. Whereas under 12h and 12.5h daylengths, temperature effect on plant carbohydrates, and more fructose accumulations is potentially regulated by invertase.

Previous study suggest that glucose and fructose variations are less dependent on temperature, and their study was in agreement with the claim of Benkeblia et al. (2002), but in contrast in agreement with our findings Hurst et al (1985) reported that temperatures had an effect on the sugar changes. Nevertheless, the variation in glucose and fructose levels in onion is not clearly elucidated, and depends on numerous factors, particularly cultivar, sugar content, which affects largely the metabolism of sugars.

The importance of these enzymes in tissues undergoing active growth, in which hexoses are highly demanded as substrates for several metabolic processes such as glycolysis, biosynthesis of starch, triacylglycerides or other molecules that take part in the primary and secondary metabolisms, has been demonstrated (Gayler & Glasziou,1972,Isla et al.,1992), as well as sucrose synthase for cell expansion and division (Winter & Huber,2000).However, it was speculated also another fraction of this sugar have been exported to sink tissues, such as fully matured old leaves.

The variation of invertase activity in onion of bulbing has not been reported previously; however, the invertase activity suggest that this enzyme tends to cause an accumulation of hexoses, which will be continuously supplied to the meristematic tissues favouring bulb development, and providing substrates for growth at different sucrose-importing sites (sinks).Similar results were observed in lily bulbs, where invertase activity was high after 2 weeks at $4^0$C and $10^0$C (Shin et al., 2002). Zrenner et al. (1996) reported also that invertase is involved in the regulation of the hexose-to sucrose ratio in cold-stored potatoes.

### 3.5 Conclusion

In conclusion, it was confirmed that the $35/18^0$C temperatures are supra-optimal for growth of all the varieties under all three daylengths. The $25/12^0$C and $30/15^0$C temperatures are more ideal temperature conditions under the inductive growing daylengths (12 h, 12.5h) particularly for bulb production.

## CHAPTER FOUR: BULB GROWTH, BULB YIELD AND QUALITY OF ONION (*ALLIUM* CEPA L) OF THREE TROPICAL CULTIVARS OF ONION

### 4.1 Abstract

An experiment was conducted to investigate the effect of onion seedlings grown under different environmental conditions on the growth, biomass yield and fresh bulb yield of onion (*Allium cepa* L. Three tropical onion cultivars namely: Red Creole, Star 5516 and Star 5517 were selected for the experiment. There were significant differences ($p<0.05$) in all onion cultivars growing under different levels of day/night temperatures (25/12$^0$C, 30/15$^0$C, 35/18$^0$C).Observation was recorded on bolting, maturity, plant height, number of leaves, leaf length and leaf diameter during bulb development.In both cultivars Star 5516 and Star 5517, had a consistently difference on Red creole cultivar across temperature regime on bolting. The onion bulb diameter and length were different for all cultivars when seedling were exposed to varying temperatures, under 30/15$^0$C, the highest bulb weight was achieved compared to others followed by 25/12 $^0$C and 35/18$^0$C consequently.

Key words: Onion, temperatures, yield, bulb.

### 4.2 Introduction

The onion (*Allium* cepa L) is a third vegetable crop in terms of production among the vegetables in the world after tomato and cabbage (FAO 1996).Onion cultivars differ in the photoperiod needed to induce bulb development, some require short day or long days. Thus the earliness of bulbing of a cultivar under field conditions can be mediated from its performance relative to other cultivars at any bulb inducing photoperiod, however, photoperiodic requirement for bulbing is the major determinant of the sustainability of a cultivar for a particular area (Smittle, 1993) .The onion plant is very responsive to both temperature and photoperiod as the critical minimum daylength for bulbing varies among cultivars but is normally between 12 and 15 hours. Even if the photoperiod is adequate, minimum temperature must be met, or bulbing is delayed. Plant growth rate and development depend on the temperature surrounding the plant and each cultivar has a specific temperature range represented by a minimum, maximum, and optimum degrees Celsius (Hatfield et al., 2015) Moreover the rate of bulb development and bulb maturity increases as the daylength increases. Onion bulbs become smaller when onions are grown under photoperiods that are noticeably longer than the minimum required for bulbing. The ideal climate would be cool weather early in the season with increasing temperature as maturity approaches (Williams et al., 1991).

Onion bulbs undergo three phases in relation to the effect of warm temperature on sprouting, immediately after harvest, dormancy is reduced at 25-35$^0$C and results in earlier sprouting. Long term storage at 25-30$^0$C retards sprouting successively. Once bulbs grow and develop roots, such temperatures are optimal for sprout growth and typical of vegetative growth process in onion. Priya et al. (2014). In field, onion growth is enhanced by the amount of nitrogen fertilizer applied according to soil sampling results or recommendations. Yields are higher where early leaf cover is produced and then maintained for a long period prior to bulb formation. This experiment investigated the effect of different growing conditions (photoperiod and temperature) of onion seedlings on the growth, biomass yield and fresh bulb yield of onion

### 4.3 Materials and Methods

An experiment was conducted to investigate the effect of different growing conditions on the growth, biomass yield and fresh bulb yield of onion at University of KwaZulu-Natal. All cultivars evaluated were randomly selected and purchased from reputable agro-dealer shops (Mc Donald& STAREAYRES).

4.3.1 Preparation of onion seedling materials

Three different onion cultivars namely: Red Creole, Star 5516 and Star 5517 were germinated in 200 cubicles germination trays cells (each cell 28x28x36mm). Three seeds per cell were sown and thinned to leave the strongest plant 2-3 weeks after sowing. Seedlings were grown under 18 h light and day/night temperature of 24/17$^0$C in a growth room to prevent bulbing prior to application of the treatments They were then transferred into three growth chambers with varying day/night temperatures (25/12$^0$C, 30/15$^0$C, and 35/18$^0$C) and were allowed to grow for 40 days before transplanting. Three uniform seedlings of each cultivar were transplanted on plastic bag of 200mm diameter; they were at the 3- to 4- leaf stage or 12 cm in height.

4.3.2 Treatments and experimental design

Three onion cultivars were put into each growth chamber. During the seedlings preparation in the growth chamber, the treatments were varying temperature levels, designated as main-plot factor and the cultivars were also appeared as sub-plot factors. The experimental design was split plot design with the treatment combinations arranged in a Randomized Complete Design with four replications. A total of 71 pots of all combinations cultivars (Red Creole, Star 5516 and Star 5517), Photoperiod (three levels of photoperiod, three levels of temperatures) were transferred to each growth room treatment following the week of transplant adjustment.

Cultivars per treatment of nine treatment combinations

| | | | |
|---|---|---|---|
| Red Creole (V1) | 11.5h X25/12$^0$C | 12h X 25/12$^0$C | 12.5h X25/12$^0$C |
| | 11.5h X30/15 $^0$C | 12h X 30/15 $^0$C | 12.5 hX30/15 $^0$C |
| | 11.5 h X 35/18 $^0$C | 12h X 35/18 $^0$C | 12.5h X35/18 $^0$C |
| Star 5516 (V2) | | | |
| | 11.5h X25/12$^0$C | 12h X 25/12$^0$C | 12.5h X25/12$^0$C |
| | 11.5h X30/15 $^0$C | 12h X 30/15 $^0$C | 12.5 hX30/15 $^0$C |
| | 11.5 h X 35/18 $^0$C | 12h X 35/18 $^0$C | 12.5h X35/18 $^0$C |
| Star 5517 | | | |
| | 11.5h X25/12$^0$C | 12h X 25/12$^0$C | 12.5h X25/12$^0$C |
| | 11.5h X30/15 $^0$C | 12h X 30/15 $^0$C | 12.5 hX30/15 $^0$C |
| | 11.5 h X 35/18 $^0$C | 12h X 35/18 $^0$C | 12.5h X35/18 $^0$C |

4.3.3 Measurements of parameters and Statistical analysis

***Bulb Length and diameter***

Bulb length and diameter refers to the height of the bulb and the average width at the widest point in the middle portion of the mature bulb measured using vernier caliper.

***Total Biomass***

Total dry biomass was recorded as the mass of the bulb, above ground parts and roots at the time of maturity after drying at a temperature of 70°C in an oven to a constant weight

***Plant height and leaf area***

The plant height was taken at the distance from the base of the pseudostem to the tip of the longest leaf. For the destructive measurement of leaf area, leaves were split and opened. The spread leaf blades were measured using a portable meter (LI-COR, L!-3000)

***Bulb mass***

Average bulb mass was computed by weighing ten bulbs together and calculating the average.

***Bolting and physiological maturity***

Plants that produced flower stalk (bolted) was counted and expressed in percentage in relation to total number of plants. Days to physiological maturity referred to the actual number of days from transplanting to a day at which more than 80% of the plants showed yellowing of leaves.

***Data analysis***

Data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical package 17. Differences among treatment were separated using the least significant different (LSD) at the 5% significance level according to Fisher's LSD test.

## 4.4 Results and Discussion

4.4.1 Bolting and physiological maturity

Onion production is influenced by the number different factors, such as seedling status, growing daylength and temperature conditions. Plant growing conditions influence various physiological responses, as a result with varying onion yields. Onion seedlings grown under varying temperature levels showed significant differences ($p<0.05$) post transplanting onion bolting, Seedlings which were raised at 25/12 $^0$C the bolting % was significantly less when compared to 30/15$^0$C and 35/18$^0$C (see Table 4.1) However, there was no significant difference between 30/15$^0$C, 35/18$^0$C while the onion cultivars showed no significant differences in their response to bolting percentage. The temperature had a subsequent cumulative effect in onion bolting percentage. Onion seedlings which were raised under 30/15$^0$C had the highest bolting percentage, followed by 35/18$^0$C and 25/12$^0$C subsequently.

The experiment also reported an interesting result on bolting percentage for the onion cultivars; the Star 5516 and Star 5517 were consistently low on bolting from Red creole across temperature regime30/15$^0$C and 35/18$^0$C. Temperature significantly affected onion physiological maturity. Onion seedlings which were raised under 25/12$^0$C took the highest number of days to reach to maturity level. Although there were no significant differences among cultivars, in average they took 119.80±2.41 days, followed by onion seedling from 30/15$^0$C, they were found intermediate to reach to physiological maturity, which took averagely 107.09 ± 2.41 days. The 35/18 $^0$C had the shortest total number of days to reach to maturity, which took averagely 91.4 ± 2.41 days.

4.4.2 Plant height and vegetative growth

The plant height was measured at 106 days; temperature had also significant effect in plant height and vegetative growth in all cultivars. A temperature of 25/12$^0$C during seedling growth favoured increased plant height and leaf sheath growth at seedling stage and carried over an advantage in their vegetative growth during post-transplanting under field growing condition in cultivar Star 5516 and Star 5517 compared to Red Creole (see Table 4.1).The following 30/15$^0$C had an intermediate growth pattern in plant height and leaf area and 35/18$^0$C had the lowest score for plant height and leaf area. Red creole showed the increased in leaf length and leaf diameter under the temperature of 25/12$^0$C.

Table 4.1. Effect of different temperature levels (25/12$^0$C, 30/15$^0$C, 35/18$^0$C) on bolting, physiological maturity, plant height, number of leaves, leaf length and leaf diameter of onion during bulb development

| **Temperature** | **Cultivars** | **Bolting (%)** | **Days to physiol. Maturity** | **plant ht.** | **leaves/plant** | **leaf length(cm)** | **leaf diameter (cm)** |
|---|---|---|---|---|---|---|---|
| **25/12$^0$C** | R Creole | 2.15a | 115.80b | 56.55b | 16.42b | 55.75b | 0.85a |
| | Star 5516 | 2.68b | 120.67a | 60.89a | 17.19b | 52.67a | 0.67a |
| | Star 5517 | 2.25c | 122.80a | 58.52a | 15.54a | 49.59a | 0.81a |
| **30/15$^0$C** | R Creole | 4.35a | 104.80b | 52.51b | 14.44b | 42.66b | 0.71a |
| | Star 5516 | 3.77b | 107.67a | 54.66a | 14.66b | 47.72a | 0.74a |
| | Star 5517 | 3.36c | 108.80a | 54.33a | 14.55a | 47.66a | 0.74a |
| **35/18C** | R Creole | 4.15a | 91.80b | 45.55b | 11.42b | 32.75b | 0.62a |
| | Star 5516 | 3.68b | 92.67a | 49.89a | 11.19b | 37.67a | 0.50a |
| | Star 5517 | 3.25c | 89.80a | 42.52a | 10.54a | 37.59a | 0.60a |
| | LSD (0.05) | 0.31 | 2.41 | 2.22 | 0.64 | | 0.05 |

*Values in the same row not sharing the same letter differ significantly at LSD (P=0.05)*

Temperature had also subsequent effect in onion timely onset of bulbing, bulb development period and final bulb quality. The temperature had a subsequent cumulative effect in onion bulb neck thickness. Onion seedlings which were raised under 30/15$^0$C had bigger neck thickness followed by 25/12$^0$C and 35/18$^0$C subsequently (Table 4.2). However, there were no significant differences in bulb neck thickness among the cultivars. From this result it is speculated that the Bulb neck thickness could have an effect in the amount of assimilates influx from leaf source to bulb sink organs as literature reveals that an excessive quantities of available nutrients especial Nitrogen with other favourable factors such as temperature will cause the formation of undesirable bulbs which are known as thick necked onion (Abdissa. et al, 2011). These onions lack quality, have a low market value and possess poor keeping quality.

Similarly Temperature affected the percentage of onion bulb splits. The onion seedlings grown under 30/15$^0$C had the highest bulbs percentage with splits defect during harvesting, followed by 25/12$^0$C, and 35/18$^0$C subsequently. Interestingly the result showed that the Star 5516 and Red Creole had the highest bulb split percentage from Star 5517 and the pattern was consistent among the temperature regimes.

4.4.3 Fresh bulb and Bulb diameter

The onion bulb diameter and length were measured at maturity and they were significant different ($P>0.05$) for all cultivars when the seedlings were exposed to different temperature (Table 4.2). During harvest, the onion bulb weight had significant differences for the seedlings which were grown under varying day/night temperature regimes. The 30/15$^0$C had the highest bulb mass compare to the others, followed by 25/12$^0$C and 35/18$^0$C subsequently. More, the two cultivars Star 5517 and Red creole scored the higher bulb weight than Star 5516 and this trend was consistent across the temperature regimes

Table 4.2. Effect of different temperature levels (25/12$^0$C, 30/15$^0$C, 35/18$^0$C) on neck thickness, split bulbs percentage, bulb diameter, bulb length and bulb average weight of onion during bulb development

| **Temperature** | **Cultivars** | **neck thickness(unit)** | **Split bulbs (%)** | **bulb diameter** | **bulb length (cm)** | **bulb wt (g)** |
|---|---|---|---|---|---|---|
| **25/12$^0$C** | R Creole | 1.27a | 1.11c | 6.44b | 3.66a | 100.71a |
| | Star 5516 | 1.08a | 1.21b | 5.04a | 3.82a | 110.10a |
| | Star 5517 | 1.19a | 1.14b | 5.82a | 3.01a | 110.10a |
| **30/15$^0$C** | R Creole | 1.37a | 1.26c | 6.44b | 4.96a | 112.79b |
| | Star 5516 | 1.07a | 1.86b | 7.12a | 5.12a | 141.58a |
| | Star 5517 | 1.78a | 1.80b | 7.19a | 5.01a | 144.00a |
| **35/18$^0$C** | R Creole | 1.10a | 0.68c | 5.02b | 3.54a | 99.66a |
| | Star 5516 | 0.94a | 0.77b | 4.12a | 4.12a | 102.21a |
| | Star 5517 | 0.97a | 0.66b | 5.19a | 4.01a | 96.06a |
| | LSD (0.05) | 0.22 | 0.21 | 0.29 | 0.18 | 4.55 |

*Values in the same row not sharing the same letter differ significantly at LSD (P=0.05)*

At 25/12$^0$ C temperature, bolting in onion seedlings were reduced in comparisons with 30/15$^0$C and 35/18$^0$C however there was little significant differences between 30/15$^0$C and 35/18$^0$C. This was an indication that onion seedlings are sensitive to either low or high temperature during bulb formation because they stop making a bulb and start sending up flower shoots and forming seeds during (Benkem, 2010).Plant cultivars, plant size and temperature all factor to whether onion plant bolt or not (Albert, 2013) .That was shown in the experiment when onion cultivars Star 5516 and Star 5517 were consistently different from Red Creole across all temperature regimes. However there was a marked effect of incremental temperature significantly affected onion physiological maturity as bulbs develop more rapidly at higher temperatures (Brewster, 1990). Seedlings that were raised under 25/12 $^0$C took long days to reach to maturity level; they took approximately 119.80±2.41 days on average whereas seedlings raised under 35/18$^0$C had the shortest total number of days on average; they took 91.4 ± 2.41 days to reach maturity. Nevertheless bulb maturity decreases with increasing temperature (Mahmud, 2015).

Seedling growth were favoured at 25/12 $^0$C temperature, as they increased in plant height and leaf sheath growth but had an intermediate growth pattern in plant height and leaf area under 30/15$^0$C . increase of temperature in excess of 25/12 $^0$C decreases plant height and leaf area which showed that plants were stressed at a high temperature (35/18$^0$C), however the main effect of cultivar and level of temperature did not show any significant difference on leaf number per plant at maturity in both Red Creole and Star 5516 but Star 5517.When temperature was raised to30/15$^0$C onion seedlings developed bigger neck thickness followed by 25/12 $^0$C and 35/18$^0$C. However no significant differences in bulb neck thickness among cultivars hence bulbing in early cultivars depend more on temperature than photoperiod (Ruiter.,1980).Although temperature had a subsequent effect in onion bulb neck thickness so as application of N fertilizer at 200kg Na-1 increased the number of thick necked bulbs. Fertilizer application also increases the number of splitted bulbs in onion (Abdissa. et al, 2011).

**4.5 Conclusions**

In conclusion, Onion requires a cool temperature at an establishment stage and warm temperature at developmental stage to avoid bolting and bulb neck thickness. The bolting rate of Red Creole was higher under 30/15$^0$C thus became reduced as temperature level was reduced. All cultivars performed well under 25/12 $^0$C temperature level in terms of bolting percentage, plant height and onion bulb development .The results also revealed that onion bulb diameter and length were different for all cultivars when seedlings were exposed to varying temperatures, under 30/15$^0$C, the highest bulb weight was achieved in all followed by 25/12 $^0$C and 35/18$^0$C consequently.

## CHAPTER FIVE: GENERAL DISCUSSIONS AND RECOMMENDATION

All parts of onion plant are edible, but the bulbs and the lower stem sections are the most popular and harvested parts of the crop (Khan et al. 2002). Quality and yield of the crops are reflected on bulbs. It was revealed in the study that growing environments influence yield and bulb quality however there are other factors that should be taken into consideration when growing onions in fields. Factors such as growing time, plant density, weed competition, fertilization and irrigation (Lancaster, 1996). They play an important role in accelerating or slowing down the bulb growth, moreover, there are two most important factors that determined the onset of bulbing are photoperiod and temperatures.

Onion bulbing begins when it is exposed to a certain number on daylight hours at least exceeding the minimal quantity of light .Therefore, It was vital to look at the growth components in response to day lengths and temperatures which, each and in combination, have an impact in determining onion growth and development. The highest bulbing rate was shown in 12.5 hours in all cultivars grown followed by 11.5 hours thus the higher yield and marketable bulb sizes achieved when plants are grown at optimum temperature levels. Onion cultivars, daylength and temperature levels significantly affect the onion bulb yield. In the study, it was revealed that the interaction of onion cultivars and temperature levels significantly affected biomass and bulb yield. Most of the cultivars performed well under 25/12$^0$C temperature level. Growing conditions of onion also had an influence on different physiological stages of onion seedlings which resulted in varying onion yields. This was proven when the experiment was conducted to study the effect of onion seedlings grown under different growing conditions on growth, biomass yield and fresh bulb yield under three levels of day/night temperatures (25/12$^0$C, 30/15$^0$C, and 35/18$^0$C) at UKZN growth chambers. No significant differences were shown amongst the three levels of temperatures although different cultivars may respond differently on the other aspects of onion development. The bolting percentage of Red creole was high when grown under 30/15$^0$C and were reduced when grown under 25/12$^0$C, this means that Red creole perform well under optimum temperature level which is 30/15$^0$C. The onion grown under 30/15$^0$C had the highest bulbs percentage with splits defect during harvesting, followed by 25/12$^0$C and 35/18$^0$C consequently. The onion bulb diameter and length were different for all cultivars when seedling were exposed to varying temperatures, under 30/15$^0$C, the highest bulb weight was achieved compared to others followed by 25/12$^0$C and 35/18$^0$C consequently. The recommended marketable bulbs were 25g according to the local market assessment so anything less or above the recommended weight can be of poor quality.

Irrespective of the variety used, planting under high levels of temperatures increase percentage of bolting, more, the results showed that onions grown under different temperature levels had significant differences on bolting.

**FUTURE RECOMMENDATION**

- More field studies to investigate on factors such as growing time, plant density, weed competition, fertilization and irrigation in accelerating or slowing down the bulb growth in the Northern part of KwaZulu-Natal.
- More studies on cultivars with longer keeping quality (postharvest handling)

## REFERENCES


Abdalla A.Abdalla 1967.Effect of temperature and photoperiod on bulbing of the common onion under arid tropical conditions of the Suden, Cambridge University,department of Horticulture.

Abdissa.Y,Tekalign.T,Pant L.M,(2011) Growth,bulb yield and quality of onion (*Allium* cepaL.) as influenced by nitrogen and phosphorus fertilization on vertisol l.growth attributes, biomass production and bulb yield.School of plant Science,Ethopia pg 1-7

Ainsworth,C (Charles),(2006) Flowering and its maniputation Annual plant reviews, Vol 20 Blackwell publishing.

Albert S, (2013).Bulb Onion Growing, Day length and temperature allies: botany, cultivation and utilization. London: World Crops Books, Leonard Hill,

Ayyachamy, M., Khelawan, K., Pillay, D., Permaul, K. and Singh, S., 2007. Production of inulinase by Xanthomonas campestris pv phaseoli using onion (*Allium* cepa) and garlic (*Allium* sativum) peels in solid state cultivation. *Letters in applied microbiology*, *45*(4), pp.439-444.

Bosekeng G, (2012).Response of Onion (*Allium* Cepa L) to sowing date and plant population. Department of Soil crop and Climate Sciences. Faculty of Natural and Agricultural Sciences. University of Free State.

Bradford MM (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem 72: 248–254

Brewster, J. L. (2008). *Onions and other vegetable alliums* (No. 15). CABI.

Brewster,JL,(1990).The influence of cultural and environmental factors on the time of maturity of bulb onion crops.267 Company, Inc., pp. 538-539.

Clark, J. E., & Heath, O. V. S. (1962). Studies in the Physiology of the Onion Plant: V. An investigation into the growth substance content of bulbing onions. *Journal of Experimental Botany*, *13*(2), 227-249.

Currah, L. and Proctor, F. J, (1990b): Onions in tropical regions Natural Resource Institute,Bulettin no 35xiii+232pp

Currah, L. and Proctor, F. J, (1990a). The genetic base and the cultivars grown in the tropics.

Dragland, S, (1972). Effect of temperature and daylength on growth, bulb formation and bolting in leeks (*Allium* porrum L.). Meldinger fra Norges Landbrukshogskole, 51, Agricultural University, Norway.

Duvick, D. N, (1967). Influence of morphology and sterility on breeding morphology. In: Plant Breeding (Fry, K. J. ed.). Ames, Iowa: University press

Eksteen GJ, Van Den Klashorst E, Van Ziji B (1997). Onions for Export Harvesting, Handling and Storage. Onions J.2. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, P. 1.

Erwin Raisz,Climate and man, The Minerva group,(2004),United States.Department of Agriculture:US Department of Agriculture

Farooq, C., Mahmood, K., Khan, M. A., & Qadir, A. (1990). Effect of plant density on plant growth, size and yield of onion. *Pakistan Journal of Agricultural Research*, *11*(4), 239-242.

Friesen,N.and Klaas,M ,(1998) Origin of some minor vegetatively propagated *Allium* Crops studied with RAPD and Gish.Genetic Resources and crop Evaluation 45,511-523

Fritsch, RM., Matin, F and Klaas,M, (2001) *Allium* vavilovii M.Popv et Vved.and a new Iranian species are the closest among the known relatives of the common Onion A cepa.,(Alliacea).genetic Resources and crop Evolution 48, 401-408.

Gopalakrishnan, T.R, 2007.Vegetable crops,Agricultural university,Thrissur,Horticultural Science Series Vol.4

Gray,D,Steckel JRA and Hands L.J (1993).Leek (*Allium* porrum L)Seed development &Germination seed science research.

Gregory E.Welbaum, (2015).Vegetable Production and Practices PhD, visiting Professor, Department of Plant Science, Seed Biotechnology center,university of Califonia:pages 279

Grevsen, K., & Sorensen, J. N. (2004). Sprouting and yield in bulb onions (Allium cepa L.) as influenced by cultivar, plant establishment methods, maturity at harvest and storage conditions. *The Journal of Horticultural Science and Biotechnology*, *79*(6), 877-884.

Halfacre, R. G. and Barden, J. A, (1979). Horticulture. New York: McGraw-Hill Book

Hamasaki, R. T., Valenzuela, H. R., & Shimabuku, R. S. (1999). Bulb onion production in Hawaii.

HatField,J.L . and Prueger J.H,(2015),Weather and Climate Extremes:Effect on plant growth and development.USDA Research and Programs on Extreme Events: pages 4-10

Hazra, P., & Dutta, A. K. (2011). *Vegetable Breeding for Quality Traits* (pp. 274-314). New India Publishing Agency: New Delhi.

Heath, O. V. S., & Holdsworth, M. (1948, January). Morphogenic factors as exemplified by the onion plant. In *Symp. Soc. Exp. Biol* (Vol. 2, pp. 326-50).

Hygrotech, 2004, Production guidelines for onions In: Onions in tropical regions Natural Resource Institute,

Jones and Mann, 1963. Effect of bulb size &Plant density on yield and quality of onion at Ziway, Central Ethopia

Jones, H. A. and Mann, L. K ,(1963a). Morphology and development. In: Onions and their
Journal ofHorticultural Science

Kahsay, Y., Belew, D., & Abay, F. (2013). Effect of intra-row spacing on yield and quality of some onion varieties (Allium cepa L.) at Aksum, Northern Ethiopia. *African Journal of Plant Science*, *7*(12), 613-622.

Kebede, B.T., Grauwet, T., Mutsokoti, L., Palmers, S., Vervoort, L., Hendrickx, M. and Van Loey, A., 2014. Comparing the impact of high pressure high temperature and thermal sterilization on the volatile fingerprint of onion, potato, pumpkin and red beet. *Food Research International*, *56*, pp.218-225.

Kedar, N., Levy, D., & Goldschmidt, E. E. (1975). Photoperiodic regulation of bulbing and maturation of Bet Alpha onions (Allium cepa L.) under decreasing daylength conditions. *Journal of Horticultural Science*, *50*(4), 373-380.

Keral Agriculture University, (2009), Basics of Horticulture, Department of Horticulture sumit pal Jain-New India publishing Agency

Khan, H., Iqbal, M., Ghaffoor, A., and Waseem, K. (2002). Effect of Various Plant Spacing and Different Nitrogen Levels on the Growth and Yield of Onion (*Allium* cepa L.). *OnLine Journal of Biological Sciences*, *2*(8), 545-547.

Khokher,KM.,2015).Effect of temperature and photoperiod on the incidence of bulbing and bolting in seedlings of onion cultivars of diverse origin.The Journal of Horticulture science and biotechnology volume 83 pg 488-496

Lancaster, J. E., Triggs, C. M., De Ruiter, J. M., & Gandar, P. W. (1996). Bulbing in onions: photoperiod and temperature requirements and prediction of bulb size and maturity. *Annals of Botany*, *78*(4), 423-430.

Liu, F., & Li, Y. (2006). Storage characteristics and relationships between microbial growth parameters and shelf life of MAP sliced onions. *Postharvest biology and technology*, *40*(3), 262-268.

McGeary DJ (1985). The effects of plant density on the shape, size, uniformity, soluble solids content and yield of onions suitable for pickling. J. Hort. Sci. 60:83-87.

Mettananda, S. A., & Fordham, S. (1999). The effects of plant size and leaf number on the bulbing of tropical short-day onion cultivars (Allium cepa L.) under controlled environments in the United Kingdom and tropical field conditions in Sri Lanka. *The Journal of Horticultural Science and Biotechnology*, *74*(5), 622-631.

Peffley E,Green C,Pare P,Thompson L,Tissue D,(1999).Plant Carborn allocation and partitioning of metabolities in a closed growth facility. Plant and soil science: Texas Tech University. Phytohormone metabolism. Pietermaritzburg, South Africa.

Pike, L. M. (1986). Onion breeding. *Breeding vegetable crops*, 357-394.

Priya E.P Banuu.,Sinja V.R,Alice R.P.J.S.,Shanmugasundaram S.,and Alagusundaram, K.,(2014).Storage of onions :Indian Institute of crop processing Technology, Thanjavur India.

Robbins, N.S. and D.M. Pharr. 1987. Leaf area prediction for cucumber from linear measurements. HortScience 22:1264–1266.

Roberts, A. M., & Walters, D. R. (1988). Nitrogen assimilation and metabolism in rusted leek leaves. *Physiological and molecular plant pathology*, *32*(2), 229-235.

Rodrigues, A.S., Pérez-Gregorio, M.R., García-Falcón, M.S. and Simal-Gándara, J., 2009. Effect of curing and cooking on flavonols and anthocyanins in traditional varieties of onion bulbs. *Food Research International*, *42*(9), pp.1331-1336.

Ruiter,JM.(1986).the effect of temperature and photoperiod on onion bulb growth and development.Plant physiology division DSIR Palmerston North.Pg 93-100

Sharma, K., Ko, E. Y., Assefa, A. D., Ha, S., Nile, S. H., Lee, E. T., & Park, S. W. (2015). Temperature-dependent studies on the total phenolics, flavonoids, antioxidant activities, and sugar content in six onion varieties. *journal of food and drug analysis*, *23*(2), 243-252.

Smith JMB, (1998).Handbook for Agricultural Advisors in KwaZulu-Natal

Smith, B., 2006. The farming handbook. University of Kwazulu-Natal Press,

Smith, C., Lombard, K.A., Peffley, E.B. and Liu, W., 2016. Genetic analysis of quercetin in onion (*Allium* cepa L.)'Lady Raider'. *Texas Journal of Agriculture and Natural Resources*, *16*, pp.24-28.

Smittle,D,(1993).Effect of environment on onion growth and development and sweet onion production in the tropics: University of Georgia

Sobeih, W. Y. and Wright, C. I. (1986). The photoperiodic regulation ofbulbing in onions. II.Effects of plant age and size. Journal of Horticultural Science

Starkeayres,(2014).Onion Production Guidelines.Department of Agriculture,Forestry &Fisheries

Steer, B. T. (1980). The bulbing response to day length and temperature of some Australasian cultivars of onion (Allium cepa L.). *Australian Journal of Agricultural Research*, *31*(3), 511-518.

Sullivan, D. M., Brown, B. D., Shock, C. C., Horneck, D. A., Stevens, R. G., Pelter, G. Q., & Feibert, E. B. G. (2001). *Nutrient management for onions in the Pacific Northwest*. [Covallis, Or.]: Oregon State University Extension Service.

Tarakanov, J. G. (2002). Environmental control of morphogenesis in onion: Possible role of

Tesfay, S.Z .,(2005).The effect of daylength and temperature on growth and onset of bulbing in tropical cultivars of onion. Faculty of Agricultural Sciences and Agribusiness, University of KwaZulu-Natal.

Van den Ende, W., Michiels, A., Van Wonterghem, D., Vergauwen, R., & Van Laere, A. (2000). Cloning, developmental, and tissue-specific expression of sucrose: sucrose 1-fructosyl transferase from Taraxacum officinale. Fructan localization in roots. *Plant Physiology*, *123*(1), 71-80.

Voss, R.E., Murray, M., Mayberry, K.S. & Miller, I., (1999). Onion seed production in California. University of California, Division of Agriculture and Natural Resources. California. United States of America

Welbaum, G. E. (2015). *Vegetable production and practices*. CABI.

Yamasaki ,A,Miura, H,Tanaka, K (2000).Effect of photoperiods before & during and after vernalization of flower initiation & development and its varietal differences in Japan bunching onion(*Allium* fistulosum.L)The Journal of Horticultural Science and Biotechnology vol 75.

Zerihum Zena, 2008. The effect of bulb size and plant density on yield and quality of onion (*Allium* Cepa var Cepa L) seed at Ziway Central Ethopia.University of Hawassa ,A wassa college of Agriculture