UNIVERSITY OF CAPE COAST

EFFECT OF DEFICIT IRRIGATION ON GROWTH, YIELD, QUALITY AND STORAGE OF TOMATO (*Solanum lycopersicum;* cv. Pectomech)

BY

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CANDIDATE'S DECLARATION

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

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SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

The study was conducted to investigate the effect of deficit irrigation on growth and quality of tomato after harvest and during storage. Four treatments (100% ETc, 90% ETc, 80% ETc and 70% ETc) with three replications were set-up in a Completely Randomized Design (CRD) in plastic buckets under a rain shelter. Water loss by the tomato plants (ETc) was assessed by weighing and the equivalent volume was computed and replaced at two-day intervals. Crop coefficient (Kc) and amount of water used (ETc) for the various water treatments were determined. Plant height, leaf area, canopy diameter and leaf area index were also determined. The fruit size, mass, number of fruits per treatment and total yield were determined. Physico-chemical, nutritional and antioxidant qualities of the fruits after harvest and during storage were determined using standard methods. Results showed that Kc and ETc values for the various growth stages were in the order 100% > 90% > 80% > 70%. There were significant differences ($p<0.05$) in the leaf area, canopy diameter and leaf area index for the various water treatments. No significant differences ($p>0.05$) were recorded for the various treatments for yield components except fruit size. Tomato fruit firmness, total soluble solids, titratable acidity, fat, fibre, carbohydrate, lycopene, vitamin E, flavonoids and total polyphenols increased with deficit irrigation while pH, moisture, ash, protein, minerals, β-carotene and ascorbic acid decreased. Total soluble solids, pH, fibre and lycopene increased significantly ($p<0.05$) with increasing storage period while titratable acidity, firmness, moisture, ash, protein, fat, carbohydrate, minerals, β-carotene, ascorbic acid, flavonoids and total polyphenols decreased.

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DEDICATION

This work is dedicated to my mother, wife and children.

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LIST OF ABBREVIATIONS

ABA	Abscisic Acid
ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
ASCE	American Society of Civil Engineers
BER	Blossom-End Rot
CK	Cytokinin
CRD	Completely Randomized Design
DAT	Days After Transplanting
EDTA	Ethylene-Diamine-Tetra-Acetic acid
ET	Evapotranspiration
ETc	Crop evapotranspiration
ETo	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
Kc	Crop Coefficient
QE	Quercetine Equivalent
RELC	Research and Extension Liaison Committee
SAW	Soil Available Water
SPSS	Statistical Package for Social Sciences
TA	Titratable Acidity
TSS	Total Soluble Solids
TWN	Third World Network
USDA	United States Department of Agriculture
WUE	Water Use Efficiency

Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
P	Phosphorus
S	Sulfur
Zn	Zinc

CHAPTER ONE

INTRODUCTION

Background of study

Tomato (*Solanum lycopersicum*) is one of the most popular and widely consumed vegetables in the world. The crop has developed into a great number of cultivated types suitable for different environments, methods of production and food uses. Its versatility in fresh or processed form has played a major role in its rapid and widespread adoption as an important food commodity (Kasem & Siemonsma, 1999). According to Di Mascio *et al.* (1998), tomatoes are major sources of lycopene, a dietary carotenoid found in high concentrations in processed tomato products. This compound is an antioxidant known to combat cancer, heart diseases and premature aging. Tomatoes are high in vitamins A, B and C and also contain good amounts of potassium, iron and phosphorus. Fresh tomatoes and canned tomato products such as concentrates, puree and paste, are increasingly in demand in West Africa where they form an essential part of the diet of the inhabitants (FIAN, 2007).

In Ghana, tomato is probably the most important vegetable grown, and a wide range of areas are suitable for its production. It is grown in the forest, transitional and savanna zones (Norman, 1992). Total land area for its production increased from 28,400 hectares in 1996 to 37,000 hectares in 2000 (GIPC, 2001). According to Wolff (1999), vegetables account for 9.6% of total food expenditure and 4.9% of total expenditure in Ghana, and tomato alone

makes up to 38% of the vegetable expenditure. Tomato production is an important source of income for smallholder farmers. In recent years, domestic tomato production has intensified across Ghana but local production is not able to meet the domestic high demand and therefore tomatoes are often imported, mainly from Burkina Faso (Horna *et al.*, 2006). This situation is as a result of a number of constraints in tomato production, among them is the dependence on rain-fed production. In the middle zone of Ghana (Ashanti and Brong Ahafo Regions), the annual Research and Extension Liaison Committee (RELC) planning workshop reports (1996 – 1998) have listed the following problems:

- Lack of water for dry season vegetable production
- High incidence of pests and diseases
- Misuse of agrochemicals
- High postharvest losses
- Lack of improved seeds
- Poor processing and storage facilities and
- Price insecurity of vegetable products.

The above problems, together with several others from other parts of the country, need to be addressed by research in order to improve vegetable production in the country.

The tomato sector in Ghana has failed to reach its potential in yields comparable to other countries, in terms of the ability to sustain processing plants, and in terms of improving the livelihoods of those households involved in tomato production and the tomato commodity chain. Despite government interventions that include the establishment of a number of tomato processing

factories, tomatoes of the right quality and quantity for commercial agro processing are not being grown. Many farmers still prefer to plant local varieties, typically with a high water content, many seeds, poor colour, and low brix. Land husbandry practices are often suboptimal. Average yields remain low, typically under 10t/h. Due to production seasonality, high perishability, poor market access, and competition from imports, some farmers are unable to sell their tomatoes, which are left to rot in the fields. Yet other farmers in Ghana have achieved higher tomato yields, production is profitable, and many farmers in Ghana continue to choose to grow tomatoes over other crops (Clottey *et al.*, 2009).

The major problem of tomato production in Ghana is its seasonality. Due to lack of water during the dry season, tomato production is limited to the rainy season. Deficit irrigation can be adopted during the dry season to offset this problem. Deficit irrigation, a practice of reducing the amount of water supplied to a crop or reducing the frequency of water application could be used to ensure optimum yields in times of drought or make proper use of irrigation water to achieve the maximum potential yields in times and areas of abundant and almost free water for irrigation. The correct application of deficit irrigation requires thorough understanding of the yield response to water (crop sensitivity to water stress) and economic impact of reductions in harvest (English, 1990). Achieving greater efficiency of water is a challenge and it includes the employment of techniques and practices that will deliver a more accurate supply of water to crops. In this context, deficit irrigation can play an important role in increasing water use efficiency. Water stress results in less evapotranspiration

by closure of stomata, reduced assimilation of carbon and decreased biomass production. The reduced biomass production has little effect on ultimate yields where the crop is able to compensate in terms of reproductive capacity (Mitchell *et al.*, 1994). In some cases, periods of reduced growth may trigger physiological processes that actually increase yield, quality and may cause the crop to adapt to other deteriorative processes thereby elongating the shelf life of the crop after harvest. Such processes include flower-induction in the case of cotton, increased root development exploring deeper soil layers, early ripening of grains and improved quality and flavour of fruits (McCarthy, 2000). However, stress applied during reproductive growth can affect fruit and grain set, resulting in decreased yields.

The effects of stress on yields are complex and may differ with species, cultivar and growth stage. There should be extensive field research for better understanding of the physical and biological processes that control crop responses to moisture stress. The adoption of deficit irrigation implies appropriate knowledge of crop evapotranspiration (ET), crop response to water deficits, including the identification of critical crop growth periods, and the economic impacts of yield reduction strategies; therefore growers may have difficulty in using it (Pereira *et al.*, 2002). In areas of water scarcity and long droughts, for example northern Ghana, deficit irrigation is recommended to mitigate drastic yield reductions (Kirda *et al.*, 2004). In preliminary studies on open-field tomato, a great influence of deficit irrigation on crop physiology, yield and fruit quality has been demonstrated (Patane & Cosentino, 2010). This water strategy may also cause wide variations in soil water content and, thus,

more or less moderate water stresses the effects of which depend on crop development stage when they occur. Indeed, according to Renquist and Reid (2001), the effects of soil water deficit at different crop stages, on tomato fruit yield and quality, are still not well-defined since they are rather complex and site specific, being mainly affected by the environmental conditions (i.e. soil and climate). A better understanding of the relationships between soil water deficit determined by deficit irrigation and fruit yield and quality could better enable growers to manipulate irrigation water management, avoiding problems in terms of plant growth, yield and fruit quality (Renquist & Reid, 2001).

Water is an essential resource used for civil, industrial and above all, agricultural purposes. On the world scale, indeed, about 70% of the overall water consumption is utilized by the agricultural sector. Irrigation allows several advantages especially in the areas of scarce rainfall and elevated evapotranspiration demand. Nevertheless, in the past years, a worrying quantitative reduction in water supplies for agriculture is taking place at world-wide level (Kirda, 2002). The future expectations do not seem to be positive for a lot of geographical areas (Fereres & Connor, 2004). There are several causes that limit water availability for agriculture. These include an increasing demand by the domestic users, a greater requirement by the industrial sector, climate change that causes a rise in the air temperature and an irregular distribution of rainfall producing more intense precipitations and run-offs and limiting infiltration in the soil as well as refill of the aquifers leading to a scarce maintenance of the water distribution networks.

Water plays a crucial role in determining the yield of tomato but it is likely that a water scarcity period will have to be faced in the near future. Water shortage and the increasing competition for water resources between agriculture and other sectors compel the adoption of irrigation strategies in regions, which may allow saving irrigation water and still maintaining satisfactory levels of production (Costa *et al.*, 2007). A positive approach to attain the goal of improving water use efficiency is deficit irrigation, a water saving strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (Pereira *et al.*, 2002). It involves irrigating the root zone with less water than required for evapotranspiration (Zegbe-Domı`nguez *et al.*, 2003). Its effects have been extensively studied on several crops, including tomato, though with contrasting results (Kirda *et al.*, 2004). For example, a glasshouse study on a processing tomato cultivar, revealed that dry mass yield did not decrease under deficit irrigation compared to full irrigation, besides making a 50% saving of water and an approximately 200% increase in irrigation water use efficiency, and some relevant fruit quality attributes were improved in a deficit irrigation treatment (Zegbe-Domı`nguez *et al.*, 2003). Conversely, Pulupol *et al.* (1996) observed a significant reduction in dry mass yield for a glasshouse cultivar.

Statement of the problem

Tomato is a vegetable crop of considerable economic importance in Ghana. High yields of tomato result in high incomes to farmers in the tomato growing areas (Robinson & Kolavalli, 2010). However, it is very perishable. The high perishability of tomato makes it quite difficult to store for long periods without

encountering high losses. Thus, fresh ripe tomatoes can be reduced to heaps of waste with the subsequent loss of income to farmers as well as the reduction in the supply to consumers leading to an escalation in prices. The high prevailing day time temperatures (30 – 35°C) in the tropics make the perishability of tomatoes more pertinent, by accelerating the ripening and decay of tomatoes immediately after harvest.

The high perishability of tomato has been linked to its high water content (Atanda *et al.*, 2011). Tomato contains about 80-95 % water and this high water content is in a way responsible for its perishability and hence short shelf life. A reduction in the water content may increase the shelf-life of tomatoes. One way of reducing the water in the fruit may be by controlling the amount of water received by the crop during cultivation. Deficit irrigation is one way by which the amount of water applied to the crop during cultivation can be reduced.

Tomato (*Solanum lycopersicum*) is one of the most demanding in terms of water and the adoption of deficit irrigation may result in significant savings of irrigation water which can be left for other purposes (Costa *et al.*, 2007). However, the effect of deficit irrigation on the quality and shelf life of tomatoes has not been reported in Ghana.

Aim and objectives

The aim of this study was to assess the effect of deficit irrigation on tomato production with respect to growth, yield, quality and postharvest storage of the tomato fruits. To achieve this aim, the following specific objectives were set to:

1. determine and compare the crop water requirement (ETc) and crop coefficient (Kc) for the various growth stages of the tomato plant under different water applications (100% ETc, 90% ETc, 80% ETc and 70% ETc) for the agro ecological area under the study.
2. determine and compare growth parameters such as plant height, canopy diameter, leaf area and leaf area index for the tomato plants grown under the different water applications.
3. determine and compare the yield of tomato fruits for all the different water applications.
4. assess the quality of the tomato fruits grown under the different water applications.
5. assess the effect of postharvest storage on the quality of the tomato fruits grown under the different water applications.

Justification

Deficit irrigation is being practiced in many parts of the world as a means of reducing irrigation water use in many drought-persistent regions but its use especially by vegetable farmers in Ghana is limited. Hence vegetable farmers in Ghana tend to either over irrigate or under irrigate their farms leading to excessive use of water that can be channelled for other uses coupled with the detrimental effects that over irrigation and under irrigation may have on the crops.

This study would therefore assist tomato farmers to determine the amount of water to apply daily to the crops by merely knowing the climatic data for the day using the crop coefficient (Kc) values for the various growth stages.

This in effect will help reduce the amount of water used for irrigating tomato farms thereby saving water for other uses. It would also help irrigation engineers to plan or schedule irrigation for similar agro-ecological zones for farmers to adopt with ease. The outcome of the study will also show whether lower water applications during cultivation of tomatoes will affect yield and quality so that farmers can decide whether to adopt it or not.

Thesis layout

Chapter One is a general introduction to the work at hand and Chapter Two reviews literature on tomato production in Ghana, water use for tomato production and previous attempts at reducing water for tomato production. It also deals with some methods of determining the crop coefficient and evapotranspiration of the tomato plant and deals with the effects of reduced water use on minerals intake and some compositions of the tomato. Chapter Three compares the amount of water used under each of the irrigation water applications, growth and yield parameters. Chapter Four compares the changes in the physicochemical quality of the tomato fruits for the various water applications and during storage. Chapter Five compares the changes in the nutritional quality of the tomato fruits for the various water applications and during storage. Chapter Six also compares the changes in some antioxidant compositions of the tomato fruits for the various water applications and during storage. Chapter Seven summarizes all the work and gives conclusions as well as recommendations.

CHAPTER TWO

LITERATURE REVIEW

Overview of tomato production in Ghana

Tomato cultivation has been a significant economic activity in Ghana, especially in the Northern, Upper East and around southern Volta Regions of Ghana (Third World Network (TWN), 2007). It has long been the most lucrative crop in the Upper East Region and it is presumed more profitable than rice, maize, groundnuts, yam, pepper and dairy. Close to 90% of the two million people living in these areas cultivate tomatoes. Tomato production is also vibrant at Akumadan and Wenchi areas. Cooperative farming, according to Norman (1992), is concentrated around Mankessim, Swedru, Agogo, Nsawam, Amasaman, Sege and Dodowa. The common tomato varieties grown in Ghana include Roma, Pectomech, Royal, Burkina and Power (Khor, 2006). In Ghana, tomato production per hectare is very low, compared to the developed countries, and this can be attributed to several reasons. Some of the most important among these are the uneven distribution of rainfall throughout the year and the vulnerability of tomato crop to various diseases including fungal, viral, bacterial and nematode diseases (Horna *et al.*, 2006).

Data for the tomato sector have not been collected consistently at a national level since the 1980s and so it is not possible to make strong statements concerning trends over area farmed to tomato, yields, or productivity. However, the available data suggest that overall production doubled between the

1970s/80s and the 1990s. In the 1970s and early 1980s tomato production fell from around 100,000 t/y to around 50,000 t/y, then in the late 1980s increased back to around 100,000 t/y. During the 1990s production expanded again, averaging around 200,000 t/y by the end of the decade.

However, during the 2000s, production appears to be falling gradually. A small proportion of Ghana's domestic production is exported to Ghana's neighbours, and domestic production is supplemented by imports from Burkina Faso during the December to May harvest season, estimated to be as high as 100,000 t/y. During the 1970s and 1980s, when data were being collected systematically by SRID/MoFA at the national level, average yields fluctuated around 4.8 t/ha with little upwards trend. In the 1990s, average yields in the country were estimated to be just over 13 t/ha (Wolf, 1999). More recent country-wide estimates suggest average yields of 7.5 t/ha in the early 2000s (ISODEC, 2004, quoting SRID, 2003 data) and 6.7 t/ha more recently (Asuming-Brempong & Asuming-Boakye, 2008).

Although difficult to make generalizations because of the limited data available, all recent estimates of yields, though higher than data from the 1970s and 1980s, are lower than Wolf's 1990 estimate, suggesting little, if any, yield increases over the past two decades and possibly falling yields. Comprehensive time series data available for the Greater Accra Region between 1998 and 2008 show low overall yields, compared to estimates from other regions, but growing gradually from 4.3-5.5 t/ha. These data suggest that over the past two decades, the tomato sector has been stagnant and possibly declining in terms of area cropped and yields (Asuming-Brempong & Asuming-Boakye, 2008).

Tomato production in Ghana is highly seasonal, reflecting differences in access to water and rainfall patterns, as illustrated by variation in harvest periods. Within the calendar year, different regions of the country produce tomato at different times of the year. From late December through April/May, Ghana's Upper East Region and Burkina Faso supply almost all the fresh tomato in the country. From June onwards the harvest picks up in the rained areas, with a longer season in Brong Ahafo and Ashanti Regions (reflecting bi-modal rainfall patterns) and shorter seasons in Greater Accra. Irrigated tomato from Greater Accra dominates the market later in the year (Asuming-Brempong & Asuming-Boakye, 2008).

Varietal choice influences yields. Two varieties, Power Rano, a variety that is grown widely in Brong Ahafo under rainfed conditions, and Pectomech, a variety suitable for processing that is grown widely in the Upper East Region and in Burkina Faso as well, out-perform other varieties under most conditions. "No name" is also believed to be Pectomech; and "Burkina" is likely Pectomech from Burkina Faso. Surprisingly, the yields of Nimagent F1, an expensive variety supplied by Trusty foods, are low in Greater Accra. A fifth to a third of the growers still use washed seeds. Farmers' choice of varieties influences and is influenced by access to seeds, growing technologies, available markets, potential yields, prices and risk. In Asia, during the Green Revolution, farmers embraced the purchase of improved seeds, yet farmers in Ghana have historically appeared reluctant to purchase seeds (Orchard & Suglo, 1999). This is, however, changing. Although seed "recycling" has been reported to account for up to 85–90% of seed supply in the past (Orchard & Suglo, 1999; Horna *et*

al., 2006), recent surveys suggested that only 33% of farmers were exclusively using their own seed (extracted from tomatoes, washed, and dried), with another 20% using both recycled seed and purchased seed, or seed from other farmers; with the remaining 47% purchasing all their required tomato seed (Monney *et al.*, 2009).

Irrigation as a solution to inadequate rainfall in food production in Ghana

Ghana is not self-sufficient in food production, and it has been difficult to ensure food availability in sufficient quantities all year round. During periods of good rains, food abounds but inadequate storage facilities result in losses of perishable crops. Inadequate agro-processing facilities for agricultural products are adding to food insecurity in the country. The rapidly growing population poses another dimension to the question of food security in the country. Food availability varies from season to season and from year to year depending on rainfall amount and its distribution in space and time. Rainfed agriculture is predominant and average farm size is small (< 1.2 ha), thus smallholder farms dominate the sector, accounting for about 80 % of total agricultural production. The average food crop farmer has limited contact with the product market and is unlikely to use fertilizers, insecticides or high yielding seed varieties.

The use of irrigation technology is not widespread but considered of great importance in view of the seasonal and incidental occurrence of drought. Traditional farming systems have developed over time as adaptations to the six major agro-ecological zones in Ghana. These agro-ecological zones from north to south are: Sudan Savannah Zone, Guinea Savannah Zone, Transition Zone, Semi-deciduous Forest zone, Rain Forest Zone and the Coastal Savannah Zone.

In the two forest zones, tree crops are significant with cocoa, oil-palm, coffee and rubber being of particular importance. Food crop production is important in all the agro-ecological zones (Asuming-Brempong & Asuming-Boakye, 2008).

Irrigation and world food demand

The present world population of over 7 billion is projected to increase to 9 billion over the next 40 years. Developing countries account for 95% of this growth. Therefore, world food production will need to more than double in the next few decades to feed everyone. To meet this expanding food demand, yields and hectarage must be increased. The potential for expanding food production in the world exists (Luis *et al.*, 1996). Food security in the world is one of the most important goals of our time. One tool to achieve these goals is irrigation. Appropriate irrigation technology has an important role to play in the achievement of this goal.

Irrigated land, about 250 million hectares make up about 17% of the total area cropped worldwide. These areas provide 36% of the world's food production. Almost 75% of the irrigated area is in developing countries. Differences in the level of irrigation technology between these areas and developed countries are due to climatological, historic and socio-economic influences (Field, 1990).

Irrigation scheduling

Irrigation scheduling concerns the farmers decision process concerning "when" to irrigate and "how much" water to apply in order to maximize profit. Knowledge on crop water requirements and yield responses to water, limitations relative to the water supply system and the economic implications of the

irrigation practice are very important in this regard. Irrigation scheduling becomes a very complex decision-making process. In third world countries, only a few farmers can understand and therefore adopt this technology (Pereira & Chaves, 1995).

There exist a large number of tools including procedures to compute crop water requirements by simulating the soil water balance, to estimate the impact of water deficits on yields and to estimate the economic returns of irrigation (Hoffman *et al.*, 1990). Notwithstanding the vast number and variety of tools existing, irrigation scheduling is not yet used by the majority of farmers. In fact, limited irrigation information is utilized worldwide by irrigation system managers, extensionists or farmer advisers.

Todd and Heerman (1988) and Martin *et al.* (1990) defined irrigation scheduling as the science of specifying future irrigation timing and amounts in the implementation of a water management strategy. If the proper amount of water is applied at the most appropriate time, water is not wasted and the crop yield will be optimum. Hillel (1990) stated that soil water dynamics should be well-defined to regulate the water supply to crops. A growing plant must be able to balance the atmospheric demand for water with the amount it can extract from the soil.

Phene *et al.* (1990) stated that irrigation scheduling involves two major decisions- how much water to apply and, when to apply water (frequency). Irrigation timing is usually based on soil water measurements, soil water accounting or various combinations of these methods. Irrigation quantity is usually based on the type of irrigation system, plant responses to water deficit,

plant growth stage, soil infiltration characteristics, salinity control and soil water deficit (Phene *et al.*, 1990).

Water conservation in irrigation scheduling

Water usage increases along with the expansion of agricultural activities. Higher irrigation efficiency is needed due to the competition between agriculture and industry for available water. As crop dry matter production is strongly influenced by available soil moisture, better irrigation is required to obtain the optimum yield (Wesseling & Van den Broeck, 1988). Joshi *et al.* (1995) stated that a water-efficient system is a basic tool for maximizing crop production. Salisu (1989) stated that irrigation scheduling is the technique, which enables an irrigator to know when to irrigate the crop and how much water to apply.

Several methods and techniques are used to predict the date and amount of irrigation water to apply (Heerman *et al.*, 1990). A variety of methods and devices are available for irrigation scheduling. These methods are based on

- soil monitoring
- crop monitoring
- soil water balance computations and
- meteorological methods and finally
- computer simulation approaches.

Crop yields under deficit irrigation

Water is a vital substrate in the photosynthetic process. Crop production as well as plant growth is restricted by water scarcity. If deficit irrigation programmes are in practice throughout the growing season or during a particular

growth period, plants are exposed to specific levels of water stress. This occurs where evapotranspiration demand or crop water requirements are significantly reduced. Close to optimum yields can be obtained under deficit irrigation, providing a specific amount of yield reduction of a given crop with a certain amount of water-saving. The saved water can be used in irrigating other areas or crops. This innovative concept has been given different name such as deficit irrigation, deficient evapotranspiration (ET) or irrigation and limited irrigation (English *et al.*, 1990).

At present deficit irrigation is widely used. Deficit irrigation programmes can allow the increase of irrigated area with a given quantity of water. Under deficiency irrigation practices, irrigated area can thus be increased without applying additional water where crop water use efficiency (WUE) is the highest. If there is a scarcity of water at the regional level, irrigation managers should adopt the same approach to manage their irrigation schemes to sustain regional crop production and the well-being of growers (Kirda & Kanber, 1998). This practice ensures optimum and sustainable agricultural production in a given region as well as maximizes the income of the growers when sources for irrigation water are limited or expensive (Stegman *et al.*, 1980).

Reduction in irrigation water may lead to a decline in crop production; however, the benefits gained by diverting the water saved by deficit irrigation to irrigate other areas or other crops for which water is not sufficient to fill demands under normal irrigation practices frequently outweigh yield losses of the original crop. It should be kept in mind that yield reduction due to plant diseases and pests, improper fertilization of fields and losses during harvest and

storage are much greater than those one might expect under a mild deficit irrigation. Crop quality may increase with proper deficit irrigation practice. It has been observed that protein content and baking quality of wheat (*Triticum aestivum* L.), fibre length and strength of cotton (*Gossypium hirsutum* L.) and sugar concentration of sugar beet (*Beta vulgaris* L.) and grape (*Vitis vinifera* L.) increased under deficit irrigation (Kirda & Kanber, 1998).

Factors affecting tomato irrigation requirements

Tomato water requirements are affected by soil, plant, climatic and management factors. Important soil factors include water intake rate and available water holding capacity of soils with different textures (Treidl, 1979). The water intake is a useful parameter for designing irrigation systems and determining the rate at which water can be applied to the soil without the soil puddling. The available water holding capacity refers to the amount of water held by the soil in the rooting zone between the field capacity and the permanent wilting point. The field capacity is the upper limit of soil water available for plant use. The permanent wilting point is the lower soil water limit below which plants cannot effectively extract water. The water holding capacity of a soil depends largely on its texture. Coarse-textured soils hold less water than fine-textured soils. This means that more frequent irrigation would be required for coarse-textured than fine-textured soils. The available water holding capacity is an important parameter for estimating how often a particular field requires irrigation (Treidl, 1979).

Plant factors include rooting depth, growth stage as affected by soil moisture deficit, and the yield threshold depletion or allowable soil water

depletion. Transplanted tomatoes are a relatively shallow-rooted crop. Although roots may penetrate beyond one (1) m in depth, the greatest concentration of roots is in the upper 30 cm. Water use by irrigated tomatoes varies with the crop development stage. The peak water use periods occur during fruit set and fruit development. Irregular and inadequate water supply during these periods can result in poor fruit set and blossom-end rot. Optimizing both yield and quality is accomplished by matching water application to peak crop water use rate. The yield threshold depletion or allowable soil water depletion is the percentage of available water that can be depleted from the soil before there is an adverse effect on yield and quality of the crop. The allowable soil water depletion value for tomatoes is about 50% (Tan & Fulton, 1980).

Important climatic factors include rainfall, solar radiation, air temperature, wind and relative humidity. The water loss by vegetation and soil during the growing season must be replenished by irrigation or rainfall for optimum crop production. Rainfall usually reduces the irrigation requirements. A gradual gentle rainfall over a long duration will adequately replenish the root zone without irrigation while heavy rains of short duration often causes runoff and deep percolation. Because rainfall is highly variable, measurements should be taken near the fields scheduled for irrigation. Tomato water use depends on solar radiation, temperature, wind and relative humidity. Over a wide range of climatic conditions, the simple product of air temperature times radiation can be used to estimate maximum tomato water use (Tan, 1980).

Good management practices are essential to ensure the greatest returns from irrigation. The grower must plant recommended varieties and plant

populations, provide the proper control of weeds, diseases and insects, and maintain proper fertility levels.

Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well-developed and completely covers the soil, transpiration becomes the main process. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration (Allen *et al.*, 1998).

Measurement of ET

Evapotranspiration is not easy to measure. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. The methods are often expensive, demanding in terms of accuracy of measurement and can only be fully exploited by well-trained research personnel. Although the methods are inappropriate for routine measurements, they remain important for the evaluation of ET estimates obtained by more indirect methods (Allen *et al.*, 1998).

Lysimeters

By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. This is done in lysimeters where the crop grows in isolated tanks filled with either disturbed or undisturbed soil. In precision weighing lysimeters, where the water loss is directly measured by the change of mass, evapotranspiration can be obtained with an accuracy of a few hundredths of a millimetre, and small time periods such as an hour can be considered. In non-weighing lysimeters the evapotranspiration for a given time period is determined by deducting the drainage water, collected at the bottom of the lysimeters, from the total water input (Allen *et al.*, 1998). A requirement of lysimeters is that the vegetation both inside and immediately outside of the lysimeter be perfectly matched (same height and leaf area index). This requirement has historically not been closely adhered to in a majority of lysimeter studies and has resulted in severely erroneous and unrepresentative ETc and Kc data. As lysimeters are difficult and expensive to construct and as their operation and maintenance require special care, their use is limited to specific research purposes (Allen *et al.*, 1998).

ET computed from meteorological data

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data. Some of the methods are only

valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed.

Numerous researchers have analysed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration, ETo. The ET from crop surfaces under standard conditions is determined by crop coefficients (Kc) that relate ETc to ETo (Allen *et al.*, 1998).

Reference Crop Evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ETo values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface (Allen *et al.*, 1998).

The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters (Allen *et al.*, 1998).

Need for a standard ETo method

A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly, and yet evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design. To meet this need, guidelines were developed and published in the FAO Irrigation and Drainage Paper No. 24 'Crop water requirements'. To accommodate users with different data availability, four methods were presented to calculate the reference crop evapotranspiration (ETo): the Blaney-Criddle, radiation, modified Penman and pan evaporation methods. The modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop. It was

expected that the pan method would give acceptable estimates, depending on the location of the pan. The radiation method was suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind speed and air humidity. Finally, the publication proposed the use of the Blaney-Criddle method for areas where available climatic data cover air temperature data only (Allen *et al.*, 1998).

These climatic methods to calculate ETo were all calibrated for ten-day or monthly calculations, not for daily or hourly calculations. The Blaney-Criddle method was recommended for periods of one month or longer. For the pan method it was suggested that calculations should be done for periods of ten days or longer. Users have not always respected these conditions and calculations have often been done on daily time steps (Allen *et al.*, 1998).

Advances in research and the more accurate assessment of crop water use have revealed weaknesses in the methodologies. Numerous researchers analyzed the performance of the four methods for different locations. Although the results of such analyses could have been influenced by site or measurement conditions or by bias in weather data collection, it became evident that the proposed methods do not behave the same way in different locations around the world. Deviations from computed to observed values were often found to exceed ranges indicated by FAO. The modified Penman was frequently found to overestimate ET_o, even by up to 20% for low evaporative conditions. The other FAO recommended equations showed variable adherence to the reference crop evapotranspiration standard of grass (Allen *et al.*, 1998).

To evaluate the performance of these and other estimation procedures under different climatological conditions, a major study was undertaken under the auspices of the Committee on Irrigation Water Requirements of the American Society of Civil Engineers (ASCE). The ASCE study analyzed the performance of 20 different methods, using detailed procedures to assess the validity of the methods compared to a set of carefully screened lysimeter data from 11 locations with variable climatic conditions. The study proved very revealing and showed the widely varying performance of the methods under different climatic conditions. In a parallel study commissioned by the European Community, a consortium of European research institutes evaluated the performance of various evapotranspiration methods using data from different lysimeter studies in Europe.

The studies confirm the overestimation of the modified Penman (Allen *et al.*, 1998) and the variable performance of the different methods depending on their adaptation to local conditions. The comparative studies may be summarized as follows:

- The Penman methods may require local calibration of the wind function to achieve satisfactory results.
- The radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and tends to underestimate evapotranspiration.
- Temperature methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the 1985 Hargreaves' method which has shown reasonable ET_o results with a global validity.

- Pan evapotranspiration methods clearly reflect the shortcomings of predicting crop evapotranspiration from open water evaporation. The methods are susceptible to the microclimatic conditions under which the pans are operating and the rigour of station maintenance. Their performance proves erratic.
- The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies.

The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ET_o. The FAO Penman-Monteith method is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has provision for application in data-short situations (Allen *et al.*, 1998).

FAO Penman-Monteith equation

In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where,

ETo reference evapotranspiration [mm day^{-1}],

R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],

G soil heat flux density [MJ m^{-2} day^{-1}],

T mean daily air temperature at 2 m height [°C],

u_2 wind speed at 2 m height [m s^{-1}],

e_s saturation vapour pressure [kPa],

e_a actual vapour pressure [kPa],

$e_s - e_a$ saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa $°C^{-1}$],

γ psychrometric constant [kPa $°C^{-1}$].

The reference evapotranspiration, ETo, provides a standard to which:

- evapotranspiration at different periods of the year or in other regions can be compared;
- evapotranspiration of other crops can be related.

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. By using the FAO Penman-Monteith definition for ETo, one may calculate crop coefficients at research sites by relating the measured crop evapotranspiration (ET_c) with the calculated ET_o, i.e., Kc = ETc/ETo (Allen *et al.*, 1998). Apart from the site location, the FAO Penman-Monteith equation requires air temperature, humidity, radiation and wind speed data for daily, weekly, ten-day

or monthly calculations. It is important to verify the units in which the weather data are reported. Altitude above sea level (m) and latitude (degrees north or south) of the location should be specified. These data are needed to adjust some weather parameters for the local average value of atmospheric pressure (a function of the site elevation above mean sea level) and to compute extraterrestrial radiation (R_a) and, in some cases, daylight hours (N). Reference crop evapotranspiration (ETo) can be computed using the CROPWAT software or the ETo Calculator.

The Pan Evaporation method

Another method of determining reference crop evapotranspiration (ETo) is the Pan evaporation method. The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There are also differences in turbulence, temperature and humidity of the air immediately above the

respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance (Allen *et al.*, 1998).

Notwithstanding the difference between pan-evaporation and the evapotranspiration of cropped surfaces, the use of pans to predict ET_o for periods of 10 days or longer may be warranted. The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

ETo = Kp Epan

Where,

ETo = reference evapotranspiration [mm/day],

Kp = pan coefficient [-],

Epan = pan evaporation [mm/day].

Crop evapotranspiration (ETc)

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also

includes additional water for leaching of salts and to compensate for non-uniformity of water application (Allen *et al.*, 1998).

Crop evapotranspiration (ETc) can be calculated from climatic data using the reference crop evapotranspiration (ETo) and an experimentally determined crop coefficient (Kc) using the relation, ETc = KcETo.

Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest.

The crop coefficient (Kc)

Every crop has four growth stages best described distinctively by the development status and phenology of the crop. These stages as noted by Norman (1992) are initial, developmental (vegetative), mid-season (reproductive) and late season which have different crop characteristics and length of time that influence the extent of water needed by the crop. Crop coefficients are low early in the season due to small leaf area and hence low water use for photosynthesis and approach unity as the canopy reaches maximum development with corresponding increase in water use (Allen *et al.*, 1998). The relationship between the reference grass crop water requirement and the water requirement of the actually grown is given by the crop factor. Allen *et al.* (1998) reported average Kc values for tomatoes as 0.6, 1.15 and 0.7-0.9 for initial, developmental and late seasons respectively. The crop coefficient (Kc) is affected by a number of factors, which include type of crop, stage of growth of crop and cropping pattern (Allen *et al.*, 1998). This implies that different crops at different growth stages have different Kc values.

The Tomato

Tomato is the second most important vegetable crop next to potato (*Solanum tuberosum* L.) in terms of production. It is a rapidly growing crop with total growing period varying from 90 to 150 days. Tomato can be grown in a wide range of soils but a well-drained sandy loam with pH of 5 to 7 is preferred. Waterlogging leads to incidence of diseases such as bacterial wilt. The ideal population is about 40000 plants/ha and fertilizer requirements for high yielding varieties vary from 100 to 150 kg/ha N, 65 to 110 kg/ha P and 160 to 240 kg/ha K, depending on the soil test. The crop has a fairly deep root system reaching as far as 1.5 m. The maximum rooting depth occurs about 60 days after transplanting resulting in a maximum ET of 5 to 6 mm/day. The plants are adversely affected when more than 40% of the total available soil water has been depleted (Doorenbos & Kassam, 1979).

Growth stages and soil moisture

The tomato needs a controlled supply of water throughout the growing period for optimal quality and higher yield. Imposing deficit irrigation in certain stages in tomato production means a certain amount of water may be saved but tomatoes are very sensitive to water deficits during and immediately after transplanting, at flowering and during fruit development (Doorenbos & Kassam, 1979).

Tomatoes consume water at a lower rate at the beginning of growth and then increase gradually until flowering, after which they reach maximum usage during the peak of fruit ripening. Water consumption remains constant until the onset of ripening after which, it decreases (Rudich & Luchinsky, 1986). The

approximate range of seasonal ET for tomatoes is 300-600 mm. This seasonal value takes into account the crop characteristics, time of planting, and stage of crop development and general climatic conditions (Doorenbos & Pruitt, 1977).

Water requirements of tomatoes

Few reports dealing specifically with tomato water requirements have been found. Miller *et al.* (1998) reported the crop evapotranspiration (ETc) for the semi-arid region of Brazil using a complete water balance approach. Cumulative ETc was found to be in the range of 451- 626 mm as soil water tension increased from 300 - 500 kPa, corresponding to 5.22 and 3.76 mm/day respectively. For an average growing period of 130 days the net total amount of applied irrigation water ranged from about 300 mm to 400 mm for good fruits in central Brazil (Silva & Marouelli, 1996). Doorenbos and Kassam (1979) reported that total water requirement for a tomato grown in the field for 90 to 120 days are 400 - 600 mm. This amount includes the pre-transplanting watering. Depending on the climatic demands, the total water may vary for different locations. The Kc values vary from 0.40 (initial) to 1.25 (mid-season). Karim *et al.* (1996) carried out a field experiment to determine the optimum soil moisture regimes and water requirement for achieving the maximum yield potential of tomato on a clayey terrace in Bangladesh. A maximum yield of 37.0 Mg/ha was obtained when allowing 30% depletion of soil available water (SAW). The total water use and the WUE were found to be 193.6 mm and 1911 kg/ha, respectively. They also concluded that at soil moisture depletions exceeding 40% of SAW, a severe water stress was placed on growing tomatoes,

hence yield was significantly reduced. Qasem and Judah (1985) found that the water applied and its uptake by plants are decreased with increasing soil moisture tension. Crop coefficients increased rapidly to reach a maximum at flowering, after that they declined. They also observed that the greatest stress (50 centibars at a depth of 30 cm) did not adversely affect the crop.

Role of irrigation at different growth stages

Excessive irrigation during the flowering period may cause an increase of flower drop and reduce fruit set as well as delay ripening due to excessive vegetative growth. For preventing stimulation of new growth at the expense of fruit development, water supply during and after fruit set should be limited to certain rate. It must be kept in mind that for a crop grown for paste production, a more extensive irrigation may be applied prior to flowering. But light irrigations improve the size, shape, juiciness and colour of the fruit. But total solids and acid content will be reduced. The fruit quality for processing may be lower due to lower solids in the fruit. The yield formation stage is very sensitive to water and any heterogeneous distribution of irrigation leads to fruit cracking. Highest demand for water is during flowering (Doorenbos & Kassam, 1979).

Helyes *et al.* (1999) conducted an experiment using two tomato varieties to observe the effect of irrigation and environmental factors on yield and found that regular irrigation has a vital role for optimum yield. They found that approximately 55-66% regular irrigation is required but in some years 20-25% irrigation can be effective.

Colla *et al.* (1999) conducted an experiment at three fertilizer levels under drip irrigation treatments. Water deficits were imposed by reducing

irrigation volume by 50% or 75% of ETç (crop evapotranspiration) in two growth periods before or after fruit set. Water deficit in the first growth period led to a decrease in the number of flowers as well as that of fruit number and ultimately to less marketable yield. However, fruit quality in terms of soluble solids and acidity was improved. Rudich *et al.* (1977) reported that the quality of tomato can be improved and water can be saved by using well-managed drip irrigation systems.

Rudich *et al.* (1977) found that irrigation during the period of fruit set and fruit development increased yield by 53 t/ha compared with non irrigated plants. They also observed that irrigation during the fruit development had a favourable influence and had an unfavourable influence on fruit quality characteristics like vitamin C, viscosity, acidity and total soluble solids.

Recommended irrigation scheduling begins irrigation at fruit set in the second and third inflorescences (15 days after the start of flowering in sown tomatoes), and the end of irrigation when about 50% of the fruits were red (Rudich *et al.*, 1979).

Lowengart-Aycicegi *et al.* (1999) conducted a series of trials for these growing seasons in order to observe the optimum timing of the beginning and end of drip irrigation of processing tomatoes and found that delay in beginning of irrigation resulted in a decrease in fresh yield significantly due to decrease in the number of fruits. However, the soluble solids content was unchanged for different cultivars.

Tomato yields and water stress

Karim *et al.* (1996) conducted an experiment for the determination of optimum soil moisture regimes and water requirements for maximum yield potential of tomato on clayey soil. A maximum yield of 37.0 Mg/ha was obtained with total water use of 187.8 mm. A reduction of water depletion from 40% to 30% of SAW did not change tomato yield. But the application of 13.7% greater irrigation water resulted in a 30.7% greater yield. They found that a soil water regime at 40% depletion of SAW produced the highest yield with maximum WUE for tomato. Kalloo (1991) reported that the optimum moisture regime for tomato cultivation ranged from field capacity (FC) to 50% of SAW.

Rudich *et al.* (1977) found that irrigation during the period of fruit set and fruit development increased yields by 53 tons/ha compared to non-irrigated plants. The application of irrigation water during the period of fruit development had a favourable influence on yield as well as on the efficiency of water utilization. However, they also found that irrigation at this stage had an unfavourable effect on fruit quality characteristics, namely, total soluble solids, acidity, viscosity, and Vitamin C. Losada and Rincon (1994) observed that fruit set of tomato was highly sensitive to water stress.

Rahman *et al.* (1999) found that water stress decreased yield, flower number, fruit set percentage and dry matter production in all varieties tested. Photosynthetic rate, transpiration rate, and leaf water potential and WUE were reduced, and leaf temperature and stomatal resistance were increased by water stress in all cultivars.

Tomato quality and water stress

With the consumer's increasing preference for mature and sweet tomato fruit, high sugar content tomato production has increased (Mochizuki *et al.*, 1987). Limitation of irrigation during culture is generally adopted in order to increase the sugar content (Imada *et al.*, 1989).

Adams (1990) conducted an experiment with two tomato crops, grown in bags of peat for 12 weeks after planting which were supplied with 60, 80, 100 and 120% of the water requirement estimated from solar radiation integrals. Restricting water to 60% and 80% of the requirements controlled vegetative vigour but reduced final yield by about 20% and 4% respectively. These decreases were mainly because of a reduction in fruit size rather than number. It was also suggested that watering should be restricted to 80% or less of the estimated requirements in order to achieve a significant improvement in the flavour components of the fruit.

Veit-Kohler *et al.* (1999) investigated whether a small reduction in water supply (without visible symptoms of water stress) results in high fruit quality together with high marketable fruit productions. In the treatment with lower water, plant growth and in particular the number of fruits were decreased and the sugar and vitamin C concentrations of the fruits were significantly increased, especially during fruit ripening. The higher levels of sugars, titratable acids, aroma volatiles and vitamin C were responsible for the higher fruit quality under the lower water supply.

Zushi and Matsuzoe (1998) observed the effects of soil water deficit on vitamin C content (fresh weight) which varied depending on the cultivar. They

found that vitamin C content increased in some cultivars whereas it remained unchanged in others. In almost all cultivars under water-stressed plants, glucose and fructose were found in higher proportions than in plants receiving full irrigation. But, on a dry weight basis there was no difference. This indicates that the soil water deficit merely reduced water accumulation by the fruits. The amount of organic acid and free amino acids both increased on fresh and dry weight basis under water stress. They also reported that enhanced lycopene concentration was observed by applying water stress caused by limited irrigation.

Kubota *et al.* (2006) reported that although the exact biological mechanisms that contribute to enhancement of lycopene concentration under water stress are not known, evidence suggests that ethylene synthesis triggered by water stress could be central to increase in lycopene deposition within the flesh of the tomatoes. Matsuzoe *et al.* (1998) investigated the effects of soil water content on fruit colour and carotene content in cherry tomato cultivars- Mini Carol (red), Cherry Pink (pink), Yellow Carol (yellow), and Orange Carol (yellow-tangerine). They observed that soil water deficit accelerated fruit colouring. Soil water deficit increased the amount of beta carotene in Yellow Carol, but had no effect on the beta-carotene content of Orange Carol.

Franco *et al.* (1999) showed that at higher irrigation levels there was a high yield potential and less blossom-end rot (BER) affected fruit. Naotaka *et al.* (1998) observed the effect of soil water content on fruit colouring and carotene formation using four cherry tomato varieties. It was found that the soil water deficit effect on the fruit colouring was more evident during the full

cropping season than in the spring season and that the amount of B-carotene increased in case of cv. Yellow carol.

Water stress severely affected fruit set as well as significantly decreased the number of red fruits (Losada and Rincon, 1994). May (1993) observed that high water stress caused lower yield, highest soluble solids and poorer viscosity. Chiaranda and Zerbi (1981) conducted an experiment with lysimeter-grown greenhouse tomatoes and observed a remarkable sensitivity of the crop to water stress during the vegetative and the flowering periods, with respect to early and late harvesting records. Shinohara *et al.* (1995) observed that water stress caused decreasing yield but increasing °Brix. Photosynthesis and transpiration were markedly inhibited immediately after the water stress was imposed, but plants gradually recovered under continuous stress treatment. Water stress improved the fruit quality, whereas, it inhibited photosynthesis and transpiration of the plant.

Perniola *et al.* (1994) carried out an experiment to study the influence of different irrigation regimes on different cultivars of tomato. They observed that crop water status was strongly influenced by the water regime and the dry matter accumulation was gradually reduced with the increase of water deficit. Lapushner *et al.* (1986) observed that fruit weight was reduced by water stress but marketable yield, fruit colour and contents of total soluble solids and reducing sugar were improved.

YoungHah *et al.* (1999) found that total and marketable yields were increased by increasing soil water tension and by varying night temperature (14 ± 1°C to 10 ± 1°C). Fruit cracking decreased with increasing soil water tensions.

They also found that total yield was positively correlated to soil water. Soluble solids content, total acidity and citric acid content were higher in cracked fruits than in normal fruits.

Reid *et al.* (1996) carried out an experiment to test whether internal blackening was caused by water deficit. They found that a greater incidence of internal blackening and blossom-end-rot, and lower Ca concentrations, in the fruit of non-irrigated plants than in those of fully irrigated plants. Root growth and root death were accelerated in these plants around the time that internally-blackened fruit were set. They suggested that internal blackening could have resulted from increased root competition for photosynthate, leading to abnormal seed development.

Tomato colour

Reflection of flesh represents the external colour of tomatoes. Different varieties have different pigmentations and the main pigments are B -carotene (yellow) and lycopene (red). The main function for fruit ripeness is tomato colour (Hobson *et al.*, 1983). For consumer, colour is a very important quality estimator. It indicates the suitability of the product for consumption. Several colour charts have been developed for classifying ripeness degree of tomatoes subjectively. US Standards (USDA, 2005) divides tomato ripeness in six categories as described in Table 2.1.

Table 1: Tomato colour classes

Stage	Class	Definition
1.	Green	Completely light to dark green surface
2.	Breaker	Break in colour from green to tannish-yellow, pink, or red colour not more than10 %
3.	Turning	Over 10% but not more than 30% red, pink or tannish-yellow or a combination thereof
4.	Pink	Over 30% but not more than 60% pinkish or red colour
5.	Light-red	Over 60% but not more than 90% red colour
6.	Red	Over 90% of the surface is red in colour

Source: (USDA,2005).

Tomato Flavour

This is another important quality of tomato. Consumer acceptance and repeat sales are dependent on flavour quality. Tomato flavour depends on the scents of different chemical compounds. The level of sugar and acid and their interactions determine the tomato flavour. The more intense flavour is associated with higher levels of those chemicals. The pericarp of tomato fruit contains less organic acids than locules. Hence, cultivars with large locules and with high accumulation of acids and sugars have better flavour than those with small locular portions (Stevens *et al.*, 1977).

Considerable attempts have been made to improve the fruit quality through genetic alteration. For example, attempts have been made to increase fruit solids content to develop the fruit and to change fruit acid content, both of which are important quality parameters. Along with improving colour of

tomato, intensive efforts have been made to develop fruits with firm flesh and tough skin for machine harvesting (Stevens *et al.*, 1977).

Tomato sweetness and sourness

The most pronounced flavour characteristics of tomato are the taste characters, sweetness and sourness (Stevens, 1985). There is some evidence that tomato breeders, in an attempt to improve sweetness, have selected those that have low acidity, and this has resulted in cultivars that lack flavour because the acids are primary determinants of the potency of the flavour (Stevens *et al.*, 1977). It is virtually impossible to develop a high yielding tomato with sweet fruits since, at best, tomato fruits contain less than 5% sugar, and this is far short of the amount required for real sweetness. There have been few attempts to quantify the impact of sugar and acids on tomato flavour. A statistical evaluation of the relationships between composition and flavour characteristics showed that sweetness is very highly correlated to reducing sugar content.

Sourness is very highly related to titratable acidity and pH. The overall flavour intensity of these hybrids is highly related to pH, acid level, and soluble solids content. It was observed that cultivars that have low-sugar and low-acid content are insipid and tasteless. Cultivars that have high-acid content and relatively low sugar content tend to be tart, which some consumers find objectionable. High acids and high sugars promote the desired flavour in the proper balance. Sugar/acid ratio is a much overused term because it is possible to have a desired sugar/acid ratio and still have poor flavour if both sugar and acid levels are low. For quantifying flavour, information on sugar content, acid

content, and the ratio between these components is very essential (Stevens, 1985).

Water stress and physiological response

Leaves are the main providers of carbon for fruit development. Consequently, most studies seeking to relate the effects of different cultivation practices or varying environmental conditions on fruit development have focused on the photosynthetic metabolism of leaves. The tomato plant is no exception to this generalization. Numerous papers published on source/sink interactions between leaves and fruit and their effect on crop yields have studied leaf photosynthetic activity by altering photon flux density, temperature, $C0_2$ concentration, nutrient and water supplies (Ho & Hewitt, 1986).

Hetherington *et al.* (1998) assessed the photosynthetic activities of different chloropnyll containing parts of tomato plants (*Lycopersicon esculentum* Mill. cv Saporo) by using chlorophyll fluorescence techniques. They concluded that the non-leaf green tissues of tomato are quite active photosynthetically and therefore potentially contribute significantly to plant growth.

This plant is very sensitive to salinity during germination and early plant development. Therefore salt, where present, needs to be removed during pre-irrigation or by over-watering during initial irrigation. HuiLian *et al.* (1997) subjected tomatoes to salinity stress (Electrical conductivity 4.5 mS/cm) and a low {55%±8%} on gravimetric basis) soil water contnt to evaluate the effects of salt accumulation and a prolonged substrate water deficit on photosynthesis and plant water relations. Net photosynthetic rate decreased by 24% compared with

the control one day after soil water content was depleted to 55%. The combined treatment of salinity and water deficit imposed an additive negative effect on net photosynthetic rate, leaf water potential and leaf turgor potential, which did not allow net photosynthetic rate to recover despite the osmotic adjustment.

Shinohara *et al.* (1995) evaluated the effects of water stress on the yield, quality, photosynthesis, transpiration, and photosynthate translocation of tomato. Water stress treatments were carried out using tomato cv"Momotaro" plants grown in porous volcanic gravel culture with different amount of solutions supplied. Fruit yield was decreased and photosynthesis and transpiration were markedly inhibited immediately after receiving the water stress, but gradually recovered under continuous stress treatment. Finally, they reported that water stress promoted the photosynthate translocation into fruit and improved the fruit quality, whereas it inhibited the photosynthesis and transpiration.

Samuel and Paliwal (1994) observed that water-stressed plants (tomato cv.PKM-l) showed a drastic reduction in tissue water content compared with controls. The midday water potential of the leaves was reduced from -1.0 MPa to -2.6 MPa as a result of the imposed water stress. Photosynthetic rate and stomatal conductance decreased by 50% as a result of water stress. Transpiration rate decreased and diffusion resistance increased after five days of water stress.

Stomatal response to soil water deficits

The classical view of the response of stomata to water stress is that stomatal aperture is regulated according to the plant water stress. At the cellular

level of the stomatal apparatus, it has been demonstrated that such feedback control does not occur during responses to vapour pressure deficit. The response of stomata may be regarded as a feed forward response, in which a signal from roots under dry soil is continuously transmitted to the leaf so that water loss is reduced before the plant experiences internal water stress (Schulze, 1986).

From very early on it had been proposed that the stress hormone abscisic acid was produced at the root tips and transported to the leaf via the xylem stream. It appears that the root tip in the actual stress sensor, and there is evidence that the root tip experiences a loss in turgor earlier than the root because it is partially disconnected from the main xylem flow. The abscisic acid response was independent of pot size (Zhang *et al.*, 1987).

Carbohydrate changes under water stress

The available reports stated that the content of soluble sugars and other carbohydrates in the leaves of various water stressed plants are altered and may act as a metabolic signal in the response to drought (Akinci & Losel, 2009). However, accumulation or decrease of sugars depending on stress intensity and role of sugar signaling in these processes is not totally clear yet (Chaves & Oliveira, 2004). Among the major effects are those involving carbohydrate metabolism, with the accumulation of sugars and a number of other organic solutes (Kameli, 1990).

Munns *et al.* (1979) and Quick *et al.* (1992) showed that sugars are major contributors to osmotic adjustment in expanding wheat leaves. Moreover, short-term water stress inhibited starch synthesis more strongly than sucrose synthesis, in both ambient CO_2 and in saturating CO_2. Short term water stress

was earlier also reported to stimulate the conversion of starch to sucrose in bean leaves (Fox and Geiger, 1986). The increase of sugar in various plant tissues response to water stress supported the idea of contribution of solutes when the plants were exposed to different stress levels. Studies have shown that soluble sugars accumulate in leaves during water stress (Al-Suhaibani, 1996), and have suggested that these sugars might contribute to osmoregulation (Morgan, 1984), at least under moderate stress.

Quick *et al.* (1992) compared the effect of water stress on the rate of photosynthesis and the partitioning of photosynthate in four different species, including two annuals (*Lupinus albus* L. and *Helianthus annuus* L.), and two woody perennials (*Vitis vinifera* cv. Rosaki and *Eucalyptus globulus* Labill.) and concluded that, when water stress develops under field conditions, there is an alteration in the balance between sucrose synthesis and translocation, which allows many species to maintain or increase the pool of soluble sugars in their leaves. In *Eucalyptus* soluble sugars were low compared to starch and non-watered plants contained higher levels of soluble sugars in their leaves than watered plants, but much less starch. Similarly, leaves of non-watered sunflower plants contained almost twice as much soluble sugar those of watered plants. Levitt (1972) detected a marked increase in reducing sugars, non-reducing sugars, and total carbohydrates, with an approximately equivalent decrease in starch.

Drossopoulos *et al.* (1987) concluded that, in two wheat cultivars, sucrose generally formed the major portion of the ethanol soluble carbohydrates. High concentrations of glucose and fructose were observed in

the stems of the water-stressed plants towards maturation as well as in the ears, immediately after heading. The major differences between cultivars were in the sucrose levels of leaves and roots before heading. There have been reports that water stress leads to a general depletion of soluble sugars and starch in leaves. Hanson and Hitz (1982) and Huber *et al.* (1984) have concluded that water stress has a larger effect on carbon assimilation than on translocation and use of photosynthate. Barlow (1986) showed that much of the sugar accumulation, which began with the first indication of suppression in leaf elongation under water stress in wheat, was due to glucose, fructose and sucrose. The inhibition of germination of *Citrullus lanatus* seeds by water stress was investigated by Botha and Small (1985), who observed a marked effect on carbohydrate metabolism. Smaller changes in glucose content and in the reducing substance content of the control seeds occurred during germination, coinciding with a decrease in sucrose. However, this decrease did not entirely account for the observed increase in glucose content. Fructose decreased in control seeds, over the first 30 hours of incubation, and then increased again, whereas the glucose content of stressed seeds tended to increase throughout the 48 hours incubation period, with fructose remaining fairly constant. On the other hand, Pattanagul and Madore (1999) also reported various sugars depletion in variegated coleus (*Coleus blumei* Benth.).

In the green leaf tissues, the diurnal-light period levels of the raffinose family oligosaccaharides stachyose and raffinose and non – structural carbohydrates (galactinol, sucrose, hexoses and starch) decreased whereas drought had little effect on soluble carbohydrate content in the other part of non

– photosynthetic white leaf tissues. There was no difference in glucose and fructose levels between the wilted (incubated) and turgid bean leaves as well as depletion of starch concentrations was observed in plants of bean exposed to drought stress (Quick *et al.*, 1992).

Protein changes under water stress

Many specified proteins synthesized under water scarcity have been isolated and characterized by researches (Pelah *et al.*, 1997). Under water stress conditions, plants synthesize alcohols, sugars, proline, glycine, betaine and putrescine (Chopra & Sinha, 1998). Dehydrins have been the most observed group among the accumulated proteins in response to loss of water and increased in barley, maize, pea, and *Arabidopsis* and under water stress LEA (late embryogenesis abundant) proteins play important role as protection of plants. Osmotin is also accumulated protein under water stress in several plant species such as tobacco, triplex, tomato and maize (Ramagopal, 1993).

Dasgupta and Bewley (1984) pointed out water stress reduced protein synthesis in all regions of barley leaf. Vartanian *et al.* (1987) mentioned the presence of drought specific proteins in tap root in *Brassica*. A stress episode which inhibits cell division and expansion, and consequently leaf expansion, will also halt protein synthesis, which is also inhibited by osmotic stress imposed on excised plant parts. The direct significance of the inhibition of protein synthesis by stress to growth and leaf expansion is difficult to assess. Hsiao (1970) concluded that inhibition of cell expansion precedes the decline in polysome content and that changes in polysome profile might be caused by cell growth rather than the reverse.

Although water stress may inhibit protein synthesis (Ho and Sachs, 1989) some specific types of proteins and mRNA increase in water stressed plants. For instance, free proline accumulation in response to drought in many plant species tissues is well-documented (Nair *et al.*, 2006). Vartanian *et al.* (1987) mentioned the presence of drought specific proteins in tap root of *Brassica*. The functions of many of these proteins have not been established (Hughes *et al.*, 1989). However, water stress may inhibit the synthesis of different proteins equally whilst inducing the synthesis of a specific stress protein (Dasgupta & Brewly, 1984).

Changes of amino acids and protein have been mentioned in many reports which have stated that water stress caused different responses depending on the level of stress and plant type. For instance, in *Avena* coleoptiles water stress clearly caused a significant reduction in rate of protein synthesis (Dhindsa & Cleland, 1975). Treshow (1970) concluded that water stress inhibited amino acid utilisation and protein synthesis. While amino acid synthesis was not impaired, the cellular protein levels decreased and since utilisation of amino acids was blocked, amino acids accumulated, giving a 10- to 100-fold accumulation of free asparagine. Valine levels increased, and glutamic acid and alanine levels decreased. Barnett and Naylor (1966) found no significant differences in the amino acid and protein metabolism of two varieties of Bermuda grass during water stress and reported that amino acids were continually synthesised during the water stress treatments, but protein synthesis was inhibited and protein content decreased. Similarly, water stress did not change protein content uniformly in the different cultivars of Cucumber and

Cucurbita pepo L., *Cucumis melo* L. (snake cucumber) and *Ecballium elaterium* L. (Akinci, 1997).

Tully and Hanson (1979) found that water stress slightly increased the amino acid to sugar ratio of the exudate, but did not change the amino acid composition very markedly. Several proteins were reduced by stress in maize mesocotyls (Bewley & Larson, 1982).

Lipid changes under water stress

The effects of water stress on lipid composition of the higher plants have been the subject of considerable research. Phospholipids and glycolipids serve as the primary nonprotein components of plant membranes, while triglycerides (fats and oils) are an efficient storage form of reduced carbon, at various developmental stages and particularly in seeds (Taiz & Zeiger, 1991). The functions of membrane proteins are influenced by the lipid bilayer, in which they are either embedded or bound at the surface. For this reason, knowledge of the lipid composition of membranes in plant cells is important. Ideas about the adaptive value of lipid changes induced by environmental conditions are often based upon physical properties of the lipids involved in membrane structure, such as phase separation temperatures and fluidity, which may affect the permeability of bio membranes (Kuiper, 1985). About 70% of the total protein and 80% of the total lipid of leaf tissue are present in chloroplasts. Any changes in chloroplast membranes, therefore, will usually be reflected by corresponding alterations to leaf total lipids (Harwood & Russell, 1984). Lipids, being one of the major components of the membrane, are likely to be affected by water stress.

In plant cell, polar acyl lipids are the main lipids associated with membraneous structures (Bishop, 1983). Glycolipids (GL) are found in chloroplasts membranes (more than 60%) and phospholipids (PL) are thought to be the most important mitochondrial and plasma membrane lipids (Harwood, 1980). Many workers have investigated the effect of different levels of water stress on lipid content and composition in different parts of plants (Navari-Izzo *et al.*, 1993). However, researches concerning plant lipids affected by water stress have often been contradictory because of absence of enough information about the plant water status i.e. description of stress effects (Navari-Izzo & Rascio, 1999). Navari-Izzo *et al.* (1993) pointed out that, since the plasma membrane has a key position in cell biology, understanding membrane function is a major challenge. The selectivity of membranes and their functioning vary with the types and proportions of lipid and protein components.

Investigations on various crop species record a general decrease in phospholipid, glycolipid and linoleic acid contents and an increase in the triacylglycerol of leaf tissues exposed to long periods of water deficits, although the intensity of the stress applied is not always specified (Navari-Izzo *et al.*, 1989). The physical state and composition of the lipid bilayer, in which enzymic proteins are embedded, influence both structural and functional properties of membranes. Enzyme activity and transport capacity are affected by the composition and phase properties of the membrane lipids (Wilson *et al.* 1987) observed that water deficit caused a significant decline in the relative degree of acylunsaturation (i.e. fatty acid-unsaturation) in phospholipids and glycolipids in two different drought tolerant cotton plants. Pham Thi *et al.* (1987) pointed

out that changes in oleic and linoleic acid during water stress resulted in desaturation changes in one drought sensitive and another more resistant cotton variety and showed that water stress markedly inhibited the incorporation of the precursors into the leaf lipids.

Navari-Izzo *et al.* (1993) found that, in plasma membranes isolated from sunflower seedlings grown under water stress, there was a reduction of about 24% and 31% in total lipids and phospholipids, respectively, and also significant decreases in glycolipids and diacylglycerols. There was no change in free fatty acids, but triacylglycerols and free sterols increased. However, diacylglycerol, triacylglycerol and glycolipid content increased in soybean seedling shoots under water stress (Navari-Izzo *et al.*, 1990). On the other hand, total lipid content of leaves tended to decrease in two cucumber cultivars as well as *C. pepo* and *Ecballium* in severe stress (Akinci, 1997). The researches indicated that phospholipids in plant tissues under long time drought have been decreased in various crop species (Quartacci & Navari-Izzo, 1992).

Navari-Izzo *et al.* (1989) studying responses of maize seedling to field water deficits, found that the diacylglycerol, free fatty acid and polar lipid contents decrease significantly with stress. In the latter class, the dryland conditions induced a decrease of more than 50% in phospholipid levels, whereas they did not cause any change in glycolipid levels; and triacylglycerols increased by about 30% over the control.

Pham Thi *et al.* (1982) investigated the effect of water stress on the lipid composition of cotton leaves. The most striking effects were a decrease of total fatty-acids, due especially to a decrease of trans-hexadecenoic acid. The fatty

acid composition of all acyl lipids changed during stress in the direction of increased saturation of the fatty acids. This increased saturation remained even after 10 days of recovery growth under non-stressed conditions. Pham Thi *et al.* (1985) pointed out that water deficits inhibit fatty acid desaturation, resulting in a sharp decrease of linoleic and linolenic acid biosynthesis. The decrease in unsaturated fatty acid biosynthesis occurs in all lipid classes, but is greatest in the galactolipid fractions. Wilson *et al.* (1987) similarly observed that water deficit caused a significant decline in the relative degree of acylunsaturation (i.e. fatty acid -unsaturation) in phospholipids and glycolipids in two different drought tolerant cotton plants (Navari-Izzo *et al.*, 1993).

Douglas and Paleg (1981) noted that the fatty acids of triglycerides, of maize seedling were quite responsive to stress and in half of the comparisons were found to differ significantly. Stem triglycerides, in general, responded, whereas the major triglyceride change in the leaf was an increase in linolenic, which is essentially absent from this fraction in stems and roots. Kameli (1990) observed that total leaf phospholipids content and, especially, phosphatidylcholine increased, rose in stressed plants of a relatively water stress resistant cultivar of wheat but did not change significantly in another, less tolerant cultivar.

Tomato requires at least twelve nutrients, also called "essential elements", for normal growth and reproduction. These are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum

(Mo). Without these nutrients, tomato cannot grow properly or bear fruits (Winsor, 1973).

Reduction in photosynthetic activity and increases in leaf senescence are symptomatic of water stress and adversely affect crop growth. Other effects of water stress include a reduction in nutrient uptake, reduced cell growth and enlargement, leaf expansion, assimilation, translocation and transpiration. Water and nutrient availability is one of suboptimal phenomenon like most of the natural environments occur continuously, with respect to one or more environmental parameters.

Table 2: Food nutrient composition of tomatoes

Nutrient	Concentration
Water (%)	93.5 – 94.5
Ash (%)	0.5 – 0.8
Protein (%)	1.0 – 1.1
Fat (%)	0.1 – 0.2
Fibre (%)	0.5 – 0.7
Total carbohydrate (%)	4.7
Food energy (cal)	22.0

Source: (USDA, 2005)

Water stress and nutrient uptake

Soils are important natural source for plant growth where the plants are anchored. However, millions of hectares of land are becoming unproductive and affecting plant growth every year. The nutrient uptake of crop plants is greatly influenced by the overuse of the land in agricultural activities, climate change, precipitation regimes, root morphology, soil properties, quantity and quality of

fertilizers and amount of irrigation (Alam, 1999). The root structures such as root extension rate and length, the means of root radius and root hair density affect the quantity of nutrient uptake by a plant. Nutrient elements availability plays vital role for plant growth. Nevertheless these physiological factors in nutrient, in soil, in plant or at the root absorption sites may interact as well as antagonistically and synergistically of the plants (Sadiq *et al.*, 1997). Many nutrient elements are actively taken up by plants. However, the capacity of plant roots to absorb water and nutrients generally decreases in water stressed plants, presumably because of a decline in the nutrient element demand (Alam, 1999). It is well-documented that essential plant nutrients are known to regulate plant metabolism even if the plants are exposed to drought by acting as cofactor or enzymes activators (Nicholas, 1975). It is rather difficult to identify the effects of water stress on mineral uptake and accumulation in plant organs.

Many workers have reported different effects of water stress on nutrient concentrations of different plant species and genotypes, and most studies have reported that mineral uptake can decrease when water stress intensity is increased (Singh & Singh, 2004). For instance, nitrogen uptake decreased in soybean plants under water stress conditions (Tanguilig *et al.*, 1987) and nitrogen deficiency causes cotton plants to be sensitive to stress with a higher water stress (Singh & Gupta, 1993) and decrease of nutrient presumably because of a decline in the nutrient element demand since the reduced root-absorbing power or capacity absorb water and nutrients generally declines accompanied to decrease in transpiration rates and impaired active transport and membrane permeability of crop plants (Levitt, 1980).

Water stress generally favoured increases in nitrogen, K^+, Ca^{2+}, Mg^{2+}, Na^+, and Cl^- but decreases in phosphorus and iron (Abdel *et al.*, 1971). Although many reports stated that water stress mostly causes reduction in uptake of nutrients (Levitt, 1980), for instance phosphorus, K^+, Mg^{2+}, Ca^{2+} in some crops (Abdalla & El-Khoshiban, 2007), Ca^{2+}, Fe^{3+}, Mg^{2+}, nitrogen and phosphorus and potassium in *Spartina alterniflora* (Brown *et al.*, 2006); Fe^{3+}, Zn^{2+} and Cu^{2+} in sweet corn (Oktem, 2008); Fe^{3+}, K^+ and Cu^{2+} in *Dalbergia sissoo* leaves, Gerakis *et al.* (1975) and Kidambi *et al.* (1990) stated that nutrient elements increased in forage plant species and alfalfa and soinfoin (*Onobrychis viciifolia* Scop.) respectively. An increase in some specific elements such as K^+ and Ca^{2+} were reported in maize (Tanguilig *et al.*, 1987), and K+ in drought tolerant wheat varieties (Sinha, 1978), and in leaves of *Dalbergia sissoo* nitrogen, phosphorus, Ca^{2+}, Mg^{2+}, Zn^{2+} and Mn^{2+} increased with increasing water stress (Singh and Singh, 2004). According to Nahar and Gretzmacher (2002), the uptake of potassium by tomato plant was significantly reduced by water stress.

Under water stress, the uptake of K^+ and Ca^{2+} by maize plants increased (Tanguilig *et al.*, 1987). The relative amounts of K^+, Ca^{2+}, and Mg^{2+} increased considerably more in barley than in rye when water stresses were imposed (Nambiar, 1977). Potassium contributes to osmotic adjustment as one of the primary osmotic substances in many plant species (Ashraf *et al.*, 2001) and under water stress conditions, K^+ application is beneficial for plant survival with improved plant growth (Umar, 2002). There are a few reports indicating that water stress favoured increases in K^+ (Abdel *et al.*, 1971) in plants such as

maize (Tanguilig *et al.*, 1987), drought-tolerant wheat varieties (Sinha, 1978), creeping bentgrass (Saneoka *et al.*, 2004) and *Ammopiptanthus mongolicus* (evergreen xerophyte shrub) (Xu *et al.*, 2002). Contrary to reports stating that water stress generally favoured increases in Ca^{2+}, Dogan and Akinci, (2011) stated that water stress can cause Ca^{2+} reduction in bell pepper, and suggested antagonistic affects of Zn^{2+} and Mn^{2+} on Ca^{2+} uptake. In moderate and severe stressed leaves of bean (*Phaseolus vulgaris* L.) Ca^{2+} content was lower than the amount of potassium with a Ca/K ratio of 0.12, 0.15 and 0.16 in the control, and in both stress levels (Dogan and Akinci, 2011). The reason for total Ca^{2+} content being lower than K^+ was considered to be directly related to antagonistic effects of Ca^{2+} on K^+ (Mathers, 2002). According to Kuchenbuch *et al.* (1986), a reduction in leaf area of onion plants can be explained by declining amount of K^+ caused by decreasing water content in the soil.

Unlike previous reports which have stated that water stress causes a reduction in nutrients uptake (Abdalla & El-Khoshiban, 2007) as well as Mn^{2+} (Nambiar, 1977), Mn^{2+} content in bean leaves tended to increase with increased water stress levels (Dogan & Akinci, 2011). Nambiar (1977) pointed out that drying the upper layer of a siliceous soil profile strongly reduced the absorption of Mn^{2+} by rye grass, but Cu^{2+} and Zn^{2+} uptake were not relatively affected. For several grassland plants, total nutrients generally decreased with increasing water stress (Gerakis *et al.*, 1975). It is generally accepted that the uptake of phosphorus by crop plants is reduced in dry soil conditions (Pinkerton & Simpson, 1986). The studies carried out before the mid 1950s, 12 of the 21 papers reported that P concentration decreased, and 9 papers stated that P status

was not changed in plants (Gerakis *et al.*, 1975). Although Fawcett and Quirk (1962) reported that only severe water stress reduced plant phosphorus absorption, Nuttall (1976), stated that increased soil moisture resulted in increased phosphorus but decreased sulphur in alfalfa. It is believed that, P uptake by plants increased with increased P levels in the soil ignoring water stress. Olsen *et al.* (1961) highlighted that the correlations among the soil P levels and monovalent phosphate uptake by plant and magnitude of water stress. In alfalfa (*Medicago sativa* L.) P and that of Ca^{2+}, Mg^{2+}, and Zn^{2+} in alfalfa and soinfoin (*Onobrychis viciifolia* Scop.) increased with decreased soil moisture supply (Kidambi *et al.*, 1990).

On the other hand, there was no effect on moisture stress on the concentrations of N, P and K (Gomez-Beltranno, 1982). Magnesium has an inverse relationship with calcium, phosphorus, iron, manganese and potassium with Ca^{2+} and Mg^{2+} having antagonistic effects on Mn^{2+} of a complex nature (Kabata-Pendias & Pendias, 2001). Although some studies have found that Mg^{2+} absorption is increased by water stress in many crops (Gerakis *et al.*, 1975), in bean leaves Mg^{2+} content decreased by 18% and 45% respectively in two increased water stress levels (Dogan & Akinci, 2011) . In particular, the presence of Ca^{2+} is of great importance since zinc absorption is closely related with nutrient concentrations, with Zn^{2+} solubility and availability negatively correlated with Ca^{2+} saturation in soils (Kabata-Pendias & Pendias, 2001). Dogan and Akıncı (2011) stated that Zn^{2+} supply is expected to decrease the uptake of most nutrients, K^{+} and Mg2+ suppressed, while Ca^{2+}, Fe^{3+} only slightly decreased in bean leaves.

According to Singh and Singh (2004), availability of soil nutrients decreases with increasing soil drying, with K^+, Ca^{2+}, Mg^{2+}, Zn^{2+}, Fe^{3+} and Mn^{2+} decreasing by 24%, 6%, 12%, 15%, 25% and 18%, respectively. Nambiar (1977) pointed out that drying the upper layer of a siliceous soil profile strongly reduced the absorption of Mn^{2+} by rye grass, but Cu^{2+} and Zn^{2+} uptake were not relatively affected. In herbage plants, the uptake and solubility of nutrient elements depressed but Ca/K and Ca/P ratios increased under water stress conditions. In dried soil, older roots lost their ability to function and nutrients are absorbed by the more active root tips. Most of the studies revealed that water stress restricted uptake of nutrient elements by crops, active transport systems were impaired or destroyed by severe water stress while the presence of various ions responded differently in growth conditions.

Postharvest storage and shelf life of tomatoes

Tomato is one of the most widely used food crops in the world (Chapagain & Wiesman, 2004). In Ghana, tomato plants are grown in almost every home garden as well as in commercial operations. Tomato fruits still live and respire after harvesting. However, their quality and appearance change during post-harvest handling. Tomato fruit has a relatively reduced post-harvest life since many processes affecting quality loss take place after harvesting. The major limiting factors in the storage of tomato fruit are transpiration, fungal infection, acceleration of the ripening process and senescence. Under ambient temperature, tomato ripens rapidly and becomes unmarketable in a short period. Since the production of ethylene accelerates the above-mentioned biochemical and physiological changes that occur during ripening leading to senescence, any

tool that prevents ethylene biosynthesis and/or action would delay the quality losses and in turn increase the post-harvest shelf life (Moneruzzaman *et al.*, 2009).

Shelf life is defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions. A number of chemical and physical processes take place in vegetables during postharvest storage. The quality of most fruits and vegetables is affected by water loss during storage, which depends on the temperature and relative humidity conditions (Perez *et al.*, 2003). Hardenburg *et al.* (1986) reported that storage under low temperature has been considered the most efficient method to maintain quality of most fruits and vegetables due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence and rot development.

The effect of storage on physiochemical quality and quantity changes in tomatoes varies with cultivar, exposition time and harvesting conditions. Tomato can be stored at ambient temperature for a period of up to 7 days. However, careful handling of fruits during their storage is essential to avoid bruises and injuries. Decay organisms enter through such breaks in the skin. Estimation in developing countries indicates that nearly 30-40% of harvested tomato can potentially be lost through spoilage (Akamine, 1970). Apart from physical quality, serious losses also occur in the essential nutrients, vitamins and minerals. Improper harvesting time (maturity), ripening conditions and lack of suitable storage facilities cause a glut during the peak harvesting period and a

large portion of yield is sold very cheaply. Therefore reduction of post harvest losses is so important to recover part of the grower's costs.

During the ripening of tomato fruit, a softening process occurs on account of the activity of several enzymes that alter the structural components of the cell wall and diminish cell adhesion. The main enzymes responsible for tomato softening are polygalacturonase, pectin-methyl-esterase, endo-β mannase, α- and β-galactosidases and β-glucanases (Carraril & Fernie, 2006). The activities of these enzymes cause softening of the whole fruit by degrading some components of the cell wall and decreasing the adhesion of the mesocarpic cells. In addition, not only the adhesion of mesocarpparenchymatic cells but also the epidermis and cuticle are important structural components for the integrity of the tomato fruit, and their role in the softening process has been reported (Bargel & Neinhuis, 2005).

However, apart from the storage environment (temperature and humidity) and fungal or pest infestation, the shelf life of tomatoes can also be linked to cultivation practices such as irrigation and methods of harvesting. Several studies have been conducted on the effects of temperature, humidity, postharvest treatment and packaging on the physicochemical, nutritional and antioxidant composition of tomato. However, no such study has been reported on the effect of deficit irrigation on the postharvest life of tomatoes. Hence one of the objectives of this study was to evaluate the effect of deficit irrigation on the physicochemical, nutritional and antioxidant composition of tomatoes during storage.

The shelf life of tomatoes is the period of time which starts from harvesting and extends up to the start of rotting of fruits (Mondal, 2000). The storage life of tomatoes depends on the maturity stage at which they were picked. Ideally, mature green tomatoes should be stored for 7-10 days at 13-18°C with 85%-90% relative humidity to ripen properly. Under excessive irrigation the stem base of tomato can be affected by *Phytophtora capsici* (Grubben & Denton, 2004).

When the weather suddenly warms up and moisture changes quickly or during dry weather and then heavy rains, there is a likelihood of growth cracks on the tomato fruit. This can be circular cracks around the stem end or lines that spread out of the stem and cracks on the mature fruit which will expose the fruit to microbial attack thus reducing its shelf life. The shelf life of vegetables can be related to some inherent biochemical activities after harvest. According to Sanchez-Mata *et al.* (2003), respiration in fruits result in an increased temperature and hence accelerates metabolic processes and decay phenomena. The quality of most fruits and vegetables is affected by water loss during storage, which depends on the temperature and relative humidity conditions (Perez *et al.*, 2003).

CHAPTER THREE

EFFECT OF DEFICIT IRRIGATION ON PERFORMANCE OF TOMATO

Introduction

The awareness of the growing impact of environmental stress has led to worldwide efforts in adapting agricultural production to adverse environmental conditions, focusing on mitigating quantitative yield losses (Godfray *et al.*, 2010). Far less attention has been devoted to the impact of abiotic environmental stresses on crop quality (Wang & Frei, 2011).

Organisms need to adapt themselves to changes in fluctuating environmental conditions. Plants, since they are not able to escape from adverse environmental conditions, have to rely entirely on their developmental plasticity to survive (Krouk *et al.*, 2011). These adaptations include the responses to temperature fluctuations, water and nutrient imbalance, UV radiation, pathogens and insects, among other biotic and abiotic stresses. Plant growth regulators (phytohormones), compounds derived from plant biosynthetic pathways, mediate these responses by acting either at the site of synthesis or following their transport, elsewhere in the plant. Collectively, plant hormones regulate every aspect of plant growth, development and the responses of plants to biotic and abiotic stresses (Peleg and Blumwald, 2011). Classical phytohormones are abscisic acid (ABA), ethylene, cytokinin (CK), auxin, gibberellin, jasmonate, as well as brassinosteroids, salicylic acid, nitric oxide, and strigolactone, and it is likely that additional growth regulators are yet to be discovered (Santner &

Estelle, 2009). ABA synthesis is one of the fastest responses of plants to water stress, triggering ABA-inducible gene expression and causing stomatal closure, thereby reducing water loss via transpiration and eventually restricting cellular growth (Wilkinson & Davies, 2010). Many ABA-mediated physiological processes induced by water deficit, including closure of the stomata and acceleration of leaf senescence, are counteracted by CKs which increase stomatal aperture and delay ABA-induced stomatal closure. It has been suggested that in longer-term responses to stress, hormones such as ABA and CK may function to regulate the production, metabolism and distribution of metabolites essential for stress survival and recovery (Pospíšilová & Dodd, 2005).

In general, wherever plants grow, they are subjected to stresses, which tend to restrict their development and survival. Moisture limitation can affect almost every plant process, from membrane conformation, chloroplast organization and enzyme activity, at a cellular level, to growth and yield reduction in the whole plant and increased susceptibility to other stresses (Pospíšilová & Dodd, 2005). Reduction in photosynthetic activity and increases in leaf senescence are symptomatic of water stress and adversely affect crop growth. Other effects of water stress include a reduction in nutrient uptake, reduced cell growth and enlargement, leaf expansion, assimilation, translocation and transpiration.

The tomato plant is known to grow well under environments with distinct dry and wet seasons and also does well under irrigation during the dry season, a time where there is minimum case of insect, fungi and other diseases

(Yayock *et al.*, 1988). The seasonal water requirement for tomato is 450 – 600mm (Schwab *et al.*, 1993). Silva and Maroucelli (1996) also reported a seasonal water requirement of 300 – 400mm for certain tomato varieties. Tindal (1965) found out that production of tomatoes experiences high yields during the dry season with irrigation than during extended periods of rainfall and wet conditions, usually characterized by high incidence of diseases. This could explain why tomato production is greater in the northern regions of Ghana than the south. Moreover, the low night temperatures often dropping to 15-20°C or less in this region is a condition favourable for flower survival and fruit setting (Norman, 1992).

In Ghana, there has been the establishment of many commercial irrigation projects especially up north. An example is the Tono irrigation project at Navrongo. Water, however, has not been as available as in the past, making the regulating agencies managing those irrigation schemes impose compulsory cut-backs in their discharge and water pumping in order to economize the scheme's limited water resources. This leaves the tomato farmers using irrigation with no option than cut down the amount of water supplied to the crops. Low moisture in the soil may, however, lead to problems of reduced growth rates, metabolic activities, development and yield of crops. Low soil moisture could also result in total loss of a farmer's whole crop or make the crop vulnerable to both biotic and abiotic complications (Owusu-Sekyere & Dadzie, 2009). In other parts of Ghana where there is almost free water and always available water sources, irrigators may not measure the amount of water applied to their crops. Therefore over watering could commonly occur and that

could lead to leaching of plant nutrients, saturation of the soil to create anaerobic conditions which can result in root damage, reduced root respiration, and lime hydrolysis as well as denitrification of nitrate fertilizers. It is therefore important to consider measuring the amount of water applied to crops like tomatoes which have an extensive shallow root system and is susceptible to water logging. Also, since climatic conditions differ from region to region, it is important to consider the climatic conditions or data for any particular agro-ecological zone in order to determine the crop coefficient for use in calculating the amount of water to be applied for a particular crop in that zone.

The aim of this study was to assess the effect of the application of less than required amount of water to the tomato plant on the growth, development and yield of tomato fruits. The specific objectives were to:

1. determine the crop coefficient (Kc) for the various growth stages of the tomato plant under different water applications (100% ETc, 90% ETc, 80% ETc and 70% ETc) for the Coastal Savannah agro ecological zone of Ghana.
2. determine the amount of water saved and water use efficiency (WUE) for all the different water applications.
3. determine growth parameters such as plant height, leaf area canopy diameter and leaf area index for the tomato plants grown under the different water applications.
4. determine plant yield parameters such as number, size (diameter), weight, yield per hectare and fruit yield reductions of the tomato fruits for all the different water applications

Material and methods

Study area

The study area was the School of Agriculture Teaching and Research Farm at the University of Cape Coast, Cape Coast. The vegetation is that of the coastal thicket and shrub type. The soil type is classified as sandy-clay loam of the Benya series, which is a member of the Edina Benya Udu compound association (Asamoah, 1973). The study area experiences one major rainy season from May to July and a minor rainy season that starts around September and usually ends around mid November to give way to the dry Harmattan season that runs through the end of March the following year. The annual rainfall is between 650 and 1100 mm (Owusu-Sekyere *et al.*, 2012).

Experimental Design

The Complete Randomized Design (CRD) was used. The experiment was carried out using 60 plastic buckets (35 cm high and 34 cm diameter) filled with sandy loam containing some organic manure to 28 kg. The plastic buckets containing the transplants were placed under a rain shelter (Plates 1-3 Appendix 6). The entire experiment was conducted from July to October 2013. The plastic buckets were arranged randomly in plots of ten making a total of 6 plots.

Treatments

There were four different water applications;100% of crop water application (ETc), 90% of crop water application (ETc), 80% of crop water application (ETc) and 70% of crop water application (ETc) as treatments respectively with 100% as the control and three replications for each treatment.

Each replicate consisted of five transplants randomly arranged under the rain shelter.

Nursing and transplanting of seedlings

Seeds of the Pectomech variety of tomato (the widely cultivated variety in Ghana) (Robinson & Kolavalli, 2010) were purchased from a recognized seed seller in Cape Coast and were nursed on July 9, 2013 on a seed bed measuring 1.5 m x 1 m prepared from a sandy loam soil. The beds were mulched with dry grass and watered at 2 days' intervals until germination. The seedlings were transplanted after 25 days on August 3, 2013 into labelled buckets filled with sandy loam soil. The plants were subjected to equal level of water application for one week to ensure uniform recovery by each plant after which treatment was imposed. Weeds were by hand removed as soon as they appeared.

Irrigation

A two-day interval irrigation regime was adopted. Irrigation days amounted to 40 days out of the 80 days of growing period excluding nursing and plant establishment. The water used for irrigation was treated tap water from the Cape Coast water treatment plant.

Data collection

Crop water requirement (Crop evapotranspiration) (ETc)

The amount of water to be applied each two-day interval was derived from the computed loss in weight of each set up (buckets) over the two days. The equivalent in volume basis was found and applied to the plants as the

various treatments demanded. ETc for a growth stage is equal to the summation of ETc for the number of irrigation days.

Reference evapotranspiration (ETo)

Daily ETo was calculated using ETo Calculator Version 3.2 based on the Penman-Monteith equation from daily climatic data. Accumulated ETo was then calculated for each growth stage.

Climatic data

Daily climatic data during the entire period of the study was collected from the University of Cape Coast weather station close to the experimental site (within the agro ecological zone). The data collected were: Maximun and minimum temperatures (°C), maximum and minimum relative humidity (%), sunshine (hours), and wind speed (m/s).

Calculation of crop coefficient (Kc)

1. $ETc = ETo \times Kc$ (FAO, 1998)
2. $Kc = \frac{ETc}{ETo}$

Where ETo = Reference evapotranspiration (mm/day) and

ETc = Crop evapotranspiration.

Determination of water use efficiency, water saving and fruit yield reduction

Water use efficiency (WUE) (kgm^{-3}) is the ratio of the total fruit yield ($kgha^{-1}$) to the total water applied (m^3ha^{-1}) for each treatment (Kirda *et al.*, 2004).

Water saving = 100 – (water use of 70%, 80%, 90% (as the case may be)/ 100% x 100).

Fruit yield reduction = 100 – (fruit yield of 70%, 80%, 90% (as the case may be) /100 x 100)

Where 100% is the full irrigation water requirement (control treatment) (Ismail, 2010).

Growth and yield data

Data were collected on plant height (PH), leaf area (LA), leaf canopy diameter (LCD), leaf area index (LAI), number of fruits per plant, fruit weight and fruit yield. PH, LA, LCD and LAI were recorded at 19, 43, 69 and 85 days after transplanting (DAT) representing the initial, developmental, mid season and late season stages respectively. Each of the parameters was measured as indicated below:

The height of each plant was measured from the base of the plant to the apex with a tape measure.

The longest part along the petiole line of the leaf and the widest breadth across the leaf were measured as the length and breadth respectively of the leaf by using a 30 cm rule. The leaf area was calculated according to the formula of Van der Varst and Postel described in Lei *et al.* (2009). LA = 0.25(L x W) / (1 – 1.48L x W), where L is the length (cm) and W the leaf width (cm).

Three plants of each treatment were selected randomly to measure the leaf area.

The canopy diameter of three selected plants for the measurement of the leaf areas were measured by covering the whole leaves with thin flexible

polythene and the diameter of the area covered by the polythene measured with a measuring tape.

The leaf area index was calculated as a ratio of the total area of all leaves on the plant to the area of ground covered by plant.

The number of fruits per treatment was determined by counting the number of harvested fruits on each plant for each treatment and the mean number of fruits determined.

The fruit size per plant was determined from the number of fruits harvested per treatment. Vernier caliper was used to transversely measure the length across the fruits.

The number of fruits produced by each plant for each treatment was weighed by the use of an electronic balance. These was then summed up and divided by the number of plants to get the mean.

Fruits harvested were weighed and records kept for each treatment and at the end of the harvest, total fruit yield for each treatment were summed up and converted to yield per hectare.

Soil analysis data

The soil before use was thoroughly mixed and samples taken for analysis for texture, organic matter, nitrogen, phosphorus, potassium and calcium contents. After harvest, soil samples were taken from each bucket, thoroughly mixed and also analyzed for nitrogen, phosphorus, potassium and calcium and organic matter contents following standard procedures.

Data Analysis

Results from the study were analyzed using SPSS (Statistical Package for Social Sciences Version 20). Descriptive statistics such as mean and standard deviation were also calculated. One way Independent Analysis of Variance (ANOVA) were conducted to measure the effect of the different types of irrigation treatment on the various parameters measured. The alpha value was set at $p=0.05$, thus significant differences existed when $p<0.05$. Tukey HSD multiple comparison was also performed to indicate where the difference exist at $p<0.05$. The results of the analysis were presented using bar graphs and tables. Simple regression and correlation were conducted to ascertain the relationship between the fruit yield components and the amount of water applied.

Results and discussion

Growth stages

Four growth stages were observed. These stages were determined by the amount of water required by the plant. They were:

1. The initial stage which was recorded 19 days after transplanting (DAT) lasted for 11 days (August 12 – August 22, 2013)
2. The developmental stage which was recorded 43 days after transplanting (DAT) lasted for 24 days (August 23 – September 15, 2013)
3. The mid-season stage which was recorded 69 days after transplanting (DAT) lasted for 27 days (September 15 – October 11, 2013).
4. The late season stage which was recorded 85 days after transplanting lasted for 16 days (October 12 – October 27, 2013).

Effect of deficit irrigation on plant water use

Growth period, ETo, ETc and Kc for all growth stages

The results for the growth period, the reference crop evapotranspiration (ETo), crop evapotranspiration (ETc) and crop coefficient (Kc), at the various growth stages for the different water applications are shown on Table 3.

From Table 3, the Kc value for the non- stressed (100% ETc) tomato grown in the coastal savannah zone of Ghana was found to be between 0.44-1.49. This was in agreement with the Kc value of 0.62– 1.61 reported by Owusu-Sekyere *et al.* (2012) for the same agro-ecological zone. However, this was not in agreement with the maximum Kc of 1.15 reported by Allen *et al.* (1998).

The difference may be attributed to the shorter growth period used for this study, environmental conditions and variety. According to Pereira (1998), environmental factors such as temperature, solar radiation, wind speed and relative humidity prevailing in the experimental site has influence on the crop water need of a plant. The highest Kc value was recorded at mid-season stage. This is because the mid-season stage was characterized by flowering and fruiting which required more water. This same trend was reported by Sam-Amoah *et al.* (2013) for pepper.

After the experiment, 300.4 mm was recorded as the water requirement for the 79 days growing period after transplanting. This is in agreement with 303.0 mm reported by Owusu-Sekyere *et al.* (2012) for tomato. It also falls within the range of 300 - 400 mm reported by Silva and Maroucelli (1996). The

range takes into account crop characteristics, time of planting and general climatic conditions of the area (Doorenbos & Pruitt, 1997).

Table 3: Growth period, ETo, ETc and Kc at various growth stages

Growth Stage	Period (days)	Treatment								
			100%		**90%**		**80%**		**70%**	
		ETo (mm)	ETc (mm)	Kc	ETc (mm)	Kc	ETc (mm)	Kc	ETc (mm)	Kc
Initial	11	38.6	16.98	0.44	15.44	0.40	13.51	0.35	14.67	0.38
Dev'tal	24	80.5	61.99	0.77	59.57	0.74	75.67	0.94	61.18	0.76
MSeason	27	94.5	140.81	1.49	114.35	1.21	97.34	1.03	86.94	0.92
LSeason	16	70.7	80.6	1.14	69.29	0.98	59.39	0.84	50.2	0.71
Sum	78		300.38		258.65		245.91		212.99	

Effect of deficit irrigation on plant growth components

The result of the plant height for the various growth stages is shown in Table 4.

Water is essential for plant growth. Plants may grow by cell expansion after the cell goes through division to increase the number and size of cell. Cells grow by taking up water. The tomato plants treated with 100% ETc had the highest mean height for all the growth stages followed by 90%, 80% and 70% ETc (Table 4). The irrigation water applied was used to the advantage of the plants that were fully irrigated. This is in agreement with Allen *et al.* (1998) that plants grow rapidly with increase in crop water use. Also as water used by

plants is optimum, growth is rapid since the plants will have enough water to be transpired by leaves to increase leaf area, plant height and root development.

Table 4: Mean (±SE) plant height (cm) for the various growth stages as affected by different water treatments

	Growth stages			
Treatment	Initial (19 DAT)	Developmental (43 DAT)	Mid-Season (69 DAT)	Late Season (87 DAT)
100%	23.90±2.01 [a]	52.20±1.11 [a]	60.73±0.50 [a]	62.13±1.19 [a]
90%	21.47±1.22 [a]	52.20±3.61 [a]	59.80±1.97 [a]	60.93±3.09 [a]
80%	21.10±1.89 [a]	46.00±4.97 [a]	58.90±4.06 [a]	60.80±1.71 [a]
70%	19.10±2.35 [a]	43.33±7.61 [a]	57.60±3.12 [a]	59.43±3.46 [a]
L.s.d.	0.086	0.118	0.576	0.652

Mean values along each column with similar or same superscripts are not significantly different at L.s.d.=p >0.05

Available water, when less than the crop water requirement would make the plant reduce its rate of metabolic activities such as photosynthesis (Kramer, 1983), root respiration (Wilcox, 1987), transpiration and translocation (Craft, 1999) which are some of the important plant metabolic activities. The works of Berrie and Berrie (1990) and Norman (1995) indicated that if the availability of soil moisture becomes a limiting factor then the extent of transpiration of the plant should be expected to decrease as the physiological mechanism to sustain the plant and subsequently the rate of growth and development will decrease. This was evidenced by plants which received 70% of the irrigation water applied as they recorded the lowest mean plant height for all the growth stages.

However, analysis of variance showed the differences in the plant height at the various growth stages were not significant ($p>0.05$).

The result of the leaf area for the various growth stages is shown in Table 5. From Table 5, the leaf area for the various treatments showed no significant difference ($p>0.05$) between them at the initial stage (19 DAT). However, significant differences were observed in the leaf area at the developmental stage (43 DAT) ($p<0.05$). Thus the leaf area of the 100% ETc was significantly different from that of 70% ETc but not significantly different from those of 90% and 80% treatments. No significant differences were observed in the leaf area at last two stages (69 DAT and 87 DAT). The results also showed that the leaf area at 69 DAT and 87 DAT were of the order 100% > 90% > 80% > 70% indicating the 100% ETc recorded the highest leaf area and 70% ETc recorded the least for all the growth stages. This result is in agreement with that obtained by Owusu-Sekyere *et al.* (2012) who reported an order of 100% > 90% > 80% > 70% for the last two growth stages. The higher leaf area for the plants treated with 100% water requirement may be attributed to the appropriate balance of moisture in the plants, which creates good conditions for nutrient uptake, photosynthesis and metabolites translocation, which finally sped up the rate of vegetative growth (Ezzo *et al.*, 2010).

The result of the leaf canopy diameter for the various growth stages is shown in Table 6. The results showed that there were no significant differences ($p>0.05$) in the canopy diameter of the tomato plant between the 100%, 90% and 80% treatments at the initial stage. However, there was a significant difference between the 100% and 70% treatments.

Table 5: Mean (±SE) leaf area (cm^2) for the various growth stages as affected by different water treatments

	Growth stages			
Treatment	Initial (19 DAT)	Developmental (43 DAT)	Mid-Season (69 DAT)	Late Season (87 DAT)
100%	15.01±1.73^{a}	53.46±2.79^{b}	64.11±1.71^{a}	65.63±2.35^{a}
90%	13.96±1.45^{a}	43.20±2.20^{ab}	50.51±7.70^{a}	54.55±2.35^{a}
80%	19.45±0.95^{a}	39.59±4.75^{ab}	50.25±4.97^{a}	52.29±4.42^{a}
70%	16.4±1.573^{a}	33.26±3.98^{a}	52.30±1.93^{a}	52.74±7.45^{a}
L.s.d.	0.118	0.023	0.204	0.207

Mean values along each column with similar or same superscripts are not significantly different at L.s.d =p >0.05

There were no significant differences in the canopy diameter during the mid-season and late season stages for the 70% ETc and 80% ETc. Significant differences were observed among the 70% ETc and 90% ETc and 100% ETc and also between 80% ETc and 90% ETc and 100% ETc and the last two growth stages. These differences may be attributed to water stress for the 70% and 80% water treatments.

Leaf area index is an important quantity that influences the photosynthesis and growth of the plant. It increases up to some point when it begins to decline because of the combined decrease in photosynthetic efficiency of individual leaves. For most plants leaf area index increases with age (up to the beginning of senescence) and reaches a maximum value of 2.0 to 5.0 (Kurt & Fernhout, 1998).

Table 6: Mean (±SE) leaf canopy diameter (cm) for the various growth stages as affected by different water treatments

	Growth stages			
Treatment	Initial (19 DAT)	Developmental (43 DAT)	Mid-Season (69 DAT)	Late Season (87 DAT)
100%	55.20±2.82^{b}	63.00±1.00^{c}	66.00±1.15^{b}	59.33±1.76^{b}
90%	44.60±2.14^{ab}	57.33±1.45^{ab}	60.67±1.76^{ab}	56.67±1.76^{ab}
80%	44.47±1.66^{ab}	51.33±1.74^{ab}	56.33±1.45^{a}	51.33±0.67^{a}
70%	37.47±429^{a}	48.67±1.76^{a}	54.67±1.79^{a}	50.67±1.33^{a}
L.s.d.	0.016	0.001	0.004	0.005

Mean values along each column with similar or same superscripts are not significantly different at L.s.d.=p >0.05

Table 7: Mean (± SE) leaf area index for the various growth stages as affected by different water treatments

	Growth stages			
Treatment	Initial (19 DAT)	Developmental (43 DAT)	Mid-Season (69 DAT)	Late Season (87 DAT)
100%	0.72±0.06^{a}	2.75±0.12^{b}	4.33±0.43^{bc}	3.63±0.15^{b}
90%	0.67±0.05^{a}	2.55±0.16^{b}	4.06±0.20^{c}	3.40±0.19^{b}
80%	0.69±0.09^{a}	2.14±0.44^{ab}	3.22±0.44^{ab}	2.77±019^{ab}
70%	0.89±0.10^{a}	1.75±0.15^{a}	2.52±0.25^{a}	2.25±0.28^{a}
L.s.d.	0.240	0.006	0.001	0.006

Mean values along each column with similar or same superscripts are not significantly different at L.s.d.=p >0.05

The results of the leaf area index for the various growth stages are shown in Table 7. The results showed that there were no significant differences

($p>0.05$) in the leaf area index for all the treatments at the initial stage (19 DAT). At the developmental stage, there were no significant differences in the leaf area index among 80%, 90% and 100% water treatments; however, there were significant differences between the 70%, 90% and 100% treatments at developmental and late season stages. These differences may also be attributed to the water stress suffered by the 70% water treatments, which tended to slow down metabolic activities for those plants and hence reduction in the total area and canopy area.

Effect of deficit irrigation on plant yield components

The results of fruit yield components are presented on Table 8. There were significant differences ($p<0.05$) in the fruit diameters of the tomato fruits from the various water treatments. The mean fruit diameter from plants treated with 100% ETc was the highest and it was significantly different from those of 80% ETc and 70% ETc treatments though not significantly different from 90% ETc treatment. The results indicated that there were no significant differences in mean fruit number, weight and yield, for the various water treatments. In all the listed yield components, treatment with 100% ETc recorded the highest and 70% ETc recorded the lowest and were in the order 100% ETc > 90% ETc >80% ETc > 70% ETc (Table 8). Regression analysis indicated strong positive correlations between water used and mean number, mean weight of fruits, and mean fruit yield (R^2 = 0.937), (R^2 = 0.976) and (R^2 = 0.974) respectively (Figures 1, 2 and 3).

The result of this study confirmed the findings of Birhanu and Tilalum (2010) who reported that total fruit weight was reduced as irrigation amount

reduced. This result can be attributed to the role of water as a vital component for growth and development of tomato fruits, since the water forms 90-95% of the total fruit weight. In general, under water stress conditions tomato plants cannot get enough water for physiological processes leading to the production of fruits (Nahar & Gretzmacher, 2002).

Table 8: Mean (± SE) fruit diameter, number weight and yield for the various water treatments

Treatment	Mean fruit Diameter (cm)	Mean fruit number/plant	Mean fruit weight (g)	Mean Fruit yield (t /ha)
100%	3.21±0.71[a]	20.20±2.03[a]	22.76±3.32[a]	50.60±9.03[a]
90%	3.11±0.72[a]	19.80±1.64[a]	21.92±3.89[a]	47.33±4.49[a]
80%	2.83±0.76[b]	19.33±2.08[a]	21.23±3.78[a]	44.76±5.24[a]
70%	2.68±0.79[b]	18.60±2.08[a]	20.49±3.82[a]	42.43±11.65[a]
L.s.d.	0.000	0.779	0.890	0.658

Mean values along each column with similar or same superscripts are not significantly different at L.s.d.=p >0.05

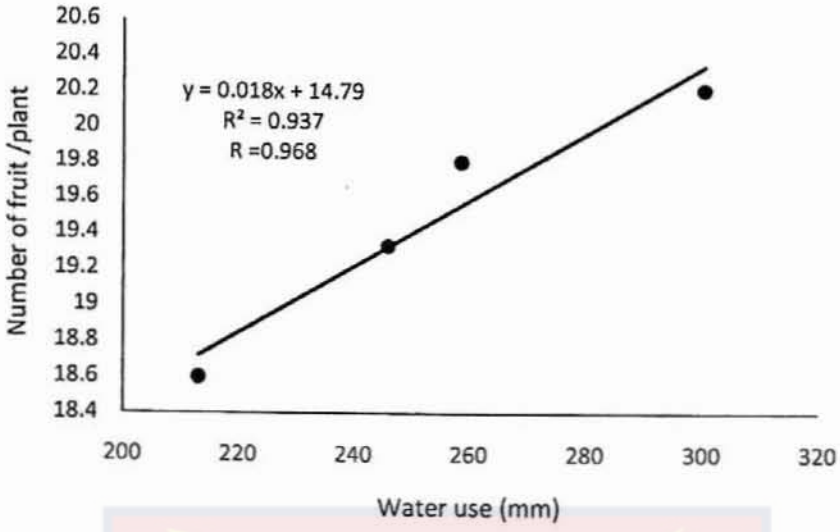

Figure 1: Effect of water used on mean number of fruits (Data points are means of replicates)

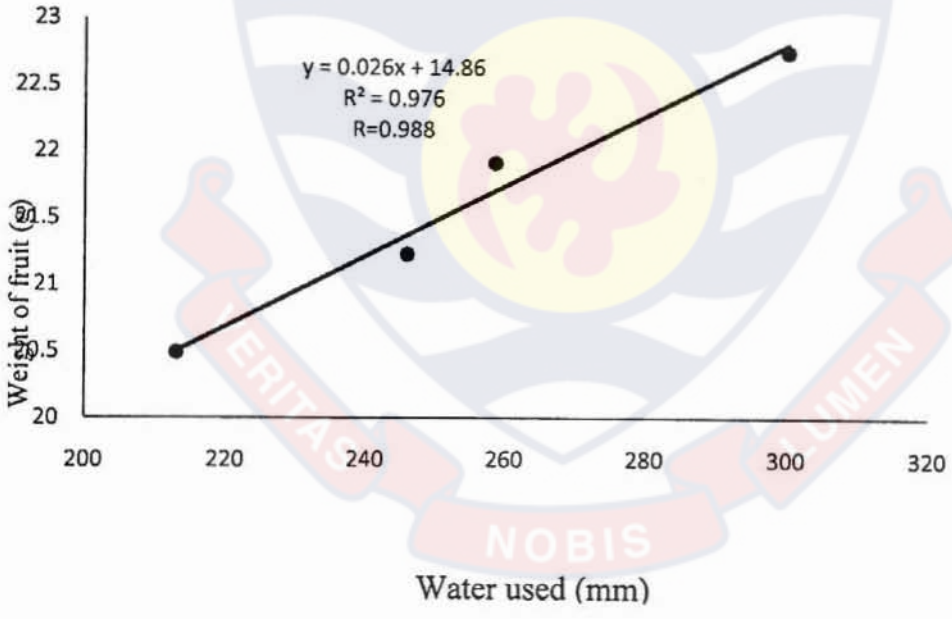

Figure 2: Effect of water used on mean weight of fruits (Data points are means of replicates)

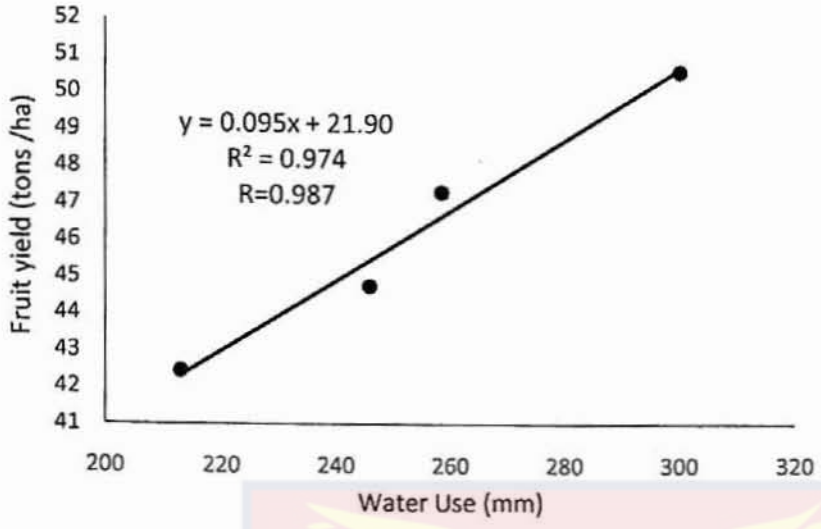

Figure 3: Effect of water used on mean fruit yield (Data points are means of replicates)

The results showed that reduction in the amount of irrigation water led to reduction in mean fruit yield (Table 9). There was a yield loss of 6.46% for 10% reduction in water use. This reduction can be compensated for by the improvement in the quality of the tomato fruits under little stress (Shahein *et al.*, 2012). This implies that above 10-15% reduction in water use, there would be a significant loss in the yield of the tomato fruits.

Water use efficiency (WUE) and water saving

Water use efficiency (WUE) decreased with increasing irrigation level (Figure 4). The lowest water level applied (70% ETc) recorded the highest WUE value. However, the highest irrigation level applied resulted in the lowest WUE. Similar tendency was observed by Aziz *et al.* (2013) who found that 50% of available water treatment gave higher WUE as opposed to 100 or 75% of available water treatments. In a similar manner, the lowest water level applied resulted in the highest water saving (Table 3.7). Thus application of 90%, 80%

and 70% of ETc resulted in the saving of 13.89%, 18.13% and 29.09% respectively. This is in agreement with that reported by Wahb-allah *et al.* (2014).

Table 9: Fruit yield reduction and water saving for the various water treatments

Treatment	Mean fruit yield (t/ha)	Mean fruit yield reduction (%)	Amount of water used (mm)	Water saving (%)
100%	50.6	0	300.38	0
90%	47.33	6.46	258.65	13.89
80%	44.76	11.54	245.91	18.13
70%	42.43	16.15	212.99	29.09

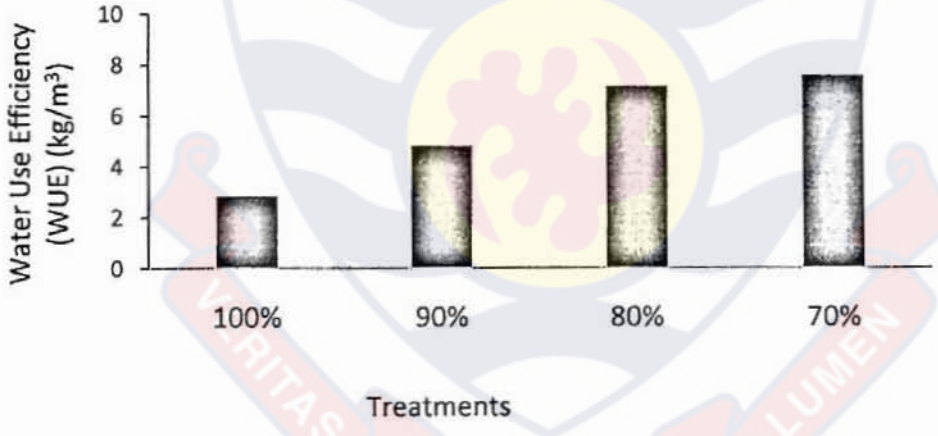

Figure 4: Influence of irrigation treatments on WUE of tomato plants

Soil analysis

The results of the nitrogen, phosphorus, potassium, calcium and organic matter content of the soil before and after the experiments for the various treatments were imposed are presented in Figures 5- 9.

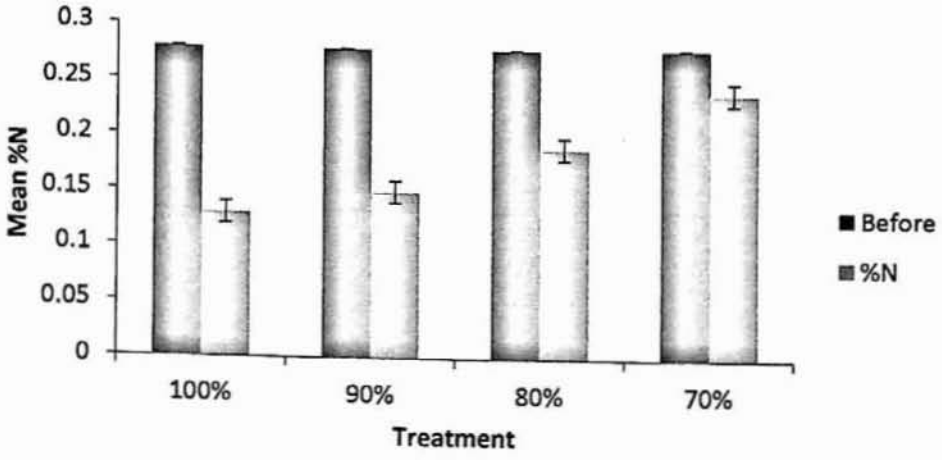

Figure 5: Nitrogen (N) content of the soil for the various treatments before and after the experiment with standard error bars

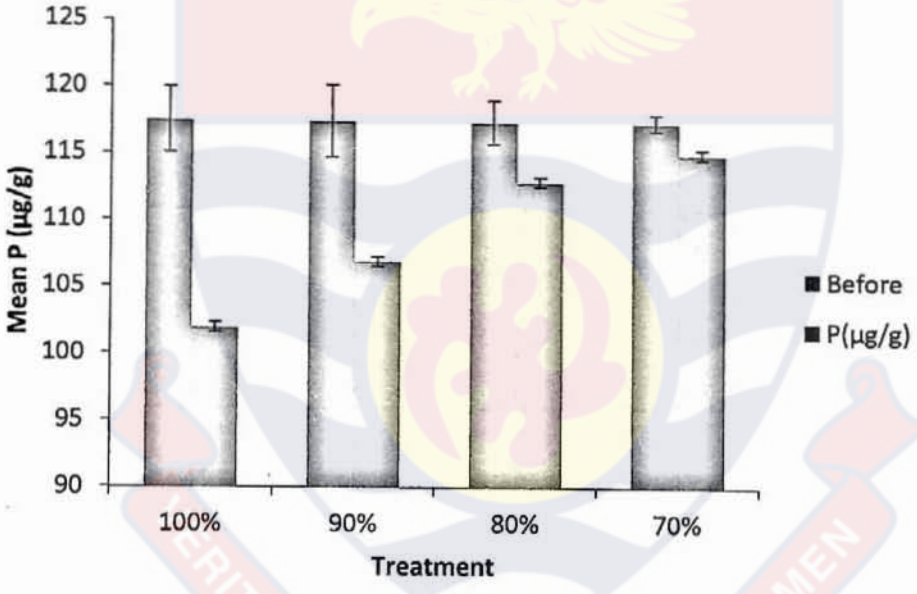

Figure 6: Phosphorus (P) content of the soil for the various treatments before and after the experiment with standard error bars

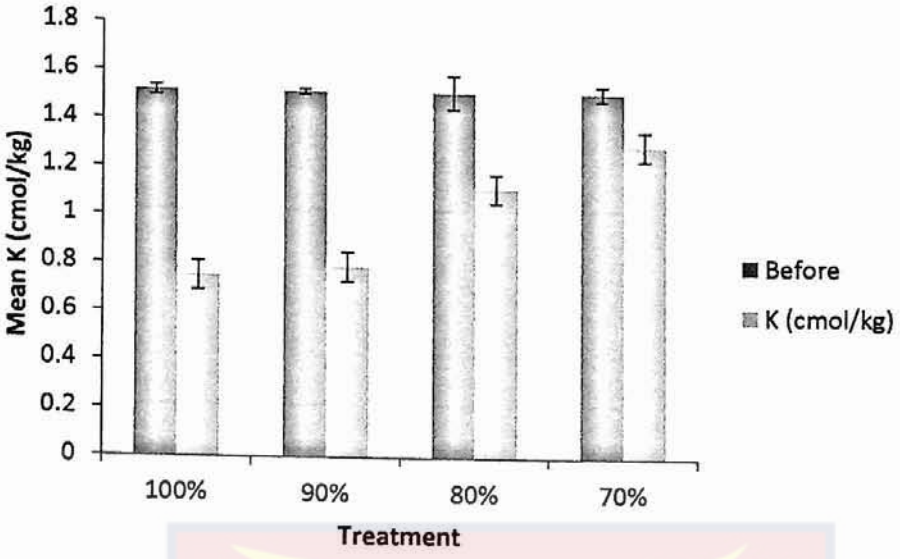

Figure 7: Potassium (K) content of the soil for the various treatments before and after the experiment with standard error bars

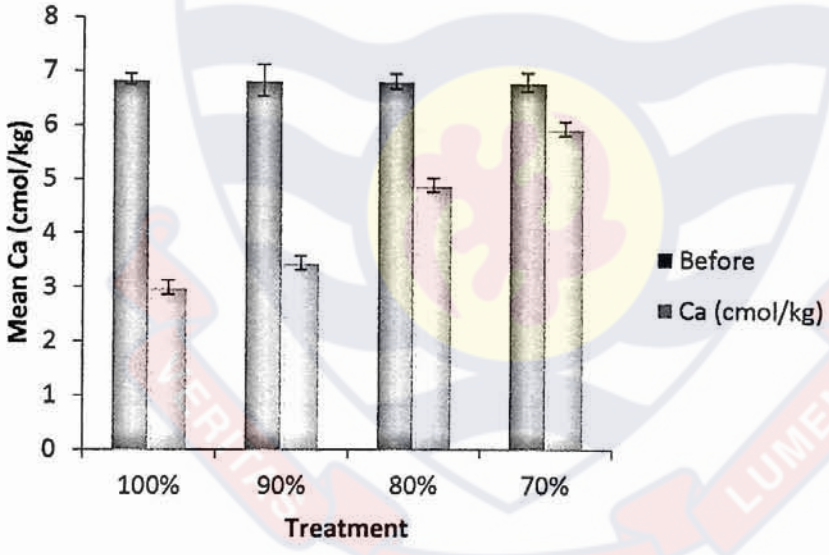

Figure 8: Calcium (Ca) content of the soil for the various treatments before and after the experiment with standard error bars

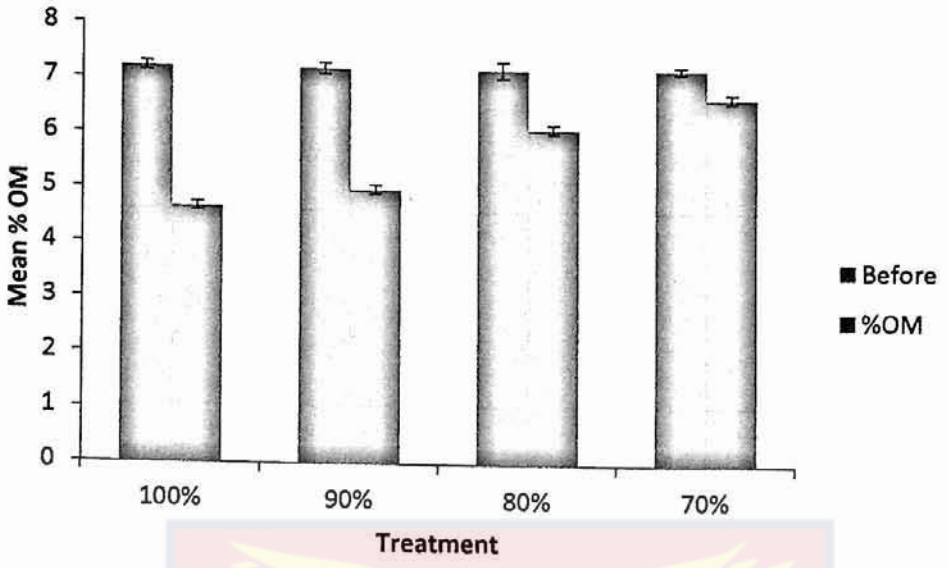

Figure 9: Organic matter (OM) content of the soil for the various treatments before and after the experiment with standard error bars

The uptake of nutrients such as nitrogen, phosphorus, potassium and calcium is influenced by the amount of water available in the soil. The results of this study showed a general decline in the minerals and organic matter contents of the soil over the experimental period. At the end of the experiment, the decline in all the nutrients (N, P, K, Ca) and organic matter were in the order 100% ETc > 90% ETc > 80% ETc > 70% ETc. This general decline in the nutrient uptake as moisture stress increased was also reported by Owusu-Sekyere *et al.* (2012). Abdalla and El-Khoshiban (2007) reported that water stress causes reduction in phosphorus, potassium and calcium uptakes by plants. Also, Brown *et al.* (2006) reported reductions in uptake of calcium, nitrogen, phosphorus and potassium in *Spartina alterniflora* plant under water stress. This decline in nutrient uptake as a result of decrease in irrigation water may be due

to unavailability of enough water to dissolve the nutrients in the soil for roots to absorb in the stressed plants.

Conclusions

Based on the results obtained from this study, it can be concluded that deficit irrigation has some effects on the growth and yield components of the Pectomech variety of tomato.

The different irrigation treatments did not have any significant effect on plant height. However, significant effects were observed for leaf area, canopy diameter and leaf area index. For yield components, no significant differences were recorded between 100% ETc and 90% ETc treatments. However, significant differences were recorded between 100% ETc, 80% ETc and 70% ETc treatments. Yield reduction and water saving were less than 10% and 15% respectively for the fruits from 90% ETc treated tomato plants. There were general reductions in nutrient uptake for all water stressed plants.

It can therefore be concluded from this study that a 10% reduction in the amount or volume of water applied in the cultivation of tomato in the coastal savanna zone of Ghana would not significantly affect the yield of the fruits.

CHAPTER FOUR

EFFECT OF DEFICIT IRRIGATION ON THE PHYSICOCHEMICAL QUALITY OF TOMATO AFTER HARVEST AND DURING STORAGE

Introduction

The tomato (*Solanum lycopersicum*) is one of the most widely consumed fresh vegetables in the world. Botanically, tomatoes are fruits (berry), but they are commonly referred to as vegetables. Fresh-market tomatoes are a popular and versatile fruit vegetable, making significant contributions to human nutrition throughout the world for their content of sugars, acids, among other constituents. It contains high concentrations of sugars and acids, major contributors to tomato flavour (Gharezi *et al.*, 2012).

A lot of pre-harvest activities during cultivation affect the quality and storability of any fruit. Irrigation is a vital agricultural practice that affects both yield and quality of fruits and vegetables. Indeed, irrigation schedule has a great impact on the growth, yield and fruit quality of tomato depending on the amount of water applied (Kere *et al.*, 2003). Fruit quality, mainly firmness, total soluble solids and acid contents are changed by moisture stress (Vijitha and Mahendran, 2010). Moisture stress not only affects the quality of the fruits but also inhibits crop yield. The major constraint to expand tomato cultivation in the dry zone of Ghana is the variety of environmental stresses such as drought and high temperature. Changes in physicochemical parameters such as total soluble solids (TSS), titratable acidity (TA) and firmness of tomato under water stress have been reported. Shahein *et al.* (2012) reported an increased TSS of tomato

under water stress. Abdel-Razik (2012) also reported that firmness and TSS increased and titratable acidity decreased in mango grown under water stress.

Postharvest storage life is defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions (Schewfelt, 1986). A number of chemical and physical processes take place in vegetables during postharvest storage. The physicochemical quality of most fruits and vegetables is affected by water loss during storage which depends on the temperature and relative humidity conditions (Perez et al., 2003). Ball (1997) suggested that a postharvest change in firmness can occur due to the loss of moisture through transpiration, as well as enzymatic changes. In addition, hemicelluloses and pectin become more soluble which result in disruption and loosening of the cell walls. Biochemical changes in the fruit during storage may also affect the acid and the total soluble solid content of the fruit.

The aim of this study was to establish the effects of deficit irrigation and postharvest storage on the physicochemical quality of tomato (Pectomech variety). The specific objectives were to:

1. determine the firmness, total soluble solids, titratable acidity and pH of tomato grown under the different water regimes.
2. determine the changes in the firmness, total soluble solids, titratable acidity and pH of tomato grown under the different water regimes during postharvest storage.

Materials and methods

Sample collection

Tomato samples grown under the various water regimes (100% ETc, 90% ETc, 80% ETc and 70% ETc) were harvested from the School of Agriculture Research Farm, University of Cape Coast and sent to the School of Agriculture Research Laboratory for analysis. Analyses were carried out for physicochemical parameters (firmness, total soluble solids, titratable acidity and pH). All analyses were carried out in triplicates.

Determination of physicochemical parameters

The firmness of the tomato fruits was determined with a penetrometer (mod FT 327 (3-27 kg). A handheld refractometer (RHB-32/ATC model) was used to measure the total soluble solids. Titratable acidity was determined by titrating 10 g of the pulp to which 50 ml of distilled water was added and boiled for 30-60 minutes replacing the water lost by evaporation with 0.1M NaOH using phenolphthalein as indicator. The % Titratable acidity was then calculated. pH was measured with a pH meter (Jenway International 3510 pH meter). pH meter was calibrated using buffer solutions of pH 7 and pH 4.

Statistical analysis

Results from the study were analyzed using SPSS (Version 20). Descriptive statistics such as mean and standard deviation were also calculated. One way Independent Analysis of Variance (ANOVA) were conducted to measure the significant effect of the different types of irrigation treatment on the various parameters measured. Tukey's HSD multiple comparison was also performed to indicate where the difference exists at $p<0.05$. Simple regression

and correlation were conducted to ascertain the relationship between the nutritional components and the amount of water applied.

Results and discussion

Effect of deficit irrigation on physicochemical quality of tomatoes

The results of firmness of tomato fruits with respect to the different water application during cultivation is presented in Figure 10. It indicated that the fruits from tomato plant grown under 70% ETc recorded the highest firmness of 7.12 kg with those grown under 100% ETc recording the least firmness of 6.33 kg.

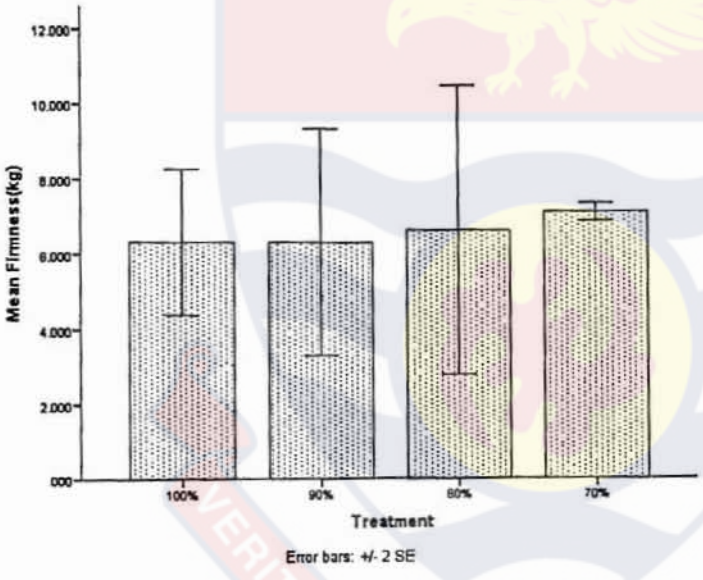

Figure 10: Firmness of tomato grown under different water treatment with standard error bars

The firmness of the tomato fruit was in the order 70% ETc > 80% ETc > 90% ETc >100% ETc. This implied that water stress had a positive effect on firmness of the tomato fruit. Analysis of variance, however, revealed that the variation in the firmness of the tomato fruits for the various water applications was not significant ($p>0.05$). The percentage increases in firmness of the

tomatoes with respect to the control (100% ETc) treatment were 5.3%, 2.7% and 14.5 % for the 90% ETc, 80% ETc and 70% ETc respectively.

Firmness is a criterion often used to evaluate fruit quality as it is directly related to fruit development, maturity, ripening and storage potential. It is also related to the likelihood of bruising when fruits are subjected to impact during handling (Lesage & Destain, 1996). Fruit firmness is also an important quality in fruit production that can decide which fruit will be harvested, transported, stored, or marketed. The results of this study showed an increase in fruit firmness with reduction in water treatment. The firmness of fruits and vegetables is mainly influenced by their moisture contents. Thus the higher the moisture content the lower the firmness and vice versa. Since the moisture content of the tomato fruits from 80% ETc treatment was lower in fruits from 100% ETc and 90% ETc treatments, it is obvious that the tomato fruits from the 80% ETc treatment can have the highest firmness as observed. This result is in agreement with the findings of Proietti and Antognozzi (1996) on olive and Abdel-Razik (2012) on mango fruit who reported that increasing irrigation water decreased the fruit firmness and vice versa. The difference in firmness may be due to differences in their pectin composition (Billy *et al*., 2008).

The results of total soluble solids (TSS) of tomato fruits with respect to the different water application during cultivation is presented on Figure 11. It indicated that the fruits from tomato plant grown under 70% ETc recorded the highest TSS of 7.50 ^{o}Brix with those grown under 100% ETc recording the least TSS. The TSS of the tomato fruit is in the order 70% ETc > 80% ETc > 90% ETc >100% ETc implying that water stress had a positive effect on TSS of the

tomato fruit. Analysis of variance, however, revealed that the variation in the TSS of the tomato fruits for the various water applications were not significant ($p>0.05$). From the results, the percentage increases in total soluble solids of the tomatoes with respect to the control (100% ETc) treatment were 4.3%, 5.8% and 8.2 % for the 90% ETc, 80% ETc and 70% ETc respectively.

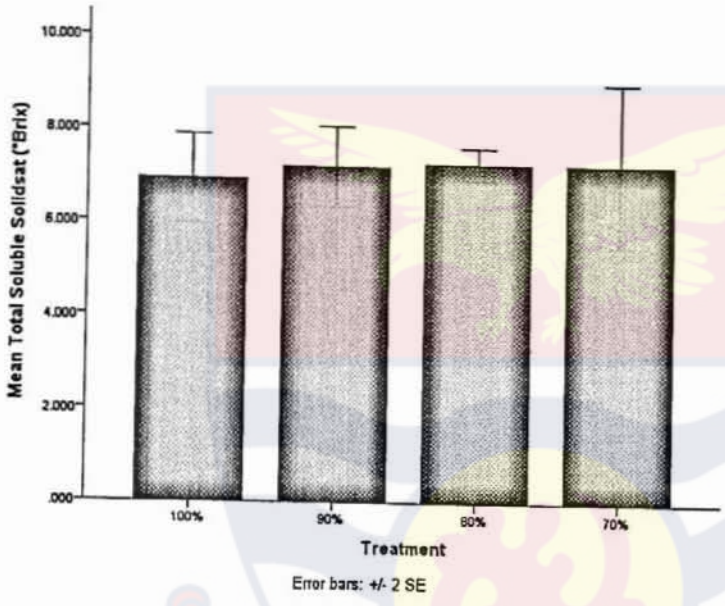

Figure 11: Total soluble solids content of tomato grown under different water treatments with standard error bars

Total soluble solids (sugar and acid in fruit) are important quality factors for processing tomatoes. It is a measure of the mass ratio of dissolved sucrose to water in the fruit. The results of this study showed an increase in total soluble solids with reduction in water application. This result is in agreement with the findings of Shahein *et al.* (2012) and Tuzel *et al.* (1993), who reported that increasing the rate of irrigation of greenhouse tomato plant can lead to a reduction in soluble solids. The difference in total soluble solid of the different water treatments was due to difference in water content of the fruits (Abdel-

Razik, 2012). This implied that reduction in the amount of water used to irrigate the tomato plant led to a reduction in the moisture content of the fruit and hence increasing the total soluble solids content of the fruits. Tomato fruits with high total soluble solids are desirable especially if the tomato fruits are to be used for processing into tomato products such as puree, paste and ketchup.

The titratable acidity of the tomato as indicated in Figure 12 showed a trend increasing with respect to water stress with mean values ranging from 0.93% for 100% ETc and maximum of 1.06% for 70% ETc. However, the differences in the titratable acidity of the tomato for the different water applications were not significant ($p>0.05$). Thus the treatments did not have any significant effect on the titratable acidity of the tomato. From the results the percentage increases in titratable acidity of the tomatoes with respect to the control (100% ETc) treatment were 8.6%, 11.8% and 14.0 % for the 90% ETc, 80% ETc and 70% ETc respectively. This implied that tomato fruits from 70% ETc treatments produced fruits with higher acid content. This is desirable since high acid and high sugar contents produce best flavoured tomato fruits (Stevens *et al.*, 1977).

The mean value for the pH was within the range 4.30-4.47, with 100% ETc treatment recording the highest and 70% ETc treatment recording the lowest (Figure 13). It was observed that the pH of the tomatoes increased with increasing water treatment. The results indicated that the pH of the tomatoes was in the order 100% ETc > 90% ETc > 80% ETc > 70% ETc. However, these differences in the pH values of the tomato were not significant ($p>0.05$) with respect to the different water applications.

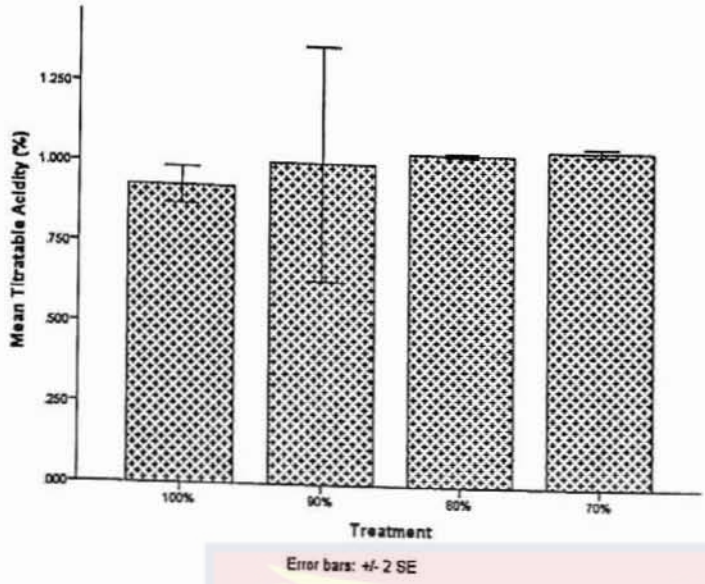

Figure 12: Titratable acidity of tomato grown under different water treatments with standard error bars

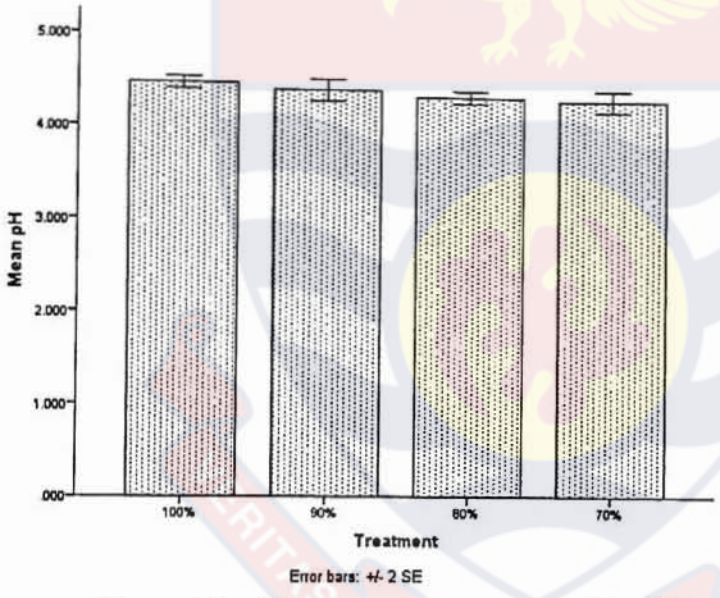

Figure 13: pH of tomatoes grown under different water treatments with standard error bars

Titratable acidity and pH are two quality characteristics of tomato fruit. The pH of tomato is determined primarily by the acid content of the fruit. Organic acids are the major taste components in tomatoes. Sugars, acids and their interactions are important for sweetness, sourness and overall flavour intensity in the tomato that contributes to the taste (Kader, 2008).

An increase in the titratable acidity content of the fruit was observed when the plants were subjected to water stress. This agrees with the study conducted by Pantane *et al.* (2011) who reported that the tritratable acidity and vitamin C contents were increased under water stress (50% ETc) compared to a full irrigation water treatment (100% ETc). Rouphael *et al.* (2008) also illustrated that water stress can improve quality in fruits and explained further that when tomato plants are irrigated with less water, the plant regulate certain metabolic activities, such as osmotic adjustment in sink organs, to increase the sucrose and organic acid transformation rate and amount. Consequently, more assimilates shift to the fruits, thus improving soluble sugar, total soluble solid and acidity content. This implied that tomato fruits from plants treated with less water had low pH values which would lead to improvement in the flavour of the fruits.

Effect of storage on physicochemical quality of tomato grown under different water treatments

The results showed a gradual decrease in firmness of the tomato for the water treatments across the storage period for all treatments except for treatment 90% ETc which recorded a slight increase in firmness on day 5 and thereafter decreased gradually till day 20 (Figure 14). There were no significant differences ($p>0.05$) in the firmness of the tomato for treatments 100% ETc, 90% ETc and 80% ETc across the storage period from day 0 to day 20. However, there were significant differences ($p<0.05$) in the firmness of the tomato for treatment 70% ETc during storage. The changes in the firmness of

the tomato from day 0 to day 20 of storage were 6.33-4.10 kg, 6.67-3.60 kg, 6.50-4.37 kg and 7.25-3.78 kg for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively.

The most important factor next to visual appearance in tomato quality is firmness which is closely associated with ripeness stage. Most consumers prefer firm fruits which do not lose too much juice when sliced and which do not have tough skins. Firmness affects susceptibility of tomatoes to physical damage and consequently their shipping ability (Raffo *et al.*, 2002). The textural quality of tomatoes is influenced by skin toughness, flesh firmness, and internal fruit structure which vary greatly among cultivars. All fruit softened progressively during storage, firmness of tomato was influenced by storage time. The reduction in firmness of the tomato fruits during storage may be due to high respiration rate and loss of water leading to weight loss. This implied that as tomato fruits were stored they lost their firmness which is an undesirable effect as far as quality of the fruit is concerned.

The results presented in Figure 15 clearly showed that there were gradual increases in total soluble solids of the tomatoes for the different water treatments during the storage period. However, these increases were not statistically significant ($p>0.05$). Among the treatments, 80% ETc treatment recorded the highest TSS (9.87°Brix) and 100% ETc recorded the lowest TSS (8.62°Brix) at the end of storage. The total soluble solids acts as a rough index of the amount of sugars present in fruits. It is the amount of sugar and soluble minerals present in fruits and vegetables.

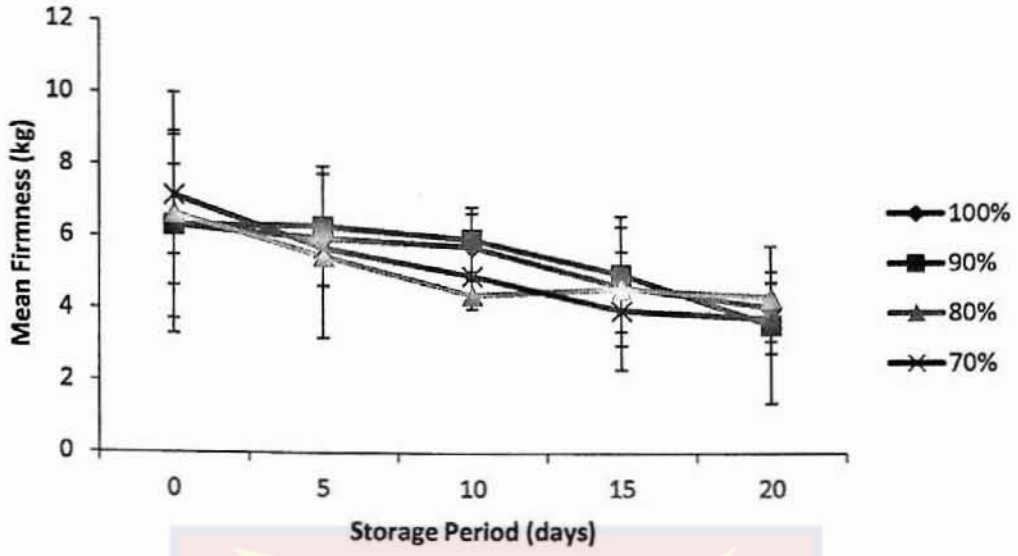

Figure 14: Changes in firmness of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

Sugars constitute 80-85% of soluble solids. The total soluble solids increased during ripening due to degradation of polysaccharides to simple sugars thereby causing a rise in TSS (Gharezi *et al.*, 2012). The result of this study revealed a decrease in moisture content (Figure 6.5) of the tomatoes during storage. The decrease in moisture led to dehydration which might result in the increase in the total soluble solids. High moisture content of fruits leads to less soluble solids (Brooks & MacGilivray, 1928). The increase in total soluble solids of the tomato fruit during storage is desirable since it may lead to an increase in the sugar content hence improving the sweetness and general flavour of the fruit.

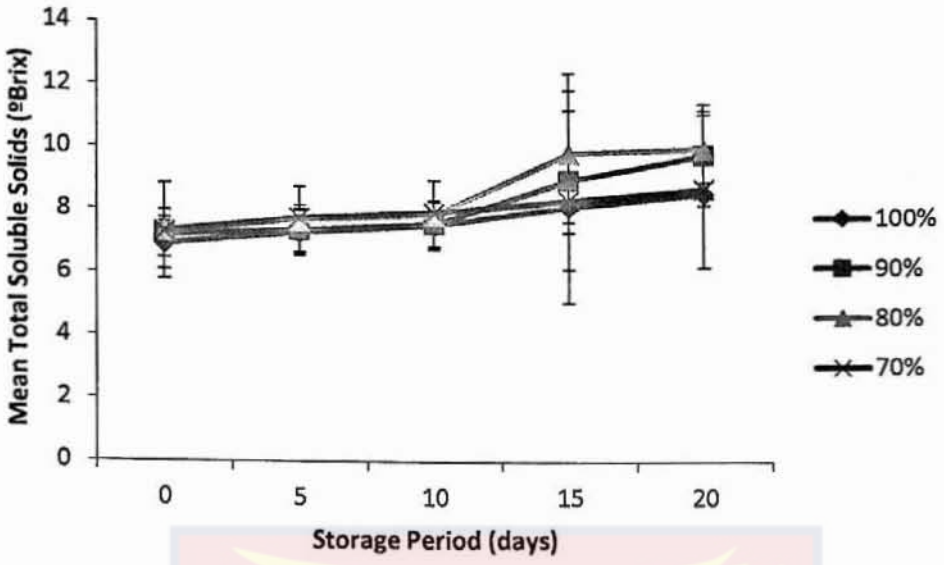

Figure 15: Changes in total soluble solids of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

From Figure 16 it is observed that the titratable acidity for all the various treatments decreased across the storage period. Analysis of variance indicated that the different treatments had significant effects ($p<0.05$) on the titratable acidity of the tomatoes during storage. The changes in the titratable acidity of the tomato from day 0 to day 20 of storage were 0.93-0.45%, 1.01-0.52%, 1.04-0.67% and 1.06-0.68% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. The decline in titratable acidity with increase in pH of the tomato fruits during storage is inevitable because during ripening, acids are converted into sugars.

The results showed that within the 70% ETc treatment, the decrease in titratable acidity across storage from day 0 to day 15 of storage was not significant ($p>0.05$). However, there was a significant difference in the titratable acidity of the tomato at day 20 of storage. Comparing 100% ETc treatment which is the control treatment to the other treatments, there were mean

differences in the acid level, and analysis of variance indicated these differences were significant ($p>0.05$).

The decrease in the titratable acidity of the tomato during storage can also be attributed to the fact that the amount of organic acid in the fruit decreased during maturity because they are substrates of respiration. During ripening of tomato, malic acid disappears first, followed by citric acid resulting in reduction in amount of acidity (Salunkhe *et al.*, 1974). This suggests that there is catabolism of citrate via malate and also that the microorganisms may use citric acid as a carbon source resulting in a reduction in titratable acidity. The decline of acidity may also be attributed to increased activity of citric acid glyoxylase during ripening which may lead to the conversion of the acids into sugars and further utilization in metabolic process during storage (Rathore *et al.*, 2007). The decrease in the titratable acidity of the tomato fruits during storage may negatively affect the flavour of the fruit since high acid coupled with high sugars produce good flavours in tomato fruits.

The results presented in Figure 17 showed that pH increased during storage for all the water treatments. Statistically, these differences in the pH values of the tomato fruits were not significant ($p>0.05$). The changes in the pH of the tomato from day 0 to day 20 of storage were 4.47-4.50, 4.40-4.55, 4.33-4.47 and 4.30-4.34 for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively.

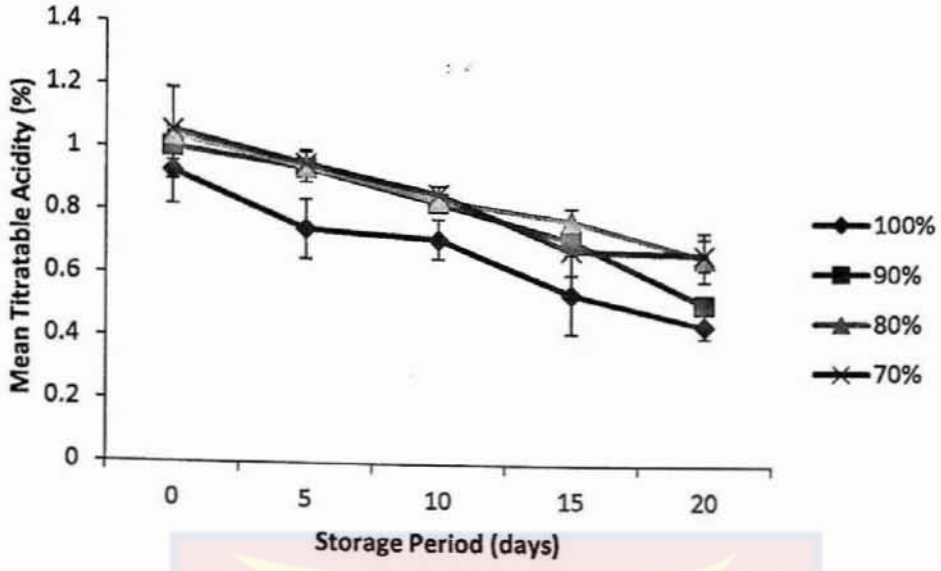

Figure 16: Changes in tritratable acidity of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

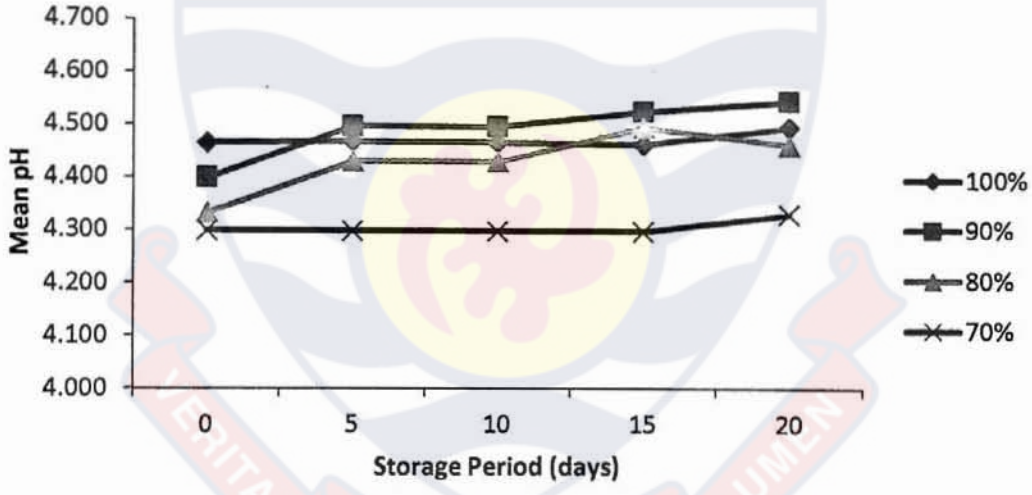

Figure 17: Changes in pH of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

This increase in pH of the tomato fruits may be due to the conversion of citric acid into sugars during storage resulting in the tomato fruit becoming less acidic (Rathore *et al.*, 2007). The increase in the pH of the tomato fruits during

storage may negatively affect the flavour of the fruit since it indicated a reduction in acidity of the fruits. It has been reported that high acid coupled with high sugars produces good flavours in tomato fruits (Stevens *et al.*, 1977).

Conclusions

Based on the results obtained from this study, it can be concluded that deficit irrigation has both positive and negative effects on the physicochemical quality of tomato fruits. Deficit irrigation caused increases in firmness, total soluble solids and titratable acidity of the tomato fruits. However, a decrease in pH of the tomato fruits with decreasing water applications was recorded.

The firmness of the tomato fruits decreased across the storage period for all water treatments with the 80% ETc treatment recording the highest firmness, followed by 100% ETc, then 70% ETc and the lowest by 90% ETc treatment at the end of storage.

In all water treatments, there were increases in the total soluble solids of the tomato fruits during storage. At the end of storage, the tomato fruits from 80% ETc treatment had the highest total soluble solids, followed by 90% ETc, then 70% ETc and finally by 100% ETc treatment. Once again, the moisture content of the tomato fruits at the end of the storage influenced the total soluble solids of the tomato fruits.

As titratable acidity of the tomato fruits decreased, pH of the fruits increased during storage for all treatments. This is inevitable because reduction in acidity leads to increase in pH. However, storage had a significant effect on titratable acidity but had no significant effect on pH of the tomato fruits.

Considering the percentage increases and decreases obtained for physicochemical quality of the tomatoes in this study, it can be concluded that a 10-20% reduction in the amount or volume of water applied in the cultivation of the Pectomech tomato variety in the coastal savannah zone of Ghana would produce tomato with optimum quality that may compensate for yield losses.

CHAPTER FIVE

EFFECT OF DEFICIT IRRIGATION ON THE NUTRITIONAL QUALITY OF TOMATO AFTER HARVEST AND DURING STORAGE

Introduction

Tomato is one of the most widely grown vegetables in the world because of the nutritive value of its fruit (rich source of minerals, vitamins, organic acids, essential amino acid, etc.). Therefore, any factor influencing tomato yield has attracted considerable interest. Among environmental factors, water availability is a major limiting factor of tomato fruit growth and productivity, thus the successful production of tomato requires irrigation (Jonson *et al.*, 1992). However, water resources in many parts of the world are limited and thus there is an urgent need to apply an effective irrigation strategy to operate under the condition of water scarcity (Fereres & Soriano, 2007). A recent positive approach to attain the goal of improving water use efficiency in agriculture is conventional deficit irrigation. Deficit irrigation is a water-saving strategy under which crops are exposed to a certain level of water stress either during a particular period or throughout the whole growing season (Pereira *et al.*, 2002). The expectation is that any yield reduction will be insignificant compared with the benefits gained from the saving of water (Eck *et al.*, 1987). The goal of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water applied or by reducing the number of irrigation events (Kirda, 2002). The reduction in the amount of water applied to the plant

may lead to some physiological and biochemical changes in the plant that may affect its nutritional composition.

Physiological and biochemical changes in carbohydrates, proteins and lipids observed in many plants under various water stress levels have been reported. Among the major effects are those involving carbohydrate metabolism, with the accumulation of sugars and a number of other organic solutes (Kameli, 1990). Short term water stress was reported to stimulate the conversion of starch to sucrose in bean leaves (Fox & Geiger, 1986). The increase of sugar in various plant tissues as a response to water stress supported the idea of contribution of solutes when the plants are exposed to different stress levels. Studies have shown that soluble sugars accumulate in leaves during water stress (Al-Suhaibani, 1996), and have suggested that these sugars might contribute to osmoregulation (Morgan, 1984), at least under moderate stress.

Changes of amino acids and protein have been mentioned in many reports which have stated that water stress caused different responses depending on the level of stress and plant type. For instance, in *Avena* coleoptiles, water stress clearly caused a significant reduction in rate of protein synthesis (Dhindsa & Cleland, 1975). Water stress has a profound effect upon plant metabolism, and results in a reduction in protein synthesis. Several proteins were reduced by stress in maize mesocotyls (Bewley & Larsen, 1982). Dasgupta and Bewley (1984) pointed out that water stress reduced protein synthesis in all regions of barley leaf. Although water stress may inhibit protein synthesis (Ho & Sachs, 1989), some specific types of proteins and mRNA increase in water stressed

plants. For instance, free proline accumulation in response to drought in many plant specie tissues is well documented (Nair *et al.*, 2006).

Changes in lipid contents of plants due to water stress have also been reported. Akinci (1997) reported a decrease in total lipids content of cucumber under water stress. Decreases in diacylglycerol, free fatty acid and polar lipid in maize were also reported (Navari-Izzo *et al.*, 1989). Other effects of water stress include a reduction in nutrient uptake, reduced cell growth and enlargement, leaf expansion, assimilation, translocation and transpiration. Many nutrient elements are actively taken up by plants, however the capacity of plant roots to absorb water and nutrients generally decreases in water stressed plants, presumably because of a decline in the nutrient element demand (Alam, 1999). It is well documented that essential plant nutrients are known to regulate plant metabolism even if the plants are exposed to water stress by acting as cofactor or enzymes activators (Nicholas, 1975). Different effects of water stress on nutrient concentrations of different plant species and genotypes were reported and most studies have reported that mineral uptake can decrease when water stress intensity is increased (Singh and Singh, 2004). For instance, nitrogen uptake decreased in soybean plants under water stress conditions (Tanguilig *et al.*, 1987) and nitrogen deficiency causes cotton plants to be sensitive to stress with a higher water stress (Singh & Gupta, 1993) and decrease of nutrient presumably because of a decline in the nutrient element demand since the reduced root-absorbing power or capacity to absorb water and nutrients generally declines accompanied by decrease in transpiration rates and impaired active transport and membrane permeability of crop plants (Levitt, 1980).

However, water stress has been reported to generally favour increases in nitrogen, K^+, Ca^{2+}, Mg^{2+}, Na^+, and Cl^- but decreases in phosphorus and iron (Abdel *et al.*, 1971) intake in certain plants.

A number of chemical and physical processes take place in vegetables during storage. Apart from physical quality, serious losses also occur in the essential nutrients, vitamins and minerals.

The aim of the study was to determine the effects of deficit irrigation and postharvest storage on the nutritional composition of tomatoes. The specific objectives were to determine the:

1. proximate composition (moisture, ash, protein, fat, fibre and carbohydrate) of tomato grown under the different water regimes.
2. mineral composition (Ca, Mg, Na, K, Fe, Cu and Zn) of the tomato grown under the different water regimes.

Materials and methods

Sample collection

Tomato samples grown under the various water regimes (100% ETc, 90% ETc, 80% ETc and 70% ETc) were harvested from the School of Agriculture Research Farm, University of Cape Coast and sent to the School of Agriculture Research Laboratory for analysis. Analysis was carried out for nutritional compositions (moisture, ash, protein, fat, fibre, carbohydrate, calcium, magnesium, sodium, potassium, iron, copper and zinc contents). All analyses were carried out in triplicates.

Determination of nutritional components

Moisture content of the tomato fruits was determined using the oven drying method described by AOAC (2000). Ash content was determined by incinerating the dry tomato fruit at 550°C in a muffle furnace as described by AOAC (2000). Protein content was determined using Kjeldahl method described by AOAC (2000). Fat content determination was carried out by soxhlet extraction described by AOAC (2000). Fibre content was determined using the method of (AOAC, 2000). Carbohydrate content of the tomato fruit was determined by difference.

Sodium and potassium contents of the tomatoes were determined by flame photometry (AOAC, 2003). Calcium and Magnesium contents were determined by EDTA titration described by AOAC (2003). Iron, copper and zinc contents were determined using Atomic Absorption Spectrometry as described by AOAC (2003).

Statistical analysis

Results from the study were analyzed using SPSS (Version 20). Descriptive statistics such as mean and standard deviation were also calculated. One way Independent Analysis of Variance (ANOVA) was conducted to measure the significant effect of the different types of irrigation treatment on the various parameters measured. Tukey's HSD multiple comparison was also performed to indicate where the difference exist at $p<0.05$. Simple regression and correlation were conducted to ascertain the relationship between the nutritional components and the amount of water applied.

Results and discussion

Effects of deficit irrigation on nutritional composition of the tomato

The moisture content of the tomato for the various water treatments was in the range of 88.02% – 91.00% with 100% ETc recording the highest and 70% ETc recording the lowest value. The moisture content was in the order 100% ETc > 90% ETc > 80% ETc > 70% ETc (Figure 18). Analysis of variance indicated the variations in the mean moisture content of the tomatoes for all the water treatments were significant ($p<0.05$). There was no significant difference in the moisture contents of fruits from treatments 90% ETc and 80% ETc. However, significant differences existed between the moisture contents of fruits from treatments 100% ETc and 70% ETc, 90% ETc and 70% ETc.

There was a strong positive correlation ($R^2 = 0.927$) between the amount of water applied to the tomato plant during cultivation and the moisture content of the tomato fruits (Figure 19). The results showed that the percentage decreases in the moisture content of the tomatoes with respect to the control (100% ETc) treatment were 2.2%, 2.6% and 3.3 % for the 90% ETc, 80% ETc and 70% ETc respectively. This trend in the percent moisture content is similar to the findings of Abdel-Razik (2012) and Proietti and Antognozzi (1996) who reported that with increasing water treatment, the pulp water content of mango and olive respectively were increased.

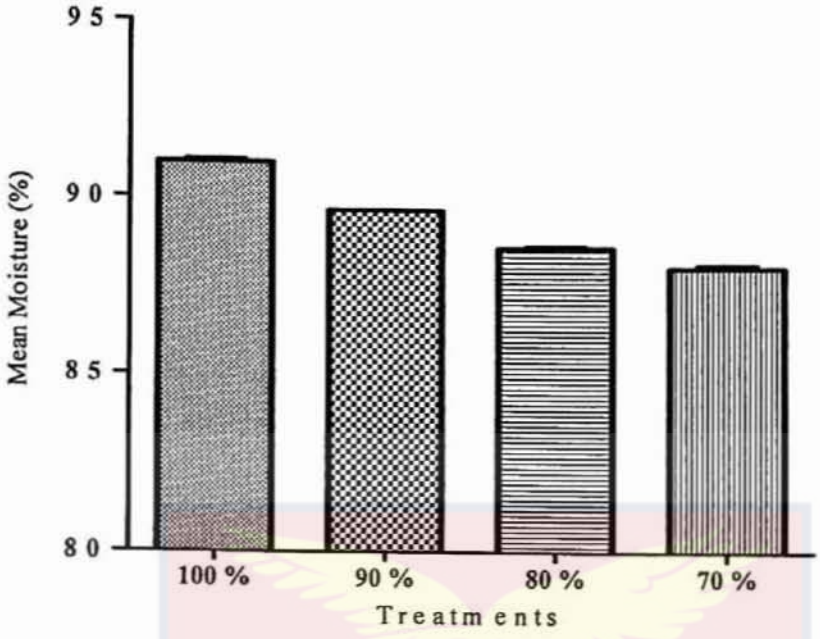

Figure 18: Moisture content of tomato grown under different water treatments with standard error bars

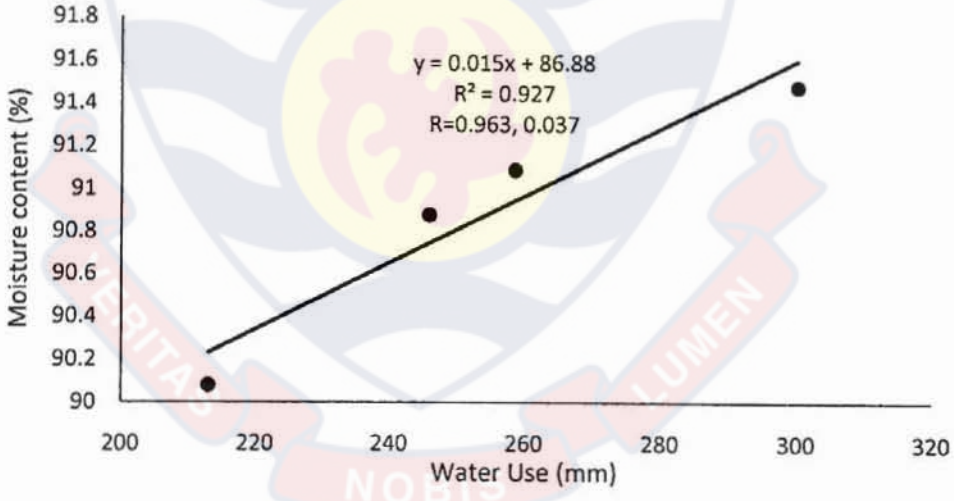

Figure 19: Effect of water used on moisture content of tomatoes (Data points are means of replicates)

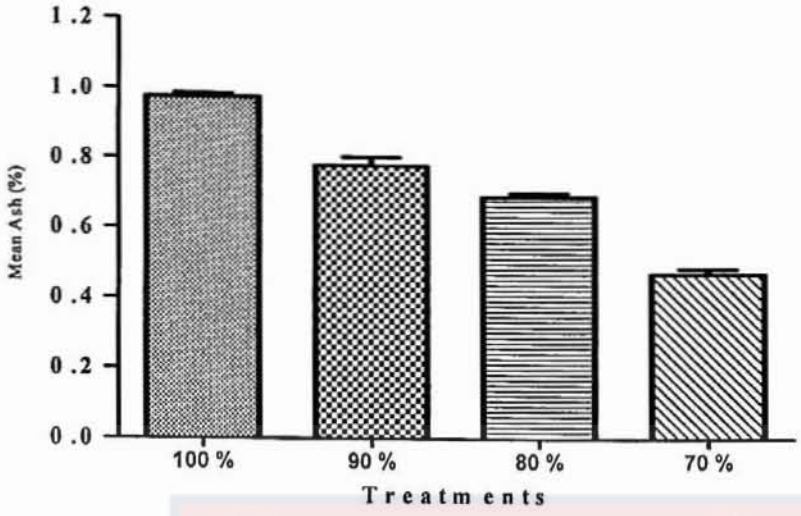

Figure 20: Ash content of tomato grown under different water treatments with standard error bars

The results of the effect of different irrigation regime on the ash content of the tomato showed that ash content decreased with water stress (Figure 20). The ash content of the tomato for the various water treatments was in the range of 0.47% – 0.98% with 100% ETc recording the highest and 70% ETc recording the lowest value. The differences in the ash contents between all water treatments were significant ($p<0.05$).

Regression analysis showed a strong correlation ($R^2 = 0.996$) between the ash content of the tomato fruits and the amount of water applied to the plant during cultivation (Figure 21). From the results, the percentage decreases in the ash content of the tomatoes with decreasing water application with respect to the control (100% ETc) treatment were 20.1%, 29.1% and 51.7 % for the 90% ETc, 80% ETc and 70% ETc respectively.

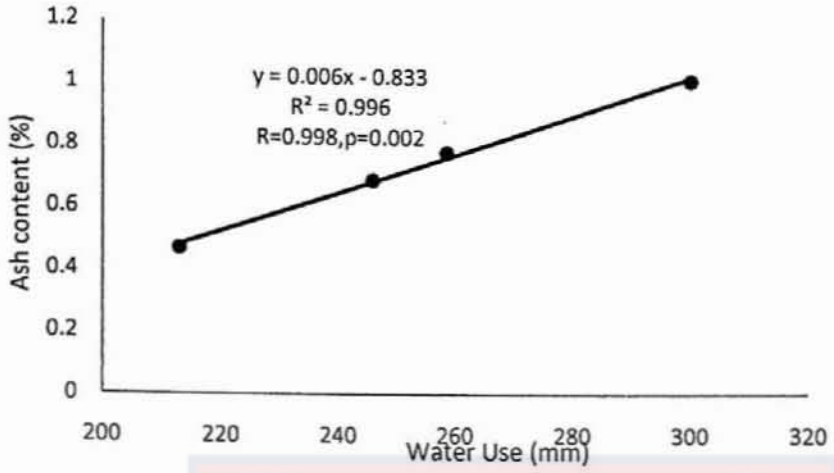

Figure 21: Effect of water used on ash content of tomatoes (Data points are means of replicates)

The ash content of a food substance is a representation of its inorganic components (minerals) (Sobulo *et al.*, 1975). Many nutrient elements are actively taken up by plants. However, the capacity of the plant roots to absorb water and nutrients generally decreases in water stressed plants (Akinci and Losel, 2012). Thus the higher ash content of the tomato from the tomato plant treated with 100% ETc may be due to the higher soil water content which led to higher absorption of minerals by the roots.

The protein contents of the tomato for the different water application ranged between 1.80% and 1.84% with treatment 100% ETc recording the highest and 70% ETc recording the least (Figure 22).

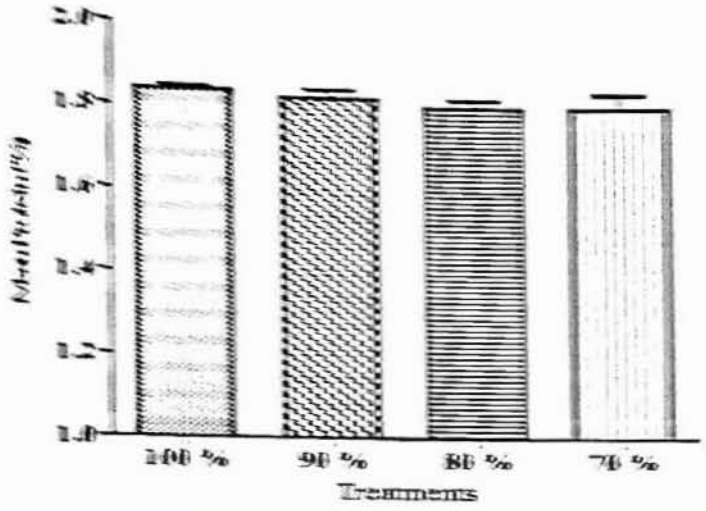

Figure 22: Protein content of tomato grown under different water treatments with standard error bars

There were no significant differences in the protein content of the tomato for the various water treatments ($p>0.05$). There was no correlation ($R^2=0.070$) between the protein content of the tomato fruits and the amount of water applied (Figure 23), implying that the amount of water used during cultivation did not have any influence on the protein content of the tomato fruits.

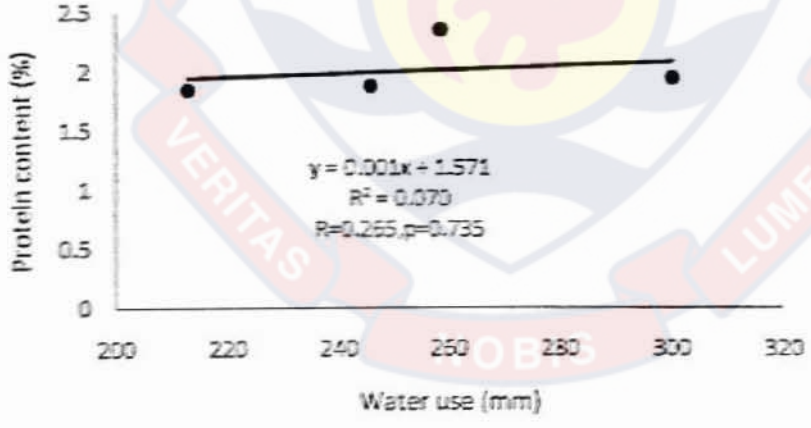

Figure 23: Effect of water used on protein content of tomatoes (Data points are means of replicates)

The results showed that the percentage decreases in the protein content of the tomatoes with respect to the control (100% ETc) treatment were 0.5%, 1.6% and 1.6 % for the 90% ETc, 80% ETc and 70% ETc respectively. The range of protein content obtained in this study was higher than the 1.0%-1.1% reported by USDA (2005). The differences may be due to the variety and other environmental conditions during production. Idah *et al.* (2010) also reported a protein content of 0.05% for tomatoes which is lower than that obtained in the current study. Analysis of variance indicated that the treatments did not have any significant effect ($p>0.05$) on the protein content of the tomato. Under water stress conditions changes in the amino acids and proteins (synthesis and utilization) have been mentioned in many reports, which stated that water stress caused different responses depending on the level of stress and plant (Dhindsa & Cleland, 1975).

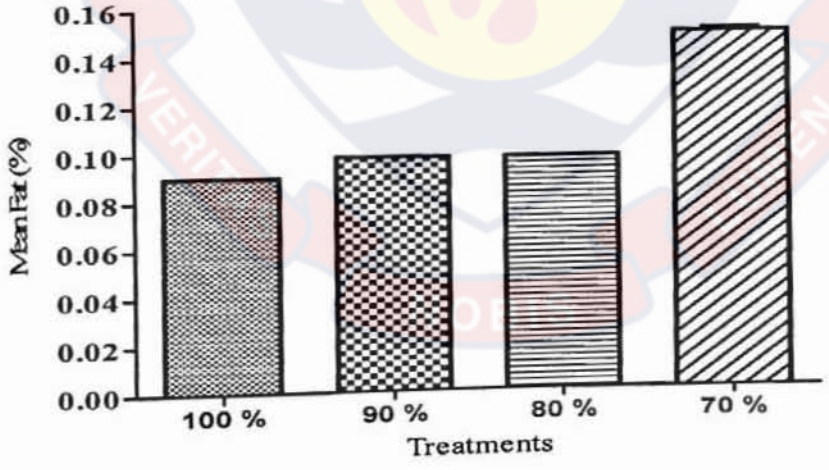

Figure 24: Fat content of tomato grown under different water treatments with standard error bars

The fat content of the tomato for the different water application ranged between 0.09% and 0.15% with treatment 70% ETc recording the highest and

100% ETc recording the least (Figure 24). There was a strong negative correlation (R^2= 0.901) between the fat content of the tomato fruits and the amount of water applied during cultivation (Figure 25).

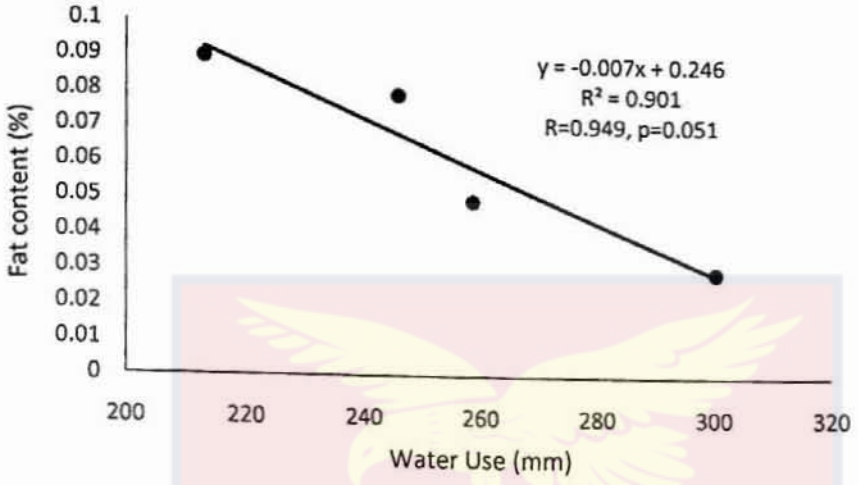

Figure 25: Effect of water used on fat content of tomatoes (Data points are means of replicates)

From the results, the percentage increases in the fat content of the tomatoes with respect to the control (100% ETc) treatment were 10%, 10% and 67.7% for the 90% ETc, 80% ETc and 70% ETc respectively. The range of fat content obtained in this study fell within the 0.1% and 0.2% reported by USDA (2005). Idah *et al.* (2010) also reported a protein content of 0.22% for tomatoes which is higher than that obtained in the current study. The difference may be due to variety and environmental conditions of cultivation. Analysis of variance indicated that the differences in the fat content of the tomato for the various water treatments were significant ($p<0.05$). This result compares favourably with the findings of Noorka and Teixeira da Silva (2012) who reported an increase in fat content with increasing water stress. Navari-Izzo *et al.* (1990)

reported an increase in diacylglycerol, triacylglycerol and glycolipid content in soybean seedling shoots under water stress.

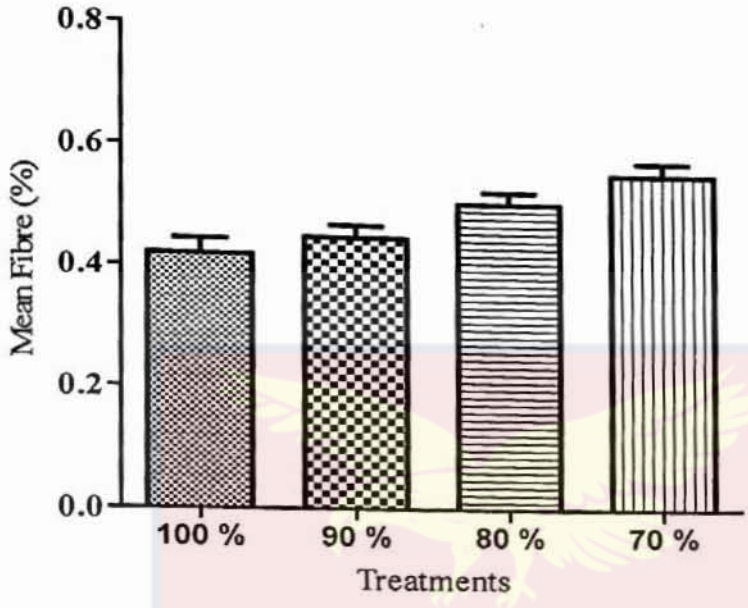

Figure 26: Fibre content of tomato grown under different water treatments with standard error bars

Fibre is the portion of food that is not digested by the digestive enzymes. However, it is very important nutrition -wise because it helps improve the peristaltic movement of the bowels thereby preventing constipation and colon cancer.

The fibre contents of the tomato for the different water applications ranged between 0.70% and 1.10% with treatment 70% ETc recording the highest and 100% ETc recording the least (Figure 26). There was a strong negative correlation (R^2=0.908) between the fibre content of the tomato fruits and the amount of water used (Figure 27).

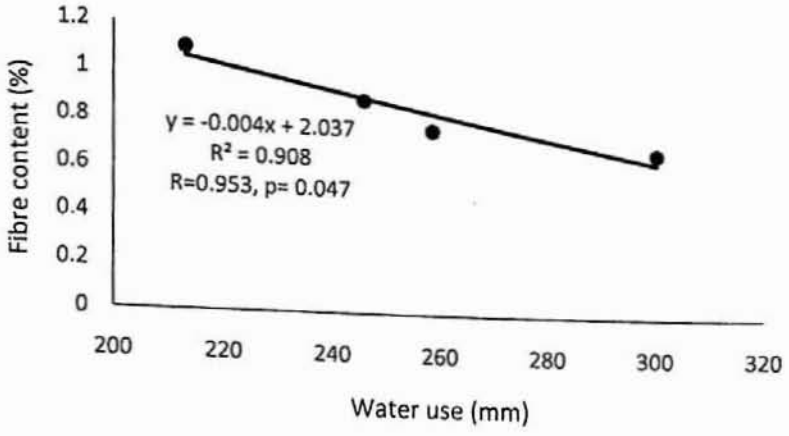

Figure 27: Effect of water used on fibre content of tomatoes (Data points are means of replicates)

The results showed that the percentage increases in the fibre content of the tomatoes with respect to the control (100% ETc) treatment were 7.1%, 21.4% and 33.3 % for the 90% ETc, 80% ETc and 70% ETc respectively. The range of fibre content obtained in the present study fell within the 0.5% and 0.7% reported by USDA (2005). Analysis of variance indicated that the differences in the fibre content of the tomato for the various water treatments were significant ($p<0.05$). There was a significant difference between treatments 100% ETc and 70% ETc, 90% ETc and 70% ETc but not between 100% ETc and 90% ETc and between 80% ETc and 70% ETc.

Carbohydrates are very important food nutrients in the body. They are major sources of energy to the body. The carbohydrate contents of the tomato for the different water application ranged between 7.21% and 11.20% with treatment 70% ETc recording the highest and 100% ETc recording the least (Figure 28). Regression analysis indicated that there was a negative correlation

(R^2= 0.981) between the carbohydrate content of the tomato fruits and the amount of water applied (Figure 29).

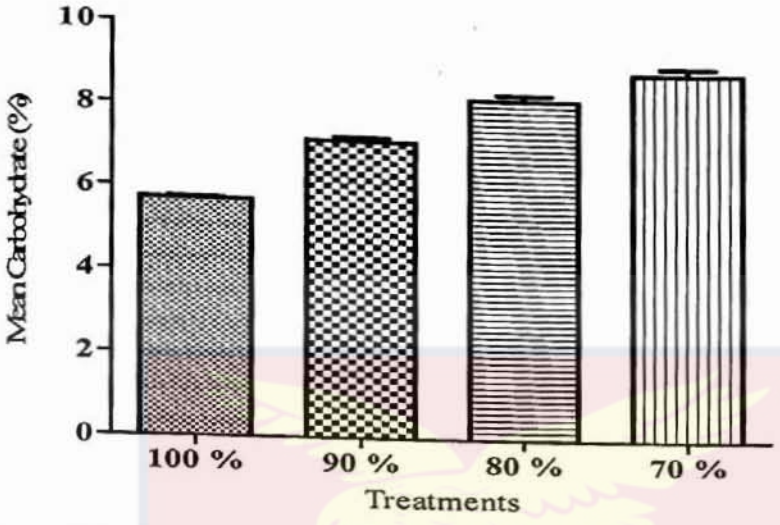

Figure 28: Carbohydrate content of tomato grown under different water treatments with standard error bars

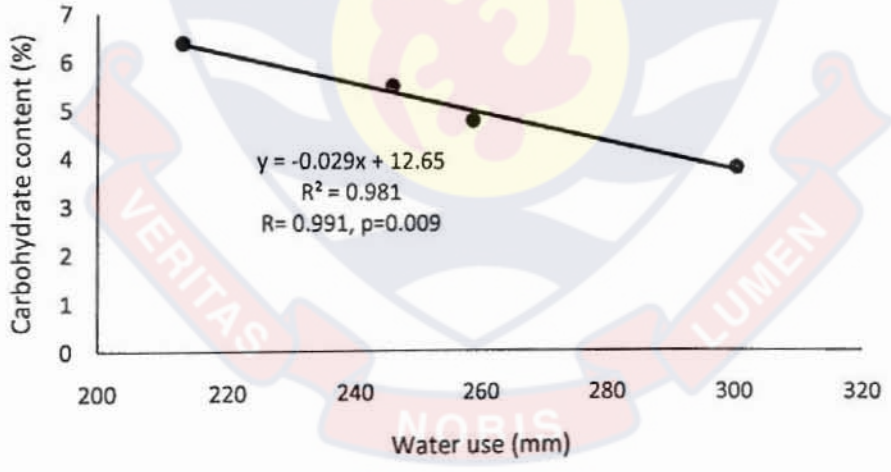

Figure 29: Effect of water used on carbohydrate content of tomatoes (Data points are means of replicates)

The range of carbohydrates obtained in the present study was higher than the 4.7% reported by USDA (2005). Idah *et al.* (2010) also reported a

carbohydrate content of 23.47% for tomatoes which is higher than that obtained in the current study. The difference may be due to variety and environmental conditions of cultivation. Analysis of variance indicated that the differences in the carbohydrate contents of the tomato for the various water treatments were significant ($p<0.05$). The higher carbohydrate content of the tomato treated with 70% ETc may be attributed to the accumulation of soluble sugars in the leaves as a result of water stress which contributed to osmoregulation (Al-Suhaibani, 1996). Levitt (1972) also reported a marked increase in reducing sugars, non reducing sugars and total carbohydrates in sunflower leaves under water stress.

The concentration of minerals K, Ca, Mg, Na, Fe, Cu and Zn of tomatoes was observed to decrease with decreasing level of irrigation water from 100% ETc to 70% ETc (Table 10). The highest mean mineral concentration in tomato fruit was obtained with 100% ETc irrigation treatment and the 70% ETc treatment had the least mineral concentration. The analysis of variance indicated that the different irrigation treatments had significant effects ($p<0.05$) on the concentrations of all the minerals (Ca, Mg, K, Na, Fe, Cu and Zn) in the tomato. Deficit irrigation affects the absorption of nutrient elements due to reduction in vegetative growth of plant (Pascale *et al.*, 2001). Reduced irrigation affects the rate of transpiration in plant (Nakajima *et al.*, 2004). The increase in mineral content of the fruit with increase in the amount of irrigation water may be attributed to the release of more mineral ions in solution as irrigation water increased which in turn increased the rate of absorption by the plant roots. Therefore, a decrease in the amount of water in the soil would

reduce the amount of minerals absorbed by the roots and hence reduce the mineral content of the fruits (Pascale *et al.*, 2001).

Table 10 shows the mean mineral (K, Ca, Mg, Fe, Cu and Zn) concentration of tomato fruits cultivated under the different water applications (70% ETc, 80% ETc, 90% ETc and 100% ETc).

Table 10: Mean concentration (ppm) of minerals in tomato fruit cultivated under different water applications

Treatment	Mean mineral concentration (ppm)						
	Ca	**Mg**	**K**	**Na**	**Fe**	**Cu**	**Zn**
100%	0.009^{b}	0.002^{b}	46.245^{c}	26.340^{c}	0.535^{c}	0.055^{b}	0.170^{c}
90%	0.009^{b}	0.002^{b}	43.480^{b}	24.110^{b}	0.490^{b}	0.050^{b}	0.150^{bc}
80%	0.006^{a}	0.001^{a}	42.320^{a}	23.530^{a}	0.475^{b}	0.045^{a}	0.120^{ab}
70%	0.003^{a}	0.001^{a}	42.253^{a}	23.217^{a}	0.297^{a}	0.043^{a}	0.097^{a}
L.s.d.	0.001	0.029	0.001	0.000	0.001	0.015	0.010

Mean values down each column with similar or same superscripts are not significantly different at L.s.d.=p >0.05

De Carvalho and Saraiva (2005) reported that water stress caused a decrease in calcium content of plants. According to Taylor *et al.* (2004), reduced irrigation increases evapotranspiration rate and hence reduces calcium uptake by tomato fruit resulting in the incidence of blossom end rot.

When plants are stressed to low internal water potential, uptake of nutrients usually decrease due to diminishing absorbing power of roots

(Dunham & Nye, 1976). According to Nahar and Gretzmacher (2002), the uptake of magnesium by tomato plant was significantly reduced by water stress.

The result of this study is in agreement with Griffith *et al.* (1992) who reported that regulated deficit irrigated fruits contain less potassium than control fruits. According to Nahar and Gretzmacher (2002), the uptake of potassium by tomato plant was significantly reduced by water stress. Osuagwu and Edeoga (2012) also observed a significant decrease in potassium content in the leaves of *Gongrolema latifolium* with decreasing water application. A decrease in potassium concentration with water stress in *Dalbergonia sisso* leaf was also demonstrated by Singh and Singh (2004). They attributed it to translocation of potassium from leaf to stem of stressed seedlings.

In tomato, the ability of roots to exclude sodium from the rest of the plant decreased rapidly as the level of K in the nutrient solutions fell (Besford, 1978). The rate of transpiration can influence uptake and movement of some ions in plants (Weatherley & Rorison, 1969). These findings confirm the decrease in sodium content of tomato fruits (Table 10). In contrast, Abdel-Rahman *et al.* (1971) reported that water stress generally favours the uptake of sodium in drought tolerant maize crops.

Iron uptake was significantly affected by the different irrigation treatments due to irrigation disruption at different stages of growth of chamomile plants (Pirzad *et al.*, 2012). According to Oktem (2008), water stress reduces iron uptake in sweet corn.

According to Singh and Singh (2004), increasing water stress decreased the level of copper in leaf of *Dalbergonia sisso* due to a decrease in biomass

accumulation and decrease in ion mobility as a result of increase in impedance in *Dalberon giasisso* seedlings.

The decrease in the concentration of zinc with water stress from this study was not in agreement with the findings of Pirzad *et al.* (2012) whose work showed that different water application had no significant effect on zinc uptake of German chamomile (*Matricaria chamomilla* L).

Effect of storage on nutritional quality of tomato grown under different water treatment

The results showed a gradual decrease in the moisture contents of the tomato fruits across the storage period for all treatments. The changes in the moisture contents of the fruits during storage were relatively small (Figure 30). The changes in the moisture contents of the tomato from day 0 to day 20 of storage were 91.00-90.19%, 89.65-89.27%, 88.60-88.29% and 88.02-87.58% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. These decreases in the moisture contents of the tomato fruits from day 0 through to day 20, although small, for all the water treatments were significant ($p<0.05$). Analysis of variance indicated also that there were significant differences ($p<0.05$) in the moisture contents of the tomato fruits for the various treatments on each day of storage. These reductions in the moisture contents of the tomato fruits during storage may be due to respiration of the fruits leading to loss of water. As tomato ripens on storage, changes in colour and texture such as development of deep red colour and softening of the tissues affect its quality attributes as they affect tomato sensory quality and determine the end of the shelf life. When loss of water reaches a certain threshold, numerous changes

occur such as decrease in turgidity and firmness, shriveling and decline in nutritional value (Nunes & Emond, 2007).

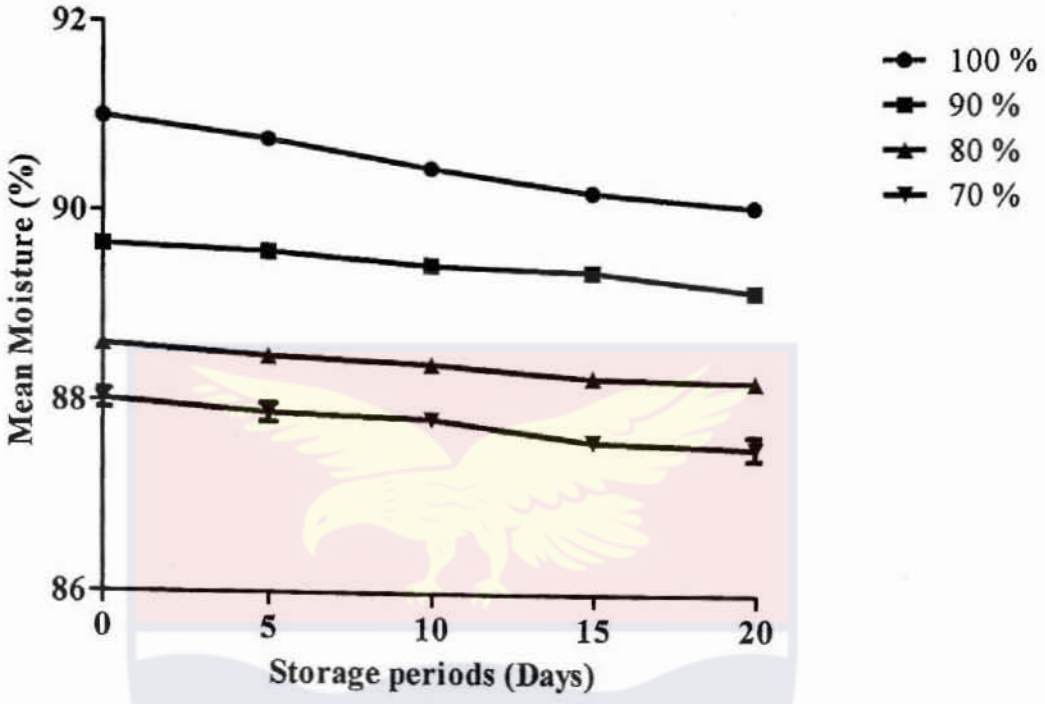

Figure 30: Changes in moisture content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The ash content of the tomato fruits for all the treatments did not change appreciably during storage except treatment 70% ETc which showed a slight decrease on day 15 and 20 of storage (Figure 31). The changes in the ash contents of the tomato from day 0 to day 20 of storage were 0.98-0.89%, 0.78-0.71%, 0.69-0.57% and 0.47-0.27% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. Analysis of variance indicated that there was no significant difference ($p>0.05$) in the ash content of the fruits from 100% ETc treatment. However, there were significant differences ($p<0.05$) in the ash contents of the fruits from treatments 90% ETc, 80% ETc and 70% ETc.

The ash content of food substances is an indication of the mineral content of the food. Mineral contents of fruits do not change during storage except due to leakages from fruits (Hui, 2006). The decrease in the ash content of the fruits at the later days of storage may be due to leakages of the juice of the fruits as storage progressed.

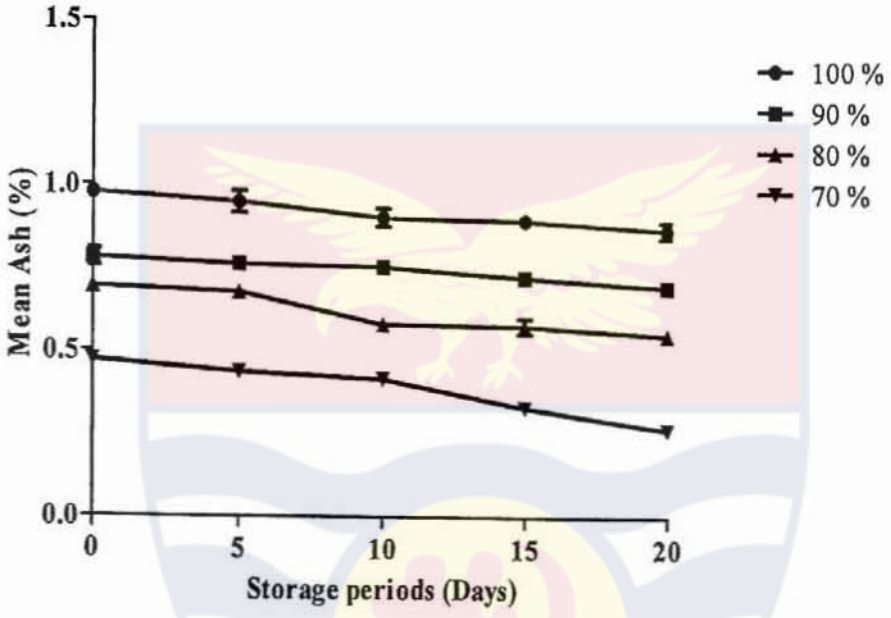

Figure 31: Changes in ash content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The protein content of the tomato decreased gradually across the storage period for all water treatments (Figure 32). The changes in the protein contents of the tomato from day 0 to day 20 of storage were 1.83-1.46%, 1.82-1.67%, 1.80-1.46% and 1.80-1.45% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. Analysis of variance indicated that the differences in the protein contents of the tomato across the storage period were significant ($p<0.05$).

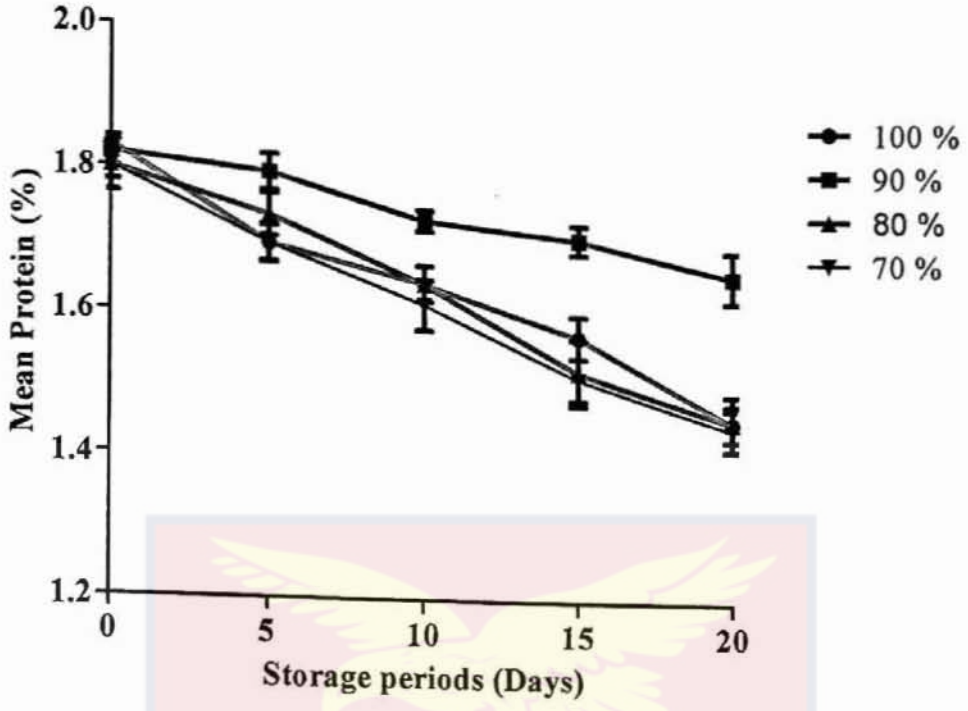

Figure 32: Changes in protein content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

These changes in the protein content during storage may be attributed to the activities of cell wall enzymes such as α-galactosidase, β-galactosidase, β-mannosidase and β-glucosidase which are also responsible for the softening of the fruit (Emadeldin *et al.*, 2012). There were no significant differences ($p>0.05$) in the protein content of the tomato on days 0 and 20 of storage for the various water treatments. However, there were significant differences ($p<0.05$) in the protein contents of the tomato on days 5, 10 and 15 of storage.

The fat content of the tomato decreased across the storage period for all water treatments (Figure 33). The changes in the fat contents of the tomato from day 0 to day 20 of storage were 0.090-0.026%, 0.099-0.047%, 0.099-0.078% and 0.151-0.089% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc

respectively. Analysis of variance indicated that the differences in the fat contents of the tomato across the storage period were significant ($p<0.05$). The differences in the fat content of the tomato from day 0 to day 20 for all the treatments were significant.

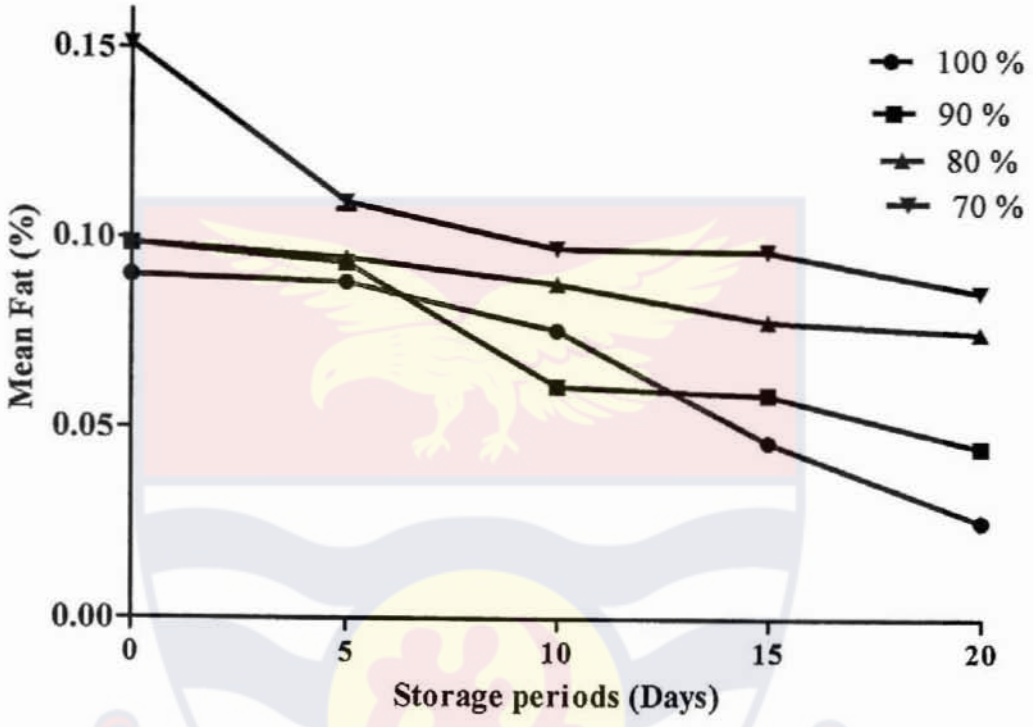

Figure 33: Changes in fat content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The fibre content of the tomato increased gradually across the storage period for all water treatments (Figure 34). The changes in the fibre contents of the tomato from day 0 to day 20 of storage were 0.42-2.00%, 0.45-2.20%, 0.51-2.50% and 0.56-2.80% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. Analysis of variance indicated that the differences in the fibre contents of the tomato across the storage period were significant ($p<0.05$).

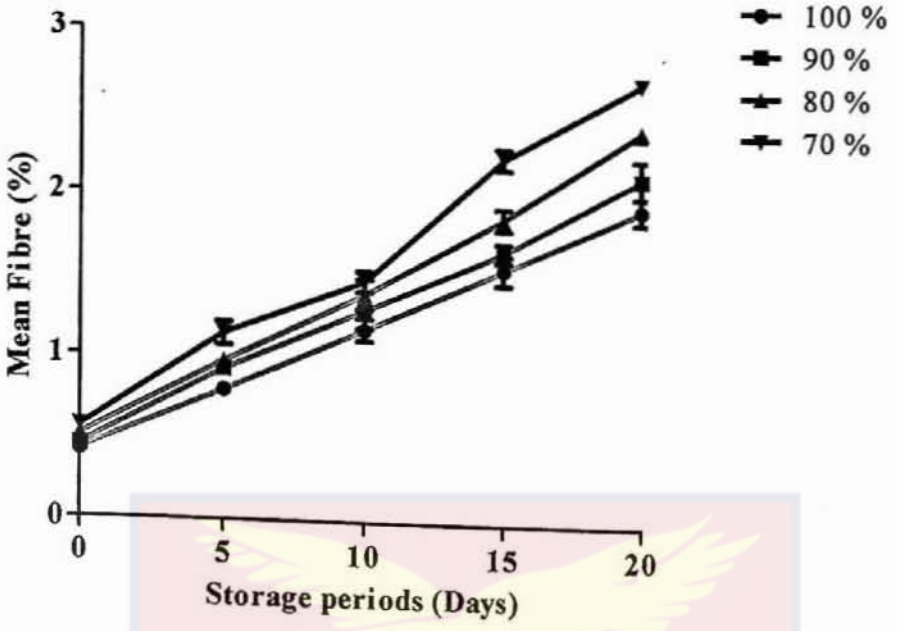

Figure 34: Changes in fibre content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The results showed a gradual decrease in the carbohydrate contents of the tomato fruits across the storage period for all treatments. The changes in the carbohydrate contents of the fruits during storage were relatively small (Figure 35). The changes in the carbohydrate contents of the tomato from day 0 to day 20 of storage were 5.72-5.43%, 7.20-6.10%, 8.30-7.10% and 9.00-7.81% for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively. These decreases in the carbohydrate contents of the tomato fruits from day 0 through to day 20, although small, for all the water treatments were significant ($p<0.05$). Analysis of variance indicated also that there were significant differences ($p<0.05$) in the carbohydrate contents of the tomato fruits for the various treatments on each day of storage. These reductions in the carbohydrate contents of the tomato

fruits during storage may be due to respiration of the fruits since carbohydrates are substrate of respiration.

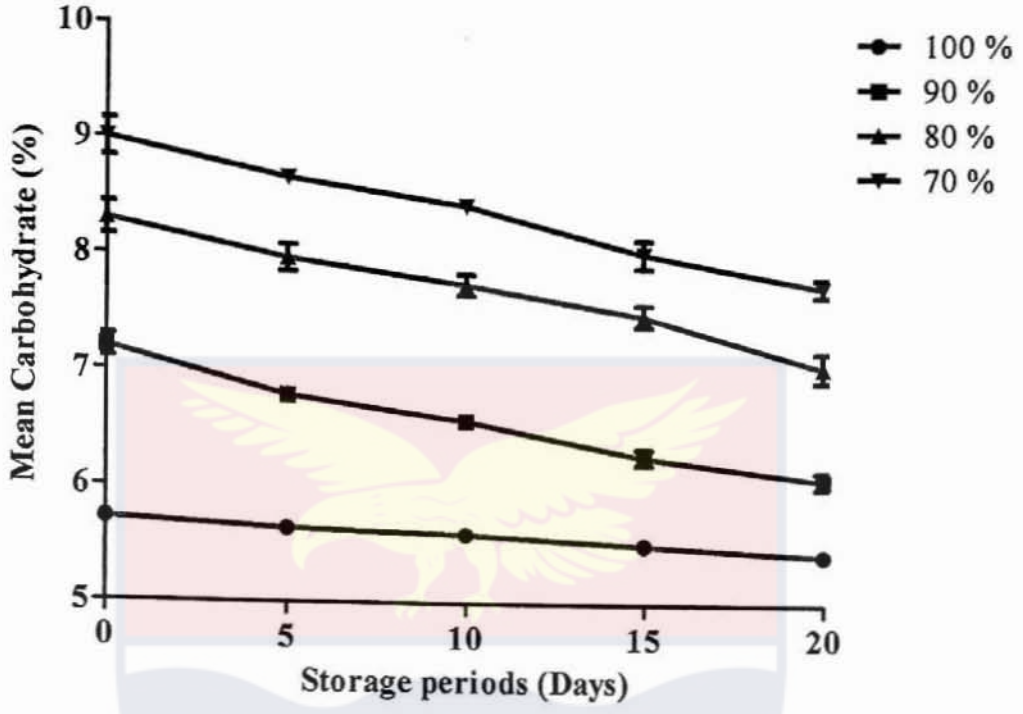

Figure 35: Changes in carbohydrate content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The effects of storage on the mineral (Ca, Mg, K, Na, Fe, Cu and Zn) contents of the tomato fruits for all water treatments are presented in Figures 36 – 42. In general, there were no changes in the mineral contents of the tomato fruits for all the water treatments from day 0 to days 10 and 15 across the storage. However, the mineral contents of the tomato fruits decreased slightly on day 20. These decreases were, however, not significant ($p>0.05$). The decreases may be due to the fact that minerals are not metabolized and therefore do not undergo any major change during storage of fruits except due to leakages as a result of rotting (Hui, 2006). There were, however, significant differences

($p<0.05$) in the minerals contents for the various water treatments on various days of storage.

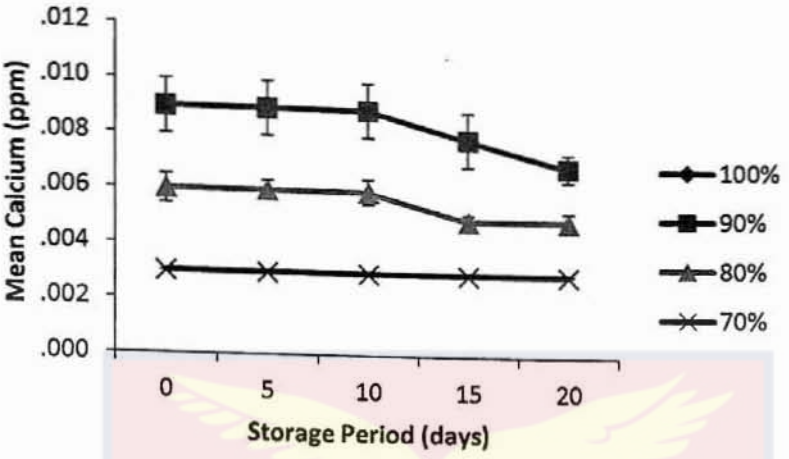

Figure 36: Changes in calcium content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The changes in the calcium contents of the tomato from day 0 to day 20 of storage were 0.009-0.007 ppm, 0.009-0.007 ppm, 0.006-0.005 ppm and 0.003-0.003 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 36). These values of calcium did not compare favourably with USDA standards of 0.4 – 1.3 ppm. The difference may be attributed to variety and soil mineral content.

The changes in the magnesium contents of the tomato from day 0 to day 20 of storage were 0.002-0.002 ppm, 0.002-0.002 ppm, 0.001-0.001 ppm and 0.001-0.001 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 37). Thus there were no changes in magnesium contents of the tomato fruits across the storage for all water treatments. However, treatments 100% ETc and 90% ETc recorded the same values for magnesium

while treatments 80% ETc and 70% ETc also recorded same values for magnesium.

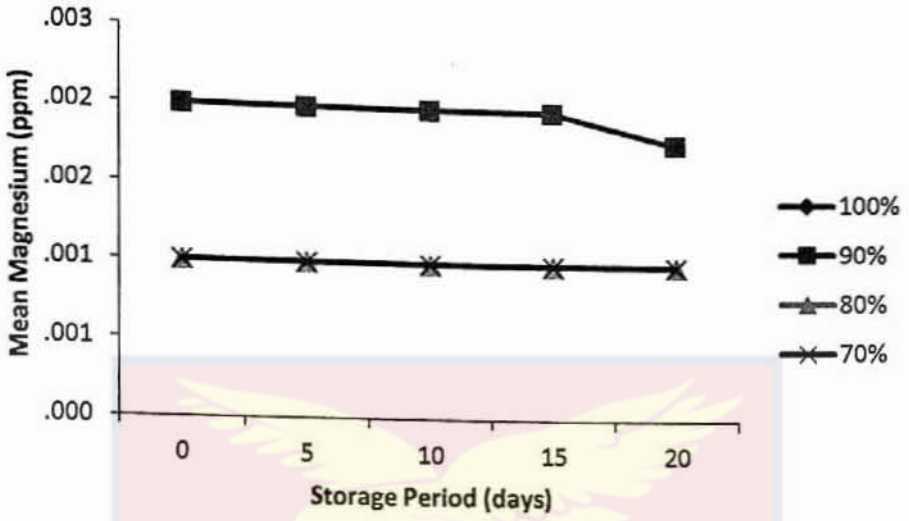

Figure 37: Changes in magnesium content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The changes in the potassium contents of the tomato from day 0 to day 20 of storage were 46.25-44.21 ppm, 43.48-43.00 ppm, 42.32-41.88 ppm and 42.25-40.86 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 38). These values of potassium were higher than that of US Department of Agriculture standards of 24.4 ppm (USDA, 2005). The difference may be attributed to variety and soil mineral content.

The changes in the sodium contents of the tomato from day 0 to day 20 of storage were 26.34-26.00 ppm, 24.11-23.62 ppm, 23.53-23.42 ppm and 23.22-23.21 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 39). These values of sodium were higher than that of US Department of Agriculture standards of 0.30 – 3.5 ppm (USDA, 2005). The difference may be attributed to variety and soil mineral content.

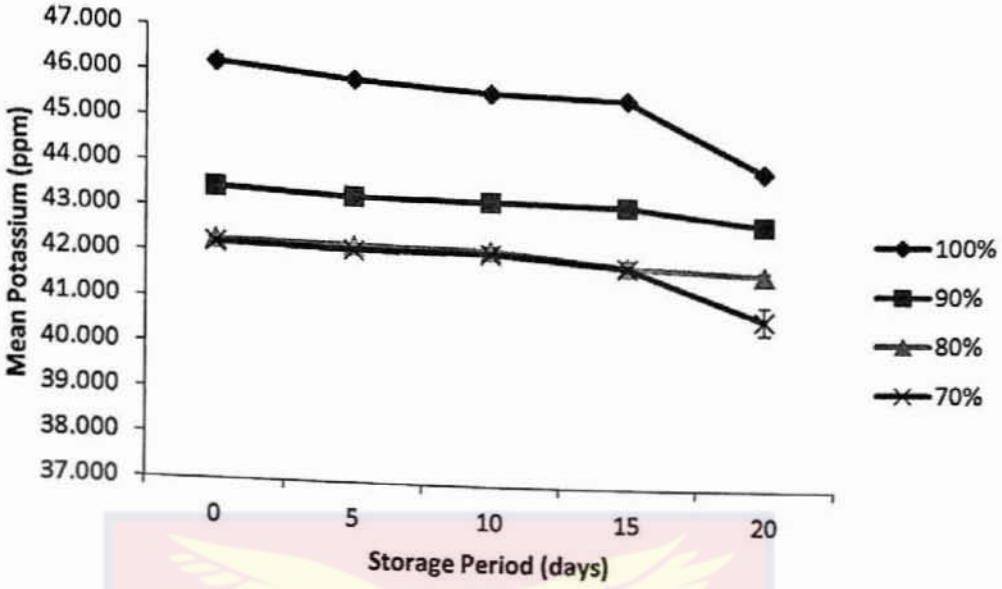

Figure 38: Changes in potassium content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

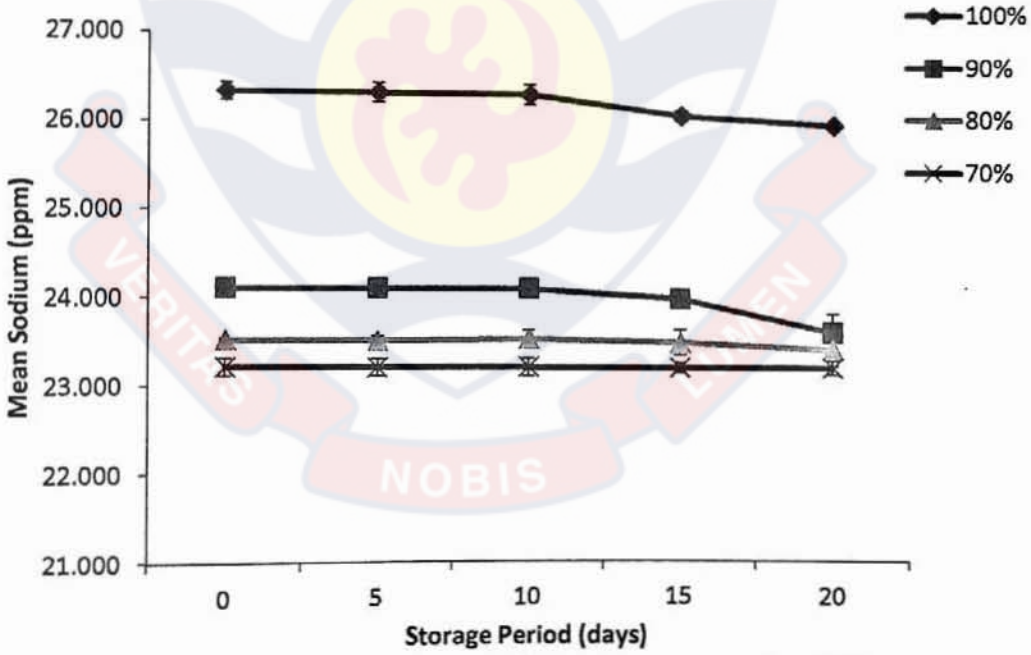

Figure 39: Changes in sodium content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The changes in the iron contents of the tomato from day 0 to day 20 of storage were 0.54-0.50 ppm, 0.49-0.44 ppm, 0.48-.044 ppm and 0.30-0.27 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 40). These values of iron were higher than that of US Department of Agriculture standards of 0.05 – 0.08 ppm (USDA, 2005). The difference may be attributed to variety and soil mineral content.

The changes in the copper contents of the tomato from day 0 to day 20 of storage were 0.055-0.052 ppm, 0.050-0.047 ppm, 0.045-.043 ppm and 0.043-0.042 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 41). These values of copper were higher than 0.005 reported by Oyetayo and Ibitoye (1994)) for fresh tomato fruits. The difference may be attributed to variety and soil mineral content.

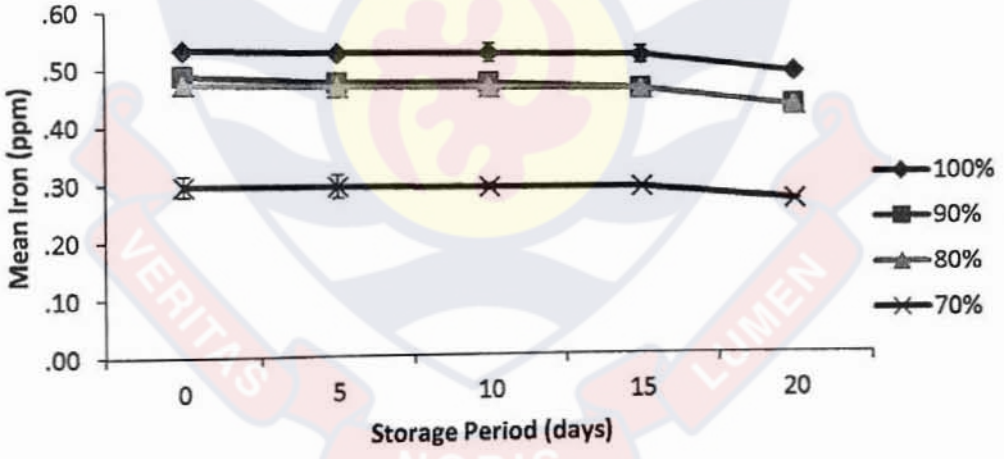

Figure 40: Changes in iron content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

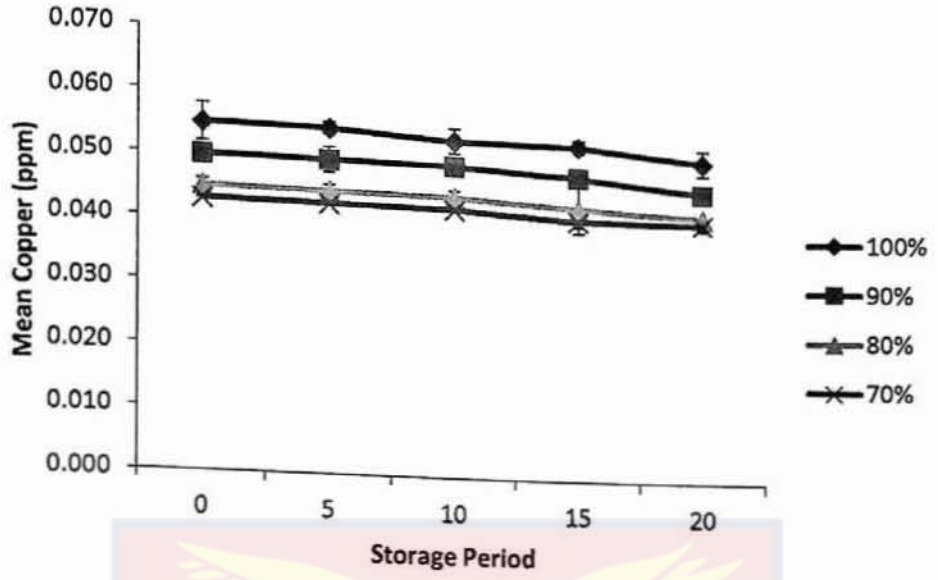

Figure 41: Changes in copper content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

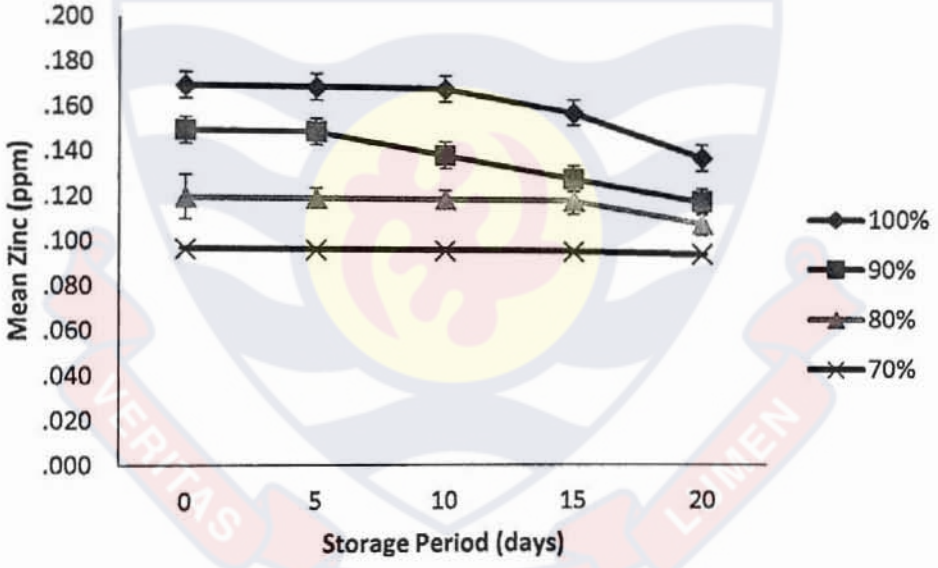

Figure 42: Changes in zinc content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The changes in the zinc contents of the tomato from day 0 to day 20 of storage were 0.170-0.140 ppm, 0.150-0.120 ppm, 0.120-.110 ppm and 0.097-0.096 ppm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively

(Figure 42). These values of zinc were higher than 0.031 reported by Oyetayo and Ibitoye (1994) for fresh tomato fruits. The difference may be attributed to variety and soil mineral content.

Conclusions

Based on the results obtained from this study, it can be concluded that deficit irrigation has both positive and negative effects on the nutritional and mineral compositions of the Pectomech variety of tomato.

Deficit irrigation caused increases in fat, fibre and carbohydrate contents of the tomato fruits. However, decreases in moisture, ash, protein, calcium, magnesium, potassium, sodium, iron, copper and zinc contents of the tomato fruits with decreasing water applications were recorded. There were significant differences ($p<0.05$) in the moisture, ash, fat, fibre, carbohydrate and all the mineral (Ca, Mg, K, Na, Fe, Cu and Zn) contents of the tomato for the various water treatments. However, the differences in the protein contents of the tomato fruits were not significant.

Considering the percentage increases and decreases obtained for nutritional compositions of the tomatoes in this study, it can be concluded that a 10-20% reduction in the amount or volume of water applied in the cultivation of the Pectomech tomato variety in the coastal savannah zone of Ghana would produce tomato with optimum quality that would compensate for yield losses.

CHAPTER SIX

EFFECT OF DEFICIT IRRIGATION ON ANTIOXIDANT QUALITY OF TOMATO AFTER HARVEST AND DURING STORAGE

Introduction

Tomato (*Solanum lycopersicum*) is one of the most widely consumed vegetables worldwide. It is a key component of the diet of many people which is strongly associated with a reduced risk of chronic degenerative diseases (Agarwal a& Rao, 2000; Rao & Agarwal, 1998).

Tomato is a major source of antioxidants contributing to the daily intake of a significant amount of these molecules. It is consumed fresh or as processed products such as canned tomato, sauce, juice ketchup, stews and soup (Lenucci *et al.*, 2006). In fact, epidemiological studies have shown that consumption of raw tomato and its tomato based products is associated with a reduced risk of cancer and cardiovascular diseases (Clinton, 1998; Giovannucci *et al.*, 2002). This protective effect has been mainly attributed to its valuable bioactive components with antioxidant properties (Borguini & Torres, 2009).

Tomato antioxidants include carotenoids such as β-carotene, a precursor of vitamin A, and mainly lycopene, which is largely responsible for the red colour of the fruit, vitamins such as vitamin C (ascorbic acid) and vitamin E (tocopherols), and phenolic compounds such as flavonoids and hydroxycinnamic acid derivatives (Borguini & Torres, 2009; Clinton, 1998; Kotkov *et al.*, 2009; Kotkov *et al.*, 2011; Moco *et al.*, 2006; Vallverdú-Queralt *et al.*, 2011). These compounds may play an important role inhibiting reactive

oxygen species (ROS) responsible for many important diseases, through free-radical scavenging, metal chelation, inhibition of cellular proliferation, and modulation of enzymatic activity and signal transduction pathways (Clinton, 1998; Crozier *et al.*, 2009). ROS are constantly produced and the production is enhanced by various environmental and biological factors. Generally, ROS induce oxidative damage to key biological sites such as DNA and the lipid membranes of cells, resulting in accumulation of oxidative damage with age which eventually contributes to the senescence and development of age-related diseases (Benzie, 2003).

Health qualities of processing tomato fruit are determined by the interactions between varieties; environmental factors such as light, temperature, and water supply; and the composition of the nutrient solution and crop management (Dorais, 2007). Water supply is important for yield quantity and quality but it is limited worldwide and there is an increasing necessity to reduce the quantity of water used in irrigation practices (Zegbe-Domínguez *et al.*, 2003; Favati *et al.*, 2009). Currently, there is not much literature regarding influence of irrigation practices on the antioxidant composition of tomato (lycopene, phenolic compounds, ascorbic acid etc.). Lycopene is the main pigment of tomato and a well-known, colourful, and nutritionally beneficial carotenoid substance in tomato berries. Lycopene is an acyclic, biologically active carotenoid contained in different foods, and its preventive role in several cancerous diseases has been proven by epidemiological and experimental data. Its beneficial role in the maintenance of human health is related to its significant antioxidant properties (Lugasi *et al.*, 2004). Processing can increase the

bioavailability of bioactive compounds like lycopene, since the bioavailability is higher after the intake of processed tomato paste or juice than of a raw tomato (Unlu *et al.*, 2007). Gartner *et al.* (1997) recorded that lycopene ingested from tomato puree had an effect 2.5 times stronger than the ingestion of the same amount of fresh tomatoes. The most important isomers of lycopene are cis- and trans-lycopene. The trans configuration makes up 95.4% of the lycopene in fresh tomatoes. During processing, a remarkable amount of trans-lycopene transforms into cis-lycopene (Barrett & Anton, 2001). The lycopene content of tomato fruits is influenced by the variety and also by the cultivation methods and environmental conditions. Chlorophyll breaks down and carotenoids, mostly lycopene, accumulate during the ripening process (Brandt *et al.*, 2006; Helyes *et al.*, 2006). According to Helyes *et al.* (2003, 2007), the lycopene content of tomato fruits ranged from 39 to 171 mg/kg. The carotenoid content in tomato can also vary with genotype and cultivar variety. The lycopene and its cis-isomer content determined in 39 tomato genotype varieties ranged from 0.6 to 6.4 mg/100 g and 0.4 to 11.7 mg/100 g for greenhouse and field-grown tomatoes respectively (Kuti & Konuru, 2005). Irrigation is believed to be an important pre-harvest factor influencing the biosynthesis of antioxidant compounds. However, the results of the effects of irrigation on lycopene are not conclusive. De Pascale *et al.* (2001) observed significant increases in lycopene contents when tomatoes were irrigated with moderately saline solution combined with different N fertilizer treatments. However, Naphade (1993) found that moisture stress reduced lycopene content in some tomato varieties, while increasing lycopene as well as beta-carotene content in others.

Tomato fruits are also rich in polyphenols, which amount to the largest part of the antioxidant capacity of the soluble phase. Thermal stress induces the accumulation of phenolic compounds like flavonoids and phenylpropanoids. At 35 °C, the polyphenol level is double that produced at 25 °C (George *et al.*, 2004). According to Helyes *et al.* (2006), the polyphenol content of tomato fruits did not change significantly during the ripening process.

Higher temperatures seem to be favourable for ascorbic acid synthesis. In addition, solar exposure is probably required for further ascorbic acid accumulation, but this was ambiguous during a ripening process (Wold *et al.*, 2004). Dumas *et al.* (2003) observed that ascorbic acid increased by as much as 66% when plants with mature green fruits were moved from the shade into the sunshine.

During postharvest storage, a number of chemical and physical processes take place in vegetables. Apart from physical quality, serious losses also occur in the essential nutrients, vitamins and antioxidant composition of tomatoes.

The aim of this study was to establish the effects of deficit irrigation and postharvest storage on the antioxidant compositions (lycopene, beta carotene, ascorbic acid, tocopherols and phenolic compounds) of tomato (pectomech variety). The specific objectives were todetermine the:

- carotenoid (lycopene and β-carotene) contents of tomato grown under different water regimes.
- min content (ascorbic acid and vitamin E) of tomato grown under the re regimes.

3. poly phenolic compounds (flavanoids and total phenolics) of tomato grown under the different water regimes.
4. changes in the lycopene, beta carotene, ascorbic acid, vitamin E, flavonoids and total phenolics compositions of tomato grown under the different water regimes during postharvest storage.

Materials and methods

Sample collection and analysis

Tomato samples grown under the various water regimes (100% ETc, 90% ETc, 80% ETc and 70% ETc) were collected from the School of Agriculture Research Farm, University of Cape Coast and sent to the School of Agriculture Research Laboratory for analysis. Analysis was carried out for carotenoids (lycopene and beta carotene), antioxidant vitamins (ascorbic acid and vitamin E) and polyphenolic compounds (flavanoids and total phenolics). All analyses were carried out in triplicates.

Determination of antioxidant components

The determination of lycopene content of the tomato was carried out using the method described by Ranganna (2003). The lycopene was extracted with acetone and petroleum ether. The absorbance of the extract was measured with a spectrophotometer (Cecil CE102/1000 series) at 503 nm using petroleum ether as blank. The lycopene content of the sample was then calculated.

The determination of the beta carotene content of the tomato was carried out according to the method of (AOAC, 1980). The beta carotene was extracted with 95% ethanol and petroleum ether (40-60°C). The absorbance of the

extracts was measured using a spectrophotometer (Cecil CE 102/1000 series) at a wavelength of 436 nm using petroleum ether (blank) as blank. The concentration of beta carotene in the sample was then calculated.

The ascorbic acid content of the tomato was determined using the method described by Sadasivam and Manickam (1996). The ascorbic acid in the tomato pulp was extracted with 4% oxalic acid and 2,4- dinitrophynyl hydrazine (DNPH) was added for colour development. The absorbance of the extract was measured by spectrophotometer (Cecil CE102/ 1000 SERIES) at 540 nm. The ascorbic acid content was extrapolated from ascorbic acid standard graph and the content in the sample was determined.

The determination of vitamin E in the tomato was carried out by using the Furter-Meyer's method which makes use of the oxidation of tocopherols by nitric acid. The vitamin E in the tomato pulp was extracted with diethyl ether and dissolved in absolute ethanol. Absorbance was measured at 470 nm using spectrophotometer (Cecil CE102/ 1000 SERIES) against a blank containing absolute ethanol and concentrated nitric acid. Vitamin E content of the tomato was extrapolated from a standard graph and Vitamin E content in the sample was determined.

The flavonoids content of the tomato was determined by aluminium trichloride method using quercetine as a reference compound described by Kumaran and Kurunakaran (2006). The flavonoids was extracted with ethanol and the absorbance of the extract was then read at 415 nm using a spectrophotometer (Cecil CE102/ 1000 SERIES). Blank samples were prepared from 100 µl of 20% aluminium trichloride and a drop of acetic acid and then

diluted to 5 ml with ethanol. Standard quercetine solutions with varied concentrations were prepared under the same conditions. All determinations were carried out in triplicates. The amount of flavonoids in plant extracts in quercetine equivalent (QE) was then calculated.

The total phenolics content of the tomato was determined using the Folin-Ciocalteau reagent method described by Kumaran and Kurunakaran (2006).

Statistical analysis

Statistical analysis was performed based on one way Analysis of Variance (ANOVA) at a confidence level of 95% using SPSS version 20.0 for Windows. Tukey's HSD Multiple comparison test was used to compare the differences in the means. Simple regression and correlation were conducted to ascertain the relationship between the antioxidant components and the amount of water applied.

Results and discussion

Effect of deficit irrigation on antioxidant quality of tomato

The results showed that the 70% water treatment recorded the highest lycopene content followed by 80% treatment, then 90% treatment and 100% treatment recording the least (Figure 43). The mean value of lycopene was within the range of 2.33-6.0 mg/100g. However, analysis of variance revealed that there was no significant difference ($p>0.05$) between the lycopene contents for the various water treatments. Regression analysis indicated that there was a negative correlation ($R^2 = 0.797$) between the lycopene content of the tomato fruits and the amount of water applied (Figure 44). This indicated that as the

amount of water applied increased lycopene content decreased but these decreases were not significant ($p>0.05$). The observed differences in the lycopene content may be due to stages of ripening of the tomatoes fruit at harvest (Raffo *et al.*, 2002).

According to Kubota *et al.* (2006), lycopene content of tomato increases with water stress. This is in agreement with highest lycopene content of the 70% water treatment than the 80% and 90% water treatment in this study. Enhanced lycopene concentration was also observed by applying water stress caused by limited irrigation (Matsuzoe *et al.*, 1998, Zushi and Matsuzoe, 1998). The higher lycopene content of tomato treated with 70% water may be due to the fact that ethylene synthesis was triggered by water stress leading to early ripening of the fruits and hence an increase in lycopene deposition within the flesh of the tomatoes (Kubota *et al.*, 2006).

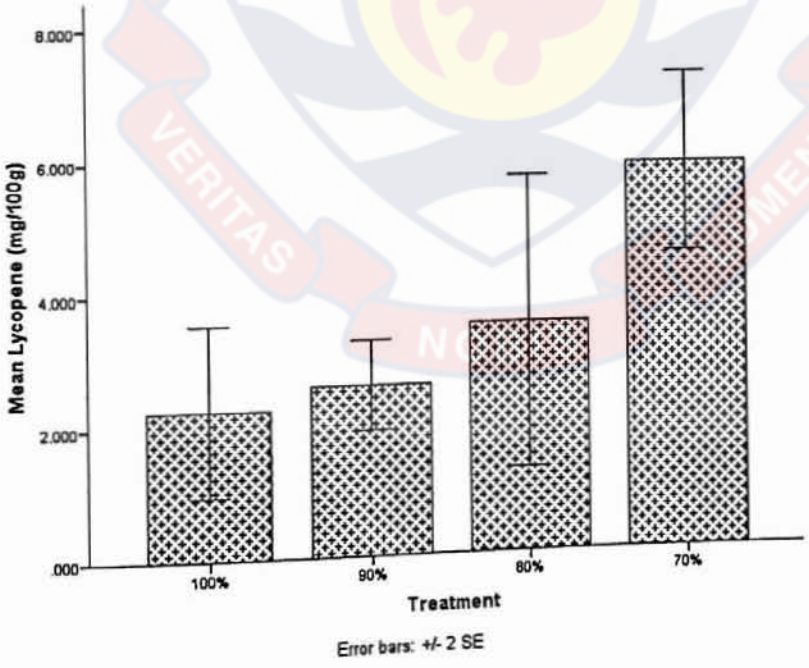

Figure 43: Lycopene content of tomatoes grown under different water applications with standard error bars

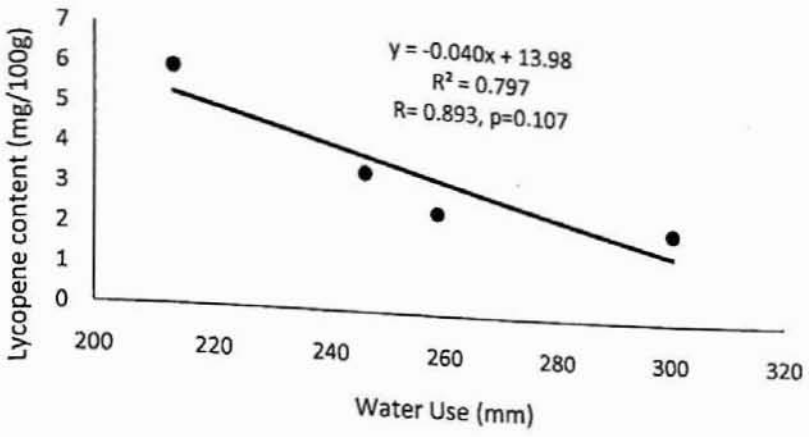

Figure 44: Effect of water used on lycopene content of tomatoes (Data points are means of replicates)

The results showed that the beta carotene content of the tomato grown under the different water regimes was within the range of 0.54-1.24 mg/100g (Figure 45). The beta carotene content of the tomatoes from the different water treatment was in the order 100% ETc > 90% ETc > 80% ETc > 70% ETc. Thus a decrease in beta carotene content with water stress was observed. However, analysis of variance showed that the differences in beta carotene contents of the tomatoes for the different water treatments were not significant ($p>0.05$). Regression analysis indicated a positive correlation ($R^2 = 0.735$) between the beta carotene content and the amount of water applied (Figure 46). Thus, as the amount of water applied increased, beta carotene content of the tomato fruits also increased but these increases in the beta carotene contents were not significant ($p>0.05$).

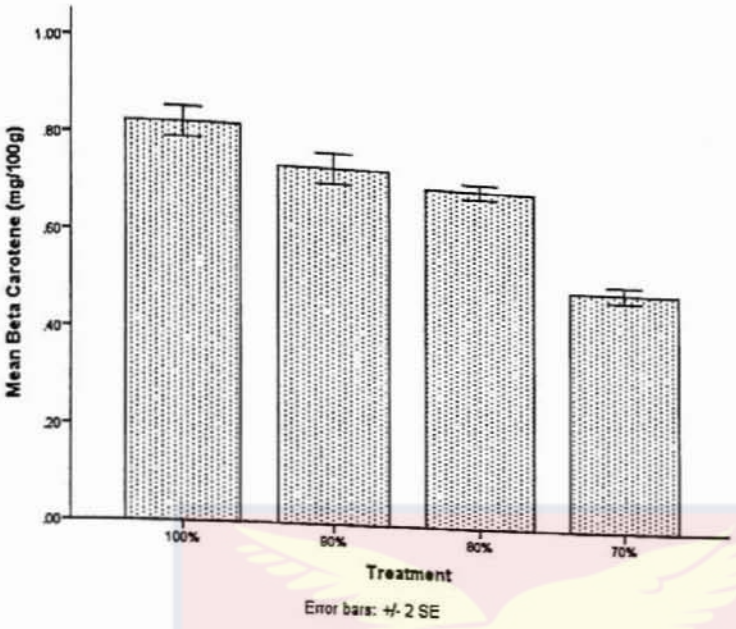

Figure 45: Beta carotene content of tomato grown under different water applications with standard error bars

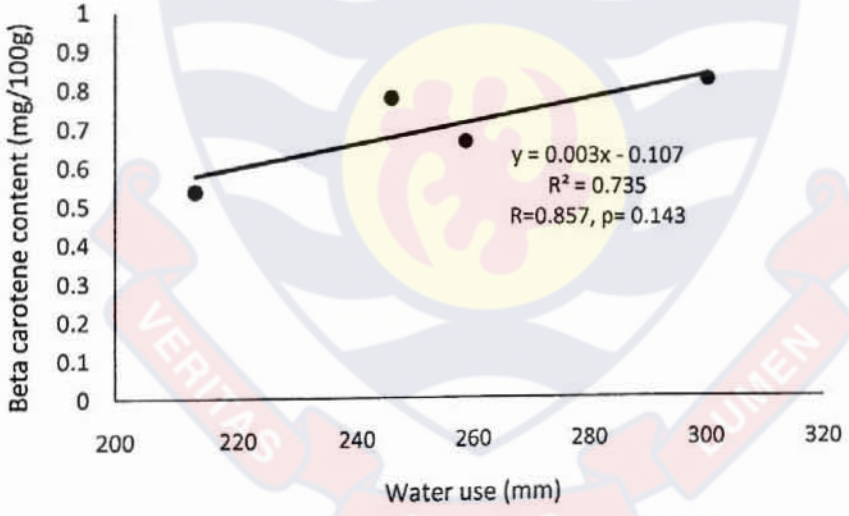

Figure 46: Effect of water used on beta carotene content of tomatoes (Data points are means of replicates)

Matsuzoe *et al.* (1998), investigated the effects of soil water content on fruit colour and beta carotene content in cherry tomato cultivars. They observed that soil water deficit increased the amount of beta carotene in yellow ripening cultivars 'Yellow Carol' but had no effect on the beta carotene content of

orange-ripening cultivars 'Orange Carol. The result of this study did not agree with that of Matsuzoe *et al.* (1998). The result of the current study showed that beta carotene decreased with water deficit. This difference may be due to cultivar, stage of maturity or geographical site of production and climate (Rodriguez –Amaya, 1993). The decrease in beta carotene may also be due the breakdown of chlorophyll as result of ethylene production associated with water stress that results lycopene accumulation withn the flesh of the tomato fruits.

The ascorbic acid content of the fresh fruits from the various water treatments ranged from 19.76±6.75 mg/100 g to 21.44±2.25 mg/100 g. This result compares favourably with that of Watada *et al.* (1976) who reported an average ascorbic acid content of 13.7 mg/100 g to 38.1 mg/100 g for various varieties of tomato. The results showed that tomato fruits produced under the 100% ETc recorded the highest ascorbic acid content (21.44±2.25 mg/100 g) followed by 90% ETc (20.75±1.61 mg/100 g), then 70% ETc (20.28±0.72 mg/100 g) and 80% ETc treatment recording the least (19.76±6.75 mg/100 g) (Figure 47). However, analysis of variance revealed that these differences in the ascorbic acid contents of the tomato for the various water treatment were not significant ($p>0.05$).

Regression analysis conducted indicated that there was a positive correlation ($R^2 = 0.594$) between the ascorbic acid content of the tomato fruits and the amount of water applied (Figure 48). This implied that only 59.4% of the increase in ascorbic acid content of the tomato fruits could be attributed to the amount of water applied and other factors such as soil fertility, variety and

temperature might be responsible for the 41.6% increase in the ascorbic acid content of the tomato fruits.

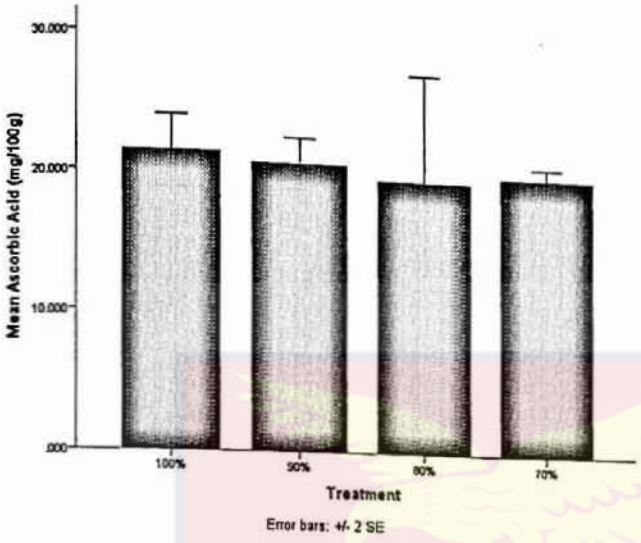

Figure 47: Ascorbic acid content of tomato grown under different water applications with standard error bars

Gharezi *et al.* (2012) also reported ascorbic acid content of 23.66 mg/100 g for cherry tomato. Mahendran and Bandara (2000) reported that moisture stress reduced the ascorbic acid content of chilli fruits. The proposed route for ascorbic acid synthesis commences from D – glucose (Counsel & Horning, 1981). When plants experience moisture stress, stomata closed followed by a decline in the CO_2 fixation. A reduction in the D – glucose synthesis would have occurred during the period of stress, which in turn may have reduced the synthesis of ascorbic acid. Moisture stress may have reduced the substrate concentration for ascorbic acid synthesis. Reduction in the substrate may possibly be due to reduced photosynthetic rate.

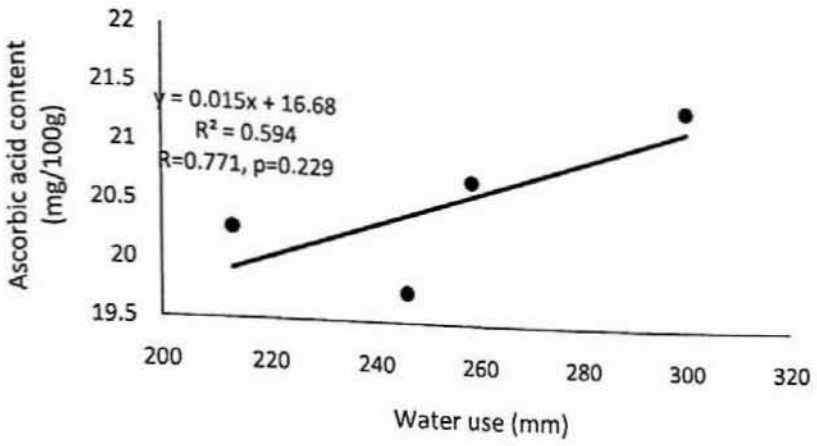

Figure 48: Effect of water used on ascorbic acid content of tomatoes (Data points are means of replicates)

Another possibility of reduction in the ascorbic acid content of the tomato fruits may be increased leaf temperature. The increase in leaf temperature may be due to lowering of transpirational cooling with the onset of stress. Ascorbic acid is very sensitive to changes in environmental conditions. It gets oxidized very rapidly when exposed to high temperatures (Davies *et al.*, 1991). The leaf temperature progressively builds up as a consequence of moisture stress and contributes towards the reduction of ascorbic acid (Mahendran & Bandara, 2000).

There was an increase in the vitamin E of the tomato content with decreasing water application (water stress). That is, treatment 70% ETc recorded the highest vitamin E concentration (1.48±0.77 mg/g), followed by 80% ETc (1.27±0.841.27±0.84 mg/g), 90% ETc (1.05±0.27 mg/g) and 100% ETc having the lowest (0.89±0.68 mg/g) (Figure 49). However, analysis of variance revealed that the differences in the vitamin E contents of the tomato for the various water treatments were not significant ($p>0.05$). Regression and correlation analysis indicated that there was a negative correlation ($R^2 = 0.856$)

between the vitamin E content of the tomato fruits and the amount of water applied (Figure 50), indicating that the reduction in the vitamin E content of the tomato fruits is 85.6% due to the amount of water applied.

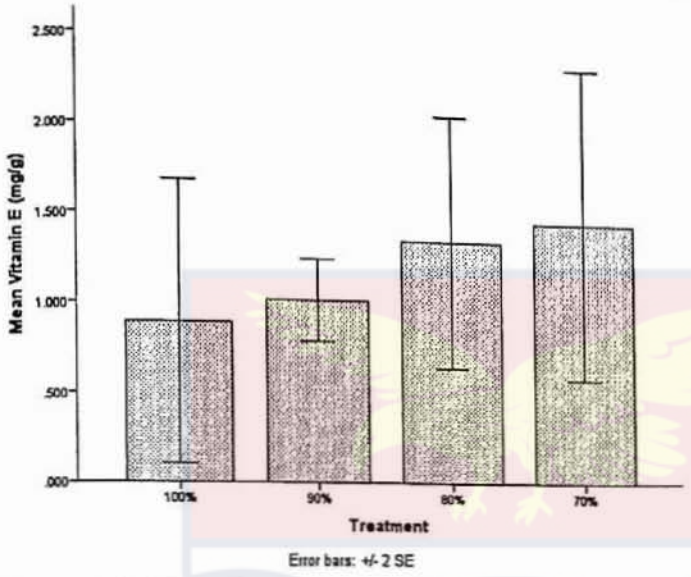

Figure 49: Vitamin E content of tomatoes grown under the different treatments with standard error bars

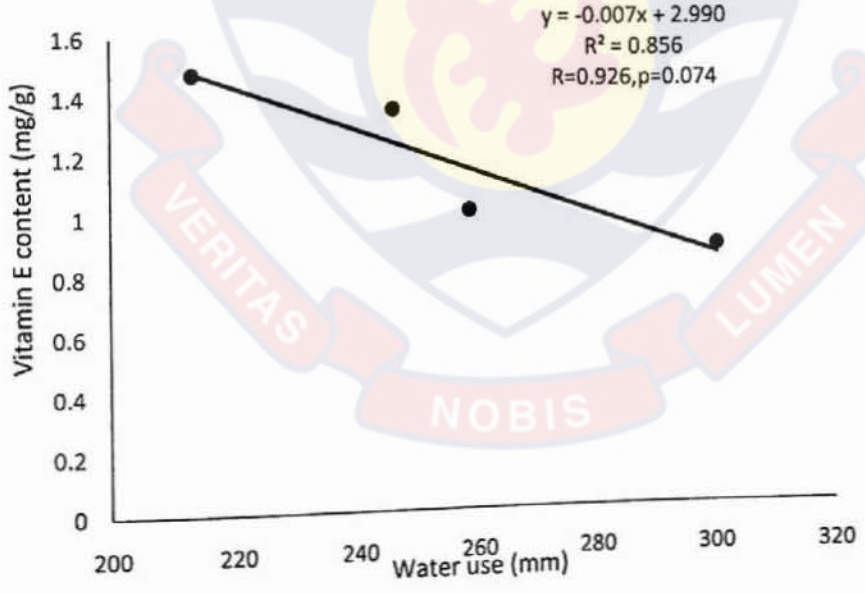

Figure 50: Effect of water used on vitamin E content of tomatoes (Data points are means of replicates)

An increase in antioxidant vitamins including vitamin E with water stress was reported by Zegbe-Dominguez *et al.* (2003) and Shinohara *et al.* (1995). They stated that in view of water stress, the water content of the fruit decreases and the concentration of the fruit constituents increases due to concentration effects.

There was an increase in the flavonoid content of the tomato with decreasing water application (water stress) (Figure 51). Treatment 70% ETc recorded the highest vitamin E concentration (14.53±5.24 mg/g), followed by 80% ETc (12.913±1.02 mg/g), 90% ETc (12.90±4.40 mg/g) and 100% ETc having the lowest (11.20±0.08 mg/g). However, analysis of variance revealed that the differences in the flavonoid contents of the tomato for the various water treatments were not significant ($p>0.05$).

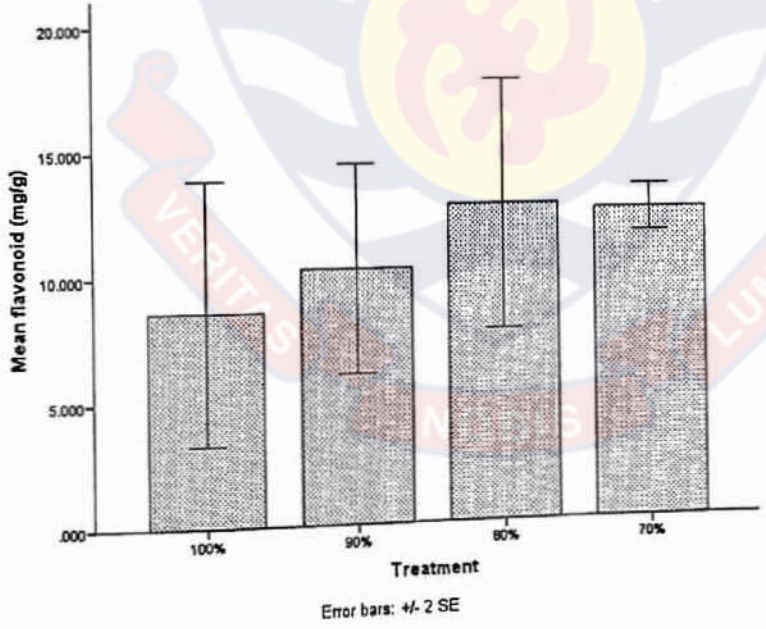

Figure 51: Flavonoid content of tomatoes grown under the different treatments with standard error bars

Regression and correlation analysis indicated that there was a negative correlation ($R^2 = 0.876$) between the flavonoid content of the tomato fruits and the amount of water applied (Figure 52).

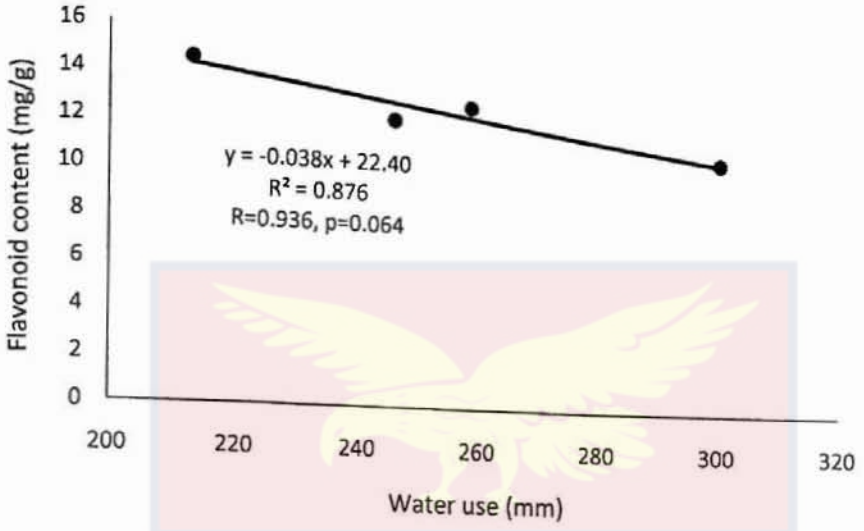

Figure 52: Effect of water used on flavonoid content of tomatoes (Data points are means of replicates)

The result of this study agrees with work done by Shinohara *et al.* (1995), who stated that, in view of water stress, the water content of the fruit decreases and the concentration of the fruit constituents increases due to concentration effects. Sanchez-Rodriguez *et al.* (2011) also reported an increase in flavonoids content of tomato with increasing water stress (Zaina variety). Zegbe-Dominguez *et al.* (2003) also reported that, plants subjected to water stress have high fruit constituents but poor plant growth and yield. Other investigators found translocation of photosynthetic elements into fruits to be promoted by water stress (Shinohara *et al.*, 1995).

The total phenolics content of the tomato for the various water treatments was in the order 70% ETc > 90% ETc > 80% ETc > 100% ETc

(Figure 53). The 100% ETc recorded the least value of 0.38±0.05 mg/g, followed by 80% ETc with a value of 0.51±0.14 mg/g, then 90% ETc with a value of 0.52±0.01 mg/g and 70% ETc recording the highest value of 0.820±0.04 mg/g. Analysis of variance indicated that the variations in the total phenolics content of the tomato for the various water treatments were significant ($p<0.05$). The total phenolics content of the tomato at 70% ETc was significantly different ($p<0.05$) from those of 80% ETc, 90%ETc and 100% ETc. However, there was no significant difference ($p>0.05$) in the total phenolics content of tomato treated with 80% ETc, 90% ETc and 100% ETc.

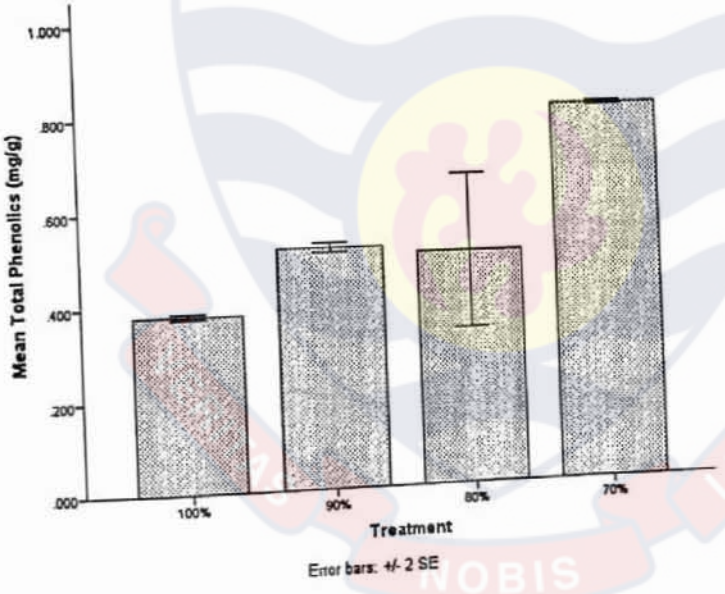

Figure 53: Total phenolics content of tomato grown under the different water treatments with standard error bars

The observed variations in the total phenolics may be attributed to water stress. In view of water stress, the water content of the fruit decreases and the concentration of the fruit constituents increases due to concentration effects. Zegbe-Dominguez *et al.* (2003) and Shinohara *et al.* (1995) reported a similar

increase in total phenolics content of tomato with increasing water stress. Sanchez-Rodriguez *et al.* (2011) also reported an increase in total phenolics contents of tomato with increasing water stress (Zaina variety).

Effect of storage on antioxidant quality of tomato grown under different water treatment

The results of the lycopene content of the tomato for the various water treatments showed a gradual increase from day 0 to day 15 of storage and decreased slightly on day 20 of storage. There were significant differences in the lycopene contents of the tomato ($p<0.05$) across the storage period for treatments 100% ETc, 90% ETc and 80% ETc. However, there were no significant differences ($p>0.05$) for treatment 70% ETc across the storage period. The changes in the lycopene contents of the tomato from day 0 to day 20 of storage were 0.2.25-7.92 mg/100g, 2.61-8.83 mg/100g, 3.53-9.33 mg/100g and 5.96-10.14 mg/100g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 54). The increase in the lycopene content of the tomato during storage might be due to ripening advancements of tomato fruits as a result of chlorophyll degradation and conversion of chloroplasts to chromoplasts (Kubota *et al.*, 2006). The increase in the redness of tomatoes during storage is due to lycopene accumulation in association with internal membrane system (Grierson & Kader, 1986).

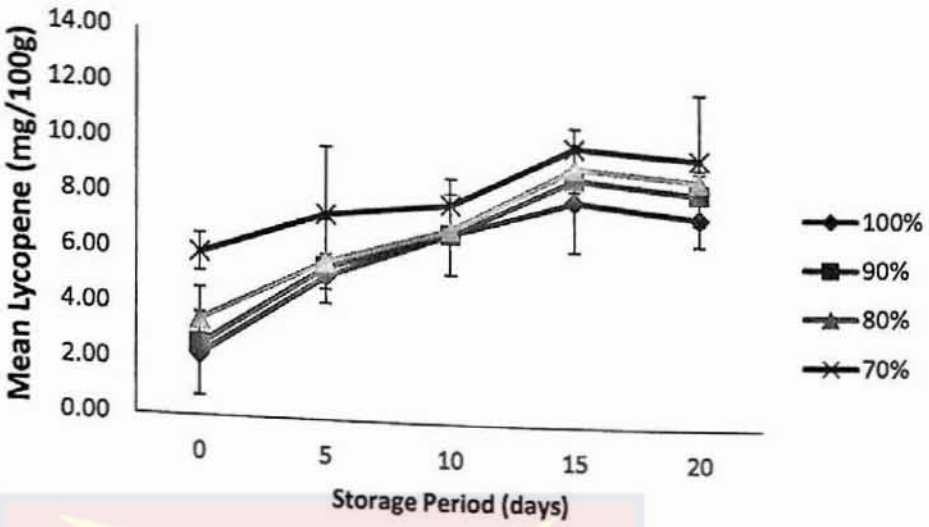

Figure 54: Changes in lycopene content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The slight decrease in the lycopene contents of the tomatoes on day 20 of storage may be due to lycopene degradation at later stage of storage due to long term exposure to oxygen.

The results showed that beta carotene content of the tomatoes decreased for all treatments across the storage period (Figure 55). There were significant differences ($p<0.05$) in beta carotene contents of the tomatoes for all the treatments. At day 20 of storage, there was no significant difference in the beta carotene content of the tomatoes for 100% ETc and 70% ETc treatments. However, from day 0 up to day 15 of storage, there were significant differences in beta carotene contents of the tomatoes for 100% ETc and 70% ETc treatments. The changes in the beta carotene contents of the tomato from day 0 to day 20 of storage were 0.82-0.54 mg/100g, 0.74-0.50 mg/100g, 0.71-0.44 mg/100g and 0.51-0.25 mg/100g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 55).

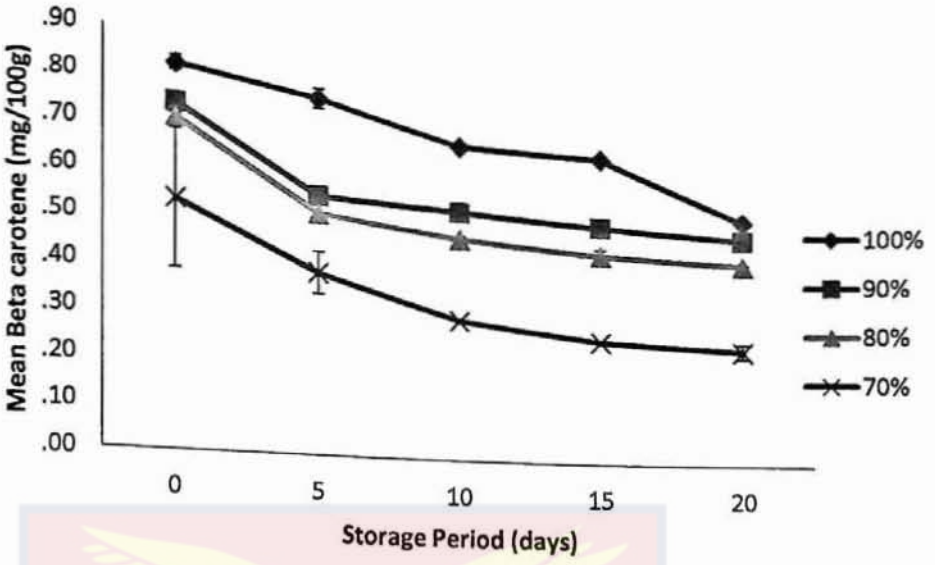

Figure 55: Changes in beta carotene content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The differences in beta carotene contents may be due to water stress and exposure to oxygen during storage. Britton (1991) and Rodriguez-Amaya (1993), reported that oxygen, especially in combination with light and heat is highly destructive. The presence of even traces of oxygen in stored fruits and vegetables (even at deep freeze temperatures) can lead to oxidative degradation leading to formation of aprocarotenoids (carotenoids with shortened carbon chains) the principal cause of extensive losses in carotenoids.

The results of the study showed a drastic reduction in the ascorbic acid content of the tomato fruits across the storage period for all water treatments. Analysis of variance indicted that the changes in the ascorbic acid content of the tomato fruits were significant ($p<0.05$). The changes in the ascorbic acid contents of the tomato from day 0 to day 20 of storage were 21.44-2.76 mg/100g, 20.75-4.14 mg/100g,19.76-4.52 mg/100g and 20.28-4.78 mg/100g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 56). Pal

et al. (2002) reported that vitamin C content of vegetables decreased gradually during storage and transport. The decrease in vitamin C content with storage duration may be attributed to the oxidation of ascorbic acid into dehydro-ascorbic acid by the enzyme ascorbic acid oxidase (Jany *et al.*, 2008). Enzymes require some essential elements and a higher energy level to carry out their malignant activities. Glucose is produced as oxidation takes place in the tomato fruit, and as such the enzymes depend on this energy for their activities. These enzymes make use of the vitamin C in the fruit, thereby decreasing the concentration of the vitamins in the fruit during storage.

Shin *et al.* (2008), Davey and Keulemans (2004) and Kevers *et al.* (2011) also reported that decrease in vitamin C storage might be due to temperature and atmospheric conditions. Under room temperature (25°C), most micro-organism can survive well. As they survive, they deplete the vitamin C concentration since they depend on such elements for growth.

The results showed a decrease in the vitamin E concentration of tomatoes during storage for all the treatments, however, analysis of variance revealed that the reductions are not significant ($p>0.05$). The changes in the vitamin E contents of the tomato from day 0 to day 20 of storage were 0.89-0.45 mg/g, 1.05-0.32 mg/g, 1.27-0.32 mg/g and 1.48-0.24 mg/g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 57). Nazar *et al.* (1996), Eris *et al.* (1994) and Pal *et al.* (2002) reported that antioxidants content decreased gradually during storage and transport. The decrease in antioxidants content with storage duration was attributed to the oxidation and the enzymatic

activities. Antioxidants are reducing agents, and limit oxidative damage to biological structures by passivating them from free radicals.

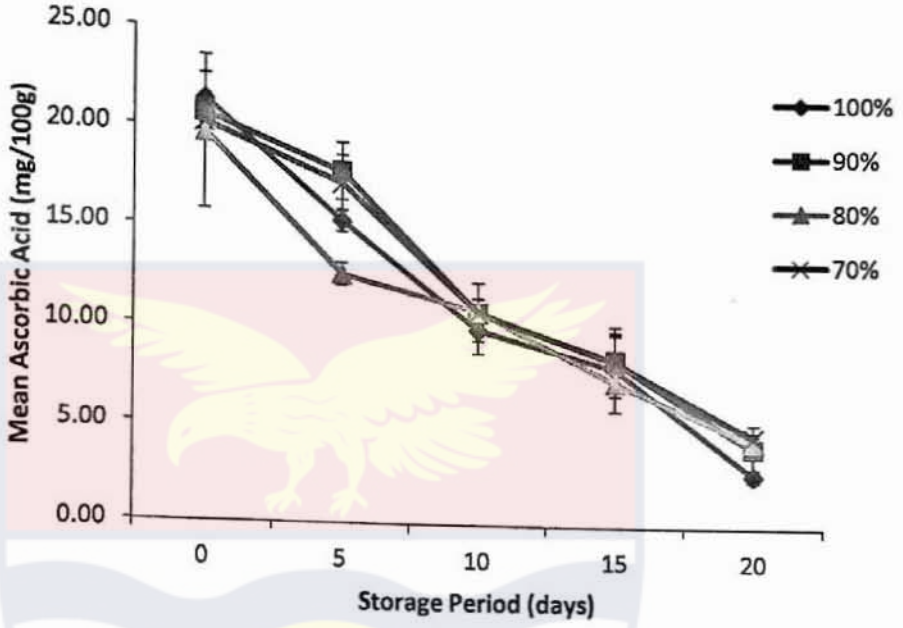

Figure 56: Changes in ascorbic acid content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

Vitamin E loses an electron to a free radical and remain stable itself by passing its unstable electron around the antioxidant molecule. As the fruit is kept for a longer period of time, the vitamin E level decreased due to its inhibiting the formation of free radicals.

The flavonoid content of the tomato decreased across the storage period for all the water treatments. However, this decreases were not significant ($p>0.05$). The changes in the flavonoid contents of the tomato from day 0 to day 20 of storage were 11.20-7.19 mg/g, 12.90-8.54 mg/g, 12.90-8.60 mg/g and 14.53-9.22 mg/g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc respectively (Figure 58).

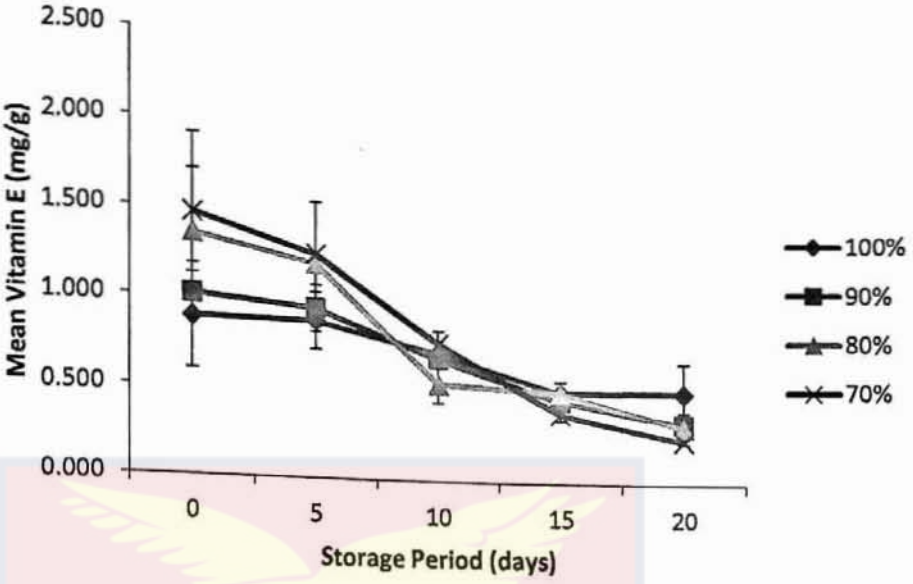

Figure 57: Changes in vitamin E content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

The decrease in the flavonoid contents of the tomato fruits may be attributed to the presence of the enzyme β-glucosidase, which hydrolysis anthocyanin (the most studied flavonoid in terms of storage effects), removing the sugar moiety and releasing the anthocyanidin, which is more easily degraded than the anthocyanin glycoside. Degradation commences with the opening of the middle ring followed by cleavage at this midpoint of the molecule (Amarowicz *et al.*, 2009).

The results showed a decrease in the total phenolics concentration of the tomato fruits during storage for all water treatments. However, analysis of variance indicated that reductions were not significant except for 70% ETc treatment. The changes in the total phenolics contents of the tomato from day 0 to day 20 of storage were 0.38-0.31 mg/g, 0.52-0.35 mg/g, 0.51-0.35 mg/g and 0.82-0.41 mg/g for the 100% ETc, 90% ETc, 80% ETc and 70% ETc

respectively (Figure 59). The decrease in the total phenolics concentration of the tomato fruits may be attributed to oxidation and enzymatic activities reported by Pal *et al.* (2002).

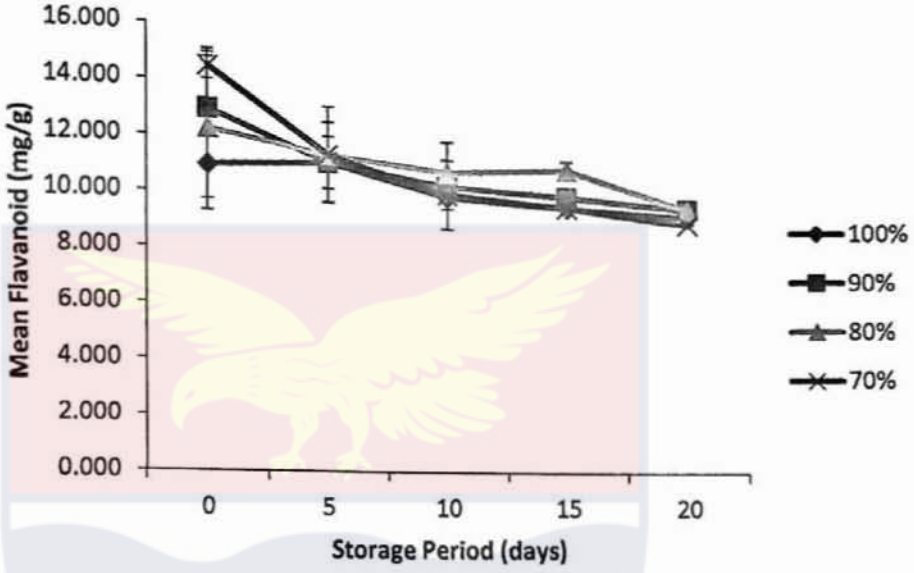

Figure 58: Changes in flavonoids content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

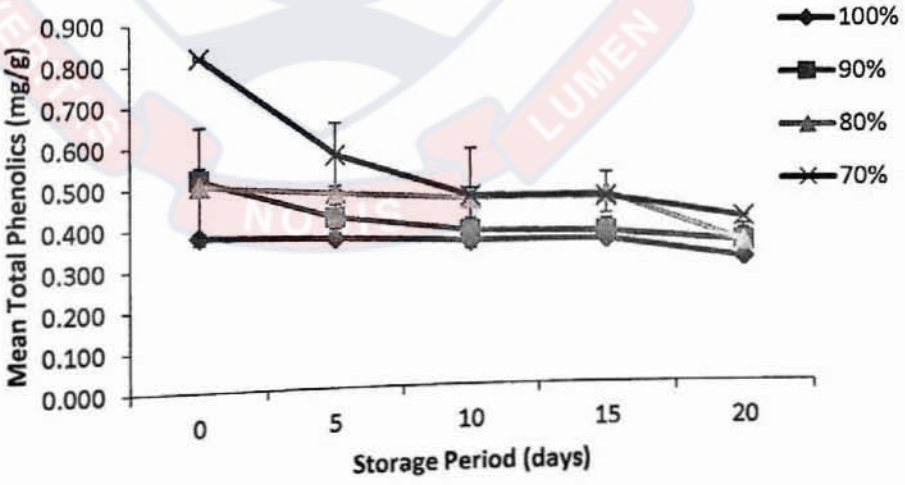

Figure 59: Changes in total phenolics content of tomato grown under different water treatments during storage (Vertical bars represent standard error of the mean)

Conclusions

The aim of the study was to determine the effects of deficit irrigation on the antioxidant compounds (lycopene, beta carotene, ascorbic acid, tocopherols and phenolic compounds) in Pectomech variety of tomato. The results of the study showed that apart from beta carotene and ascorbic acid which decreased with water stress, all the other antioxidant compounds (lycopene, vitamin E, flavonoids and total phenolics) increased with increasing water stress. The analysis of variance indicated that there were no significant differences ($p>0.05$) in the lycopene, beta carotene, ascorbic acid, vitamin E and flavonoid contents of the tomato for the various water treatments. However, the total phenolics content of the tomato at 70% ETc was significantly different ($p<0.05$) from those of 80% ETc, 90%ETc and 100% ETc. There was no significant difference ($p>0.05$) in the total phenolics content of tomato treated with 80% ETc, 90% ETc and 100% ETc.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Introduction

A study involving deficit irrigation practices was conducted at the School of Agriculture Research Farm, University of Cape Coast from July - November 2013. The Pectomech variety of tomato was used in this experiment to observe the effects of water stress on growth and development of tomato plant, physicochemical quality, nutritional and antioxidant compositions of the tomato fruits and postharvest storage of the tomato fruits under different irrigation regimes. Four treatments with three replications were set-up in completely randomized design (CRD).

Throughout the growing period, water lost by the tomato plants under a rain shelter was assessed by weighing (using a weighing scale) and the water equivalent in volume was computed and replaced at two-day intervals. Irrigation was given manually on the basis of water loss from the soil in the different containers (plastic buckets). Plant development components such as height and canopy diameter were measured at initial stage (19 DAT), developmental stage (43 DAT), mid-season stage (69 DAT) and late season stage (87 DAT) by use of a measuring tape, and leaf area and leaf area index were then computed. Reference evapotranspiration (ETo) was determined from climatic data (daily maximum and minimum temperatures, relative humidity, sunshine and wind

speed) obtained from a nearby weather station using the ETo calculator which is based on the FAO modified Penman-Montieth method. Crop coefficient (Kc) and crop water requirement (ETc) for each growth stage were determined. Water use efficiency (WUE) and water saving were also determined. Soil nutrients level (NPK, Ca and organic matter contents) before planting and after harvest were also determined.

At harvest, tomato fruit diameter and tomato yield in terms of number of fruits per plant per treatment, weight of fruits and total yield per hectare were determined. Physicochemical components (fruit firmness, total soluble solids, titratable acidity and pH) were measured. Nutritional components (moisture, ash, protein, fat, fibre and carbohydrate), mineral composition (Ca, Mg, K, Na, Fe, Cu and Zn) and antioxidant components (lycopene, beta carotene, ascorbic acid, vitamin E, flavonoids and total phenolics contents) were also determined.

Storage studies were carried out by determining the changes that occurred in the physicochemical, nutritional, minerals and antioxidant compositions of the tomato fruits on storage at an average temperature of 26.6°C and relative humidity of 87.5%.

General conclusions

The first specific objective of the study was to:

1. Determine the crop water requirement (ETc) and crop coefficient (Kc) for the various growth stages of the tomato plant under different water applications (100% ETc, 90% ETc, 80% ETc and 70% ETc) for the agro ecological area under the study.

From the study, it was observed that:

(a) The crop water requirement (ETc) for the initial stage were 16.98 mm, 15.44 mm, 13.51 mm and 14.37 mm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(b) The crop water requirement (ETc) for the developmental stage were 61.99 mm, 59.57 mm, 75.67 mm and 61.18 mm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(c) The crop water requirement (ETc) for the mid season stage were 140.81 mm, 114.35 mm, 97.34 mm and 86.94 mm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(d) The crop water requirement (ETc) for the late season stage were 80.6 mm, 69.29 mm, 59.39 mm and 50.20 mm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(e) The total crop water requirement (ETc) for the tomato plants were 300.38 mm, 258.65 mm, 245.91 mm and 212.99 mm for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(f) The crop coefficient (Kc) for the initial stage were 0.44, 0.40, 0.35 and 0.38 for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(g) The crop coefficient (Kc) for the developmental stage were 0.77, 0.74, 0.94 and 0.76 for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(h) The crop coefficient (Kc) for the mid season stage were 1.49, 1.21, 1.03 and 0.92 for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(i) The crop coefficient (Kc) for the late season stage were 1.14, 0.98, 0.84, 0.71 for the 100% ETc, 90% ETc, 80% ETc and 70% ETc treatments respectively.

(j) The crop coefficient (Kc) was higher in the mid season growth stage than the other growth stages.

The second specific objective was to:

2. Determine growth parameters such as plant height, canopy diameter, leaf area and leaf area index for the tomato plants grown under the different water applications.

From the study, it was observed that:

(a) There were no significant differences in the height of the tomato plant for the various water treatments at all growth stages. Thus the amount of water applied had no effect on the plant height.

(b) There were no significant differences in the canopy diameter of the tomato plant between the 100%, 90% and 80% treatments. However, there was a significant difference between the 100% and 70% treatments.

(c) The leaf area of the 100% ETc was significantly different from that of 70% ETc but not significantly different from those of 90% ETc and 80% ETc treatments.

(d) There were no significant differences in the leaf area index between 80% ETc, 90% ETc and 100% ETc water treatments; however, there were significant differences between the 70% ETc, 90% ETc and 100% ETc treatments.

The third specific objective was to:

3. Determine the yield of tomato fruits for all the different water applications.

From the study, it was observed that:

(a) The fruit diameter from plants treated with 100% ETc was the highest and it was significantly different from 80% ETc and 70% ETc treatments though not significantly different from 90% ETc treatment. It could therefore be concluded that a slight reduction of water requirement of tomato does not affect the fruit diameter. However, above 10% water stress reduces the fruit diameter.

(b) The number and weight of fruits increased with increasing amount of water applied. Thus the tomato fruits from plants treated with 100% ETc recorded the highest number and weight of fruits while those treated with 70% ETc recorded the least.

(c) A reduction of 10% to 20% in irrigation water led to a reduction of 6.46% to 11.54% in fruit yield. Hence, 10-15% reduction in irrigation water would not significantly affect total yield of tomato fruits.

The fourth specific objective was to:

4. Assess the quality of the tomato fruits grown under the different water applications.

From the study, it was observed that:

(a) The firmness, total soluble solids (TSS) and titratable acidity (TA) of the tomato fruits increased with decreasing water application (water stress). Thus tomato fruits from plants treated with 70% ETc were firmer with higher TSS and TA than those from 80% ETc, 90% ETc and 100% ETc

in that order. This implied that water stress had a positive effect on firmness, TSS and TA of the tomato fruits.

(b) pH of the tomato fruits increased with increasing water application. Thus tomato fruits from plants treated with 100% ETc had higher pH than those from 80% ETc, 90% ETc and 70% ETc in that order.

(c) Moisture and ash contents of the tomato fruits decreased with decreasing water application (water stress). Thus as water application increased, moisture and ash contents of the fruits increased significantly.

(d) Fat, fibre and carbohydrate contents of the tomato fruits increased with decreasing water application (water stress). Thus as water application increased, fat, fibre and carbohydrate contents decreased significantly.

(e) Protein content of the tomato fruits did not show any significant change with different water applications.

(f) Concentration of minerals (Ca, Mg, K, Na, Fe, Cu and Zn) of tomatoes was observed to decrease with decreasing level of irrigation water from 100% ETc to 70% ETc.

(g) Lycopene, vitamin E, flavonoids and total phenolics concentrations of the tomato fruits increased with decreasing water application (water stress). Tomato fruits from plants treated with 70% ETc had the highest lycopene, vitamin E, flavonoids and total phenolics contents and in that order.

(h) Beta carotene and ascorbic acid concentrations of the tomato fruits decreased with decreasing water application (water stress). Tomato fruits

from plants treated with 100% ETc had the highest beta carotene and ascorbic acid contents and in that order.

The fifth specific objective was to:

5. Assess the effect of postharvest storage on the quality of the tomato fruits grown under the different water applications.

From the study, it was observed that during storage:

(a) Firmness and titratable acidity of the tomato fruits decreased while total soluble solids and pH increased across the storage period for all the water treatments.

(b) Moisture, protein, fat and carbohydrate contents of the tomato fruits decreased while fibre content increased as storage progressed for all water treatments. Ash content of the fruits did not show any significant change during storage for all the water treatments.

(c) Mineral (Ca, Mg, K, Na, Fe, Cu and Zn) concentration of the tomato fruits showed no change within the first 10-15 days of storage but showed slight changes by the twentieth day of storage for all the water treatments.

(d) Apart from lycopene concentrations which increased, all the other antioxidant components (beta carotene, ascorbic acid, vitamin E, flavonoids and total phenolics) decreased for all the water treatments during storage.

(e) Based on 40% rotting, tomato fruits from 90% ETc treatment had the shortest shelf life of 8 days, those from 100% ETc had shelf life of 13

days, those from 70% had shelf life of 15 days and fruits from 80% ETc treatment had the longest shelf life of 19 days.

It can therefore be concluded based on all the observations enumerated that application of 80% of tomato water requirement may produce tomato fruits with optimum yield, good quality and maximum shelf life thereby saving an appreciable amount of water for other uses. It is also hoped that the present study might serve as a guideline for irrigation management and could provide insight into the production of the most economical and best quality tomato fruit.

Recommendations for future research

1. In the present study, data from only 60 plants was collected and analyzed. In order to have more representative results, field trials could provide better and more extensive yield and fruit quality.
2. Studies should be carried out with various tomato varieties known to respond to irrigation in order to determine which variety is best for a particular percentage of water required for best results.
3. Studies should be carried out in other agro-ecological areas since environmental conditions such as climate influence the results.
4. Studies of deficit irrigation practices in the field rather than under a rain shelter could be more effective in identification and evaluation of some field problems and the development of practices which the farmer can implement to improve the yield which could in turn improve their socio-economic status.

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APPENDICES

APPENDIX 1: ANOVA TABLES FOR GROWTH, DEVELOPMENT AND YIELD COMPONENTS ($p<0.05$)

1A: Effect of treatment on the plant height of tomato at the various growth stages

		Sum of Squares	df	Mean Square	F	Sig.
INITIAL (19DAT)	Between Groups	34.903	3	11.634	3.148	0.086
	Within Groups	29.567	8	3.696		
DEV'TAL (43 DAT)	Between Groups	180.920	3	60.307	2.673	0.118
	Within Groups	180.507	8	22.563		
MID- SEASON (69DAT)	Between Groups	16.042	3	5.347	0.704	0.576
	Within Groups	60.727	8	7.591		
LATE SEASON (87DAT)	Between Groups	10.982	3	3.661	0.566	0.652
	Within Groups	51.720	8	6.465		
	Total	62.702	11			

1B: Effect of treatment on the leaf area of tomato plant growth stages

		Sum of Squares	df	Mean Square	F	Sig.
INITIAL (19DAT)	Between Groups	51.114	3	17.038	2.681	0.118
	Within Groups	50.848	8	6.356		
	Total	101.962	11			
DEV'TAL (43DAT)	Between Groups	643.621	3	214.540	5.610	0.023
	Within Groups	305.935	8	38.242		
	Total	949.556	11			
MID-SEASON (69DAT)	Between Groups	392.695	3	130.898	1.925	0.204
	Within Groups	543.891	8	67.986		
	Total	936.587	11			
LATE- SEASON (87 DAT)	Between Groups	356.431	3	118.810	1.904	0.207
	Within Groups	499.083	8	62.385		
	Total	855.515	11			

1C: Effect of treatment on the leaf area index of tomato plant at the various growth stages

		Sum of Squares	df	Mean Square	F	Sig.
INITIAL (19DAT)	Between Groups	0.095	3	0.032	1.720	0.240
	Within Groups	0.147	8	0.018		
	Total	0.242	11			
DEV'TAL (43 DAT)	Between Groups	1.772	3	0.591	9.241	0.006
	Within Groups	0.511	8	0.064		
	Total	2.283	11			
MID- SEASON (69DAT)	Between Groups	6.075	3	2.025	16.549	0.001
	Within Groups	0.979	8	0.122		
	Total	7.054	11			
LATE -SEASON (87DAT)	Between Groups	3.530	3	1.177	9.023	0.006
	Within Groups	1.043	8	0.130		
	Total	4.574	11			

1D: Effect of treatment on the canopy diameter of tomato plant at the various growth stages

		Sum of Squares	df	Mean Square	F	Sig.
INITIAL (19DAT)	Between Groups	481.453	3	160.484	6.349	0.016
	Within Groups	202.213	8	25.277		
DEV'TAL (43 DAT)	Between Groups	368.917	3	122.972	17.567	0.001
	Within Groups	56.000	8	7.000		
MID- SEASON (69DAT)	Between Groups	230.917	3	76.972	10.617	0.004
	Within Groups	58.000	8	7.250		
LATE –SEASON (87DAT)	Between Groups	158.333	3	52.778	8.333	0.008
	Within Groups	50.667	8	6.333		

1E: Effect of treatment on the yield components of tomato

		Sum of Squares	df	Mean Square	F	Sig.
Diameter of fruits	Between Groups	21.727	3	7.242	0.562	0.000
	Within Groups		8	4.840		
No. of fruits per plant	Between Groups	4.250	3	1.417	0.367	0.779
	Within Groups	30.907	8	3.863		
weight/fruit (g)	Between Groups	8.467	3	2.822	0.205	0.890
	Within Groups	110.128	8	13.766		
Weight of fruits/plant/trt (g)	Between Groups	9124.342	3	3041.447	0.557	0.658
	Within Groups	43689.052	8	5461.132		
Fruit Yield (tons/ha)	Between Groups	110.661	3	36.887	0.557	0.658
	Within Groups	529.864	8	66.233		
	Total	640.525	11			

APPENDIX 2: ANOVA TABLES FOR PHYSICOCHEMICAL QUALITY OF TOMATO FRUITS ($p<0.05$)

2A: Effect of different treatment on Firmness of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day zero	Between Groups	1.396	3	0.465	0.089	0.964
	Within Groups	41.847	8	5.231		
	Total	43.243	11			
day5	Between Groups	1.156	3	0.385	0.174	0.911
	Within Groups	17.713	8	2.214		
	Total	18.869	11			
day10	Between Groups	4.807	3	1.602	3.309	0.078
	Within Groups	3.873	8	0.484		
	Total	8.680	11			
day15	Between Groups	1.604	3	0.535	0.369	0.778
	Within Groups	11.588	8	1.449		
	Total	13.192	11			
Day20	Between Groups	1.037	3	0.346	0.207	0.889
	Within Groups	13.348	8	1.669		
	Total	14.386	11			

2B: Effect of treatment on Firmness of tomato fruits during storage

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	10.851	4	2.713	1.834	0.199
	Within Groups	14.793	10	1.479		
	Total	25.644	14			
90%	Between Groups	16.419	4	4.105	1.143	0.391
	Within Groups	35.915	10	3.592		
	Total	52.334	14			
80%	Between Groups	10.623	4	2.656	0.761	0.574
	Within Groups	34.893	10	3.489		
	Total	45.516	14			
70%	Between Groups	22.887	4	5.722	17.984	0.000
	Within Groups	3.182	10	0.318		
	Total	26.069	14			

2C: Effect of treatment on Total Soluble Solids content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day 0	Between Groups	0.320	3	0.107	0.116	0.948
	Within Groups	7.361	8	0.920		
	Total	7.681	11			
day5	Between Groups	0.463	3	0.154	0.263	0.850
	Within Groups	4.687	8	0.586		
	Total	5.149	11			
day10	Between Groups	0.376	3	0.125	0.213	0.885
	Within Groups	4.713	8	0.589		
	Total	5.089	11			
day15	Between Groups	5.507	3	1.836	0.292	0.830
	Within Groups	50.353	8	6.294		
	Total	55.860	11			
Day20	Between Groups	4.971	3	1.657	0.650	0.605
	Within Groups	20.402	8	2.550		
	Total	25.372	11			

2D: Effect of treatment on the Total Soluble Solids content of tomato fruits during storage

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	5.447	4	1.362	0.592	0.676
	Within Groups	22.995	10	2.300		
	Total	28.442	14			
90%	Between Groups	7.489	4	1.872	0.558	0.698
	Within Groups	33.535	10	3.354		
	Total	41.024	14			
80%	Between Groups	20.388	4	5.097	2.465	0.113
	Within Groups	20.681	10	2.068		
	Total	41.069	14			
70%	Between Groups	3.643	4	0.911	0.489	0.744
	Within Groups	18.613	10	1.861		
	Total	22.256	14			

2E: Effect of treatment on Titratable acidity of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day 0	Between Groups	0.030	3	0.010	0.380	0.770
	Within Groups	0.211	8	0.026		
	Total	0.241	11			
day5	Between Groups	0.092	3	0.031	3.082	0.090
	Within Groups	0.080	8	0.010		
	Total	0.172	11			
day10	Between Groups	0.039	3	0.013	3.693	0.062
	Within Groups	0.028	8	0.004		
	Total	0.068	11			
day15	Between Groups	0.090	3	0.030	1.671	0.249
	Within Groups	0.144	8	0.018		
	Total	0.234	11			
Day20	Between Groups	0.116	3	0.039	2.486	0.135
	Within Groups	0.124	8	0.016		
	Total	0.240	11			

2F: Effect of treatment on the Titratable Acidity of tomato fruits during storage

		Sums of Squares	df	Mean Square	F	Sig
70%	Between Groups	0.333	4	0.083	12.778	0.001
	Within Groups	0.065	10	0.007		
	Total	0.398	14			
80%	Between Groups	0.150	4	0.037	18.507	0.000
	Within Groups	0.029	10	0.002		
	Total	0.170	14			
90%	Between Groups	0.449	4	0.112	3.827	0.039
	Within Groups	0.294	10	0.029		
	Total	0.743	14			
100%	Between Groups	0.417	4	0.104	5.761	0.011
	Within Groups	0.181	10	0.018		
	Total	0.598	14			

2G: Effect of treatment on pH of the tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day 0	Between Groups	0.049	3	0.016	2.458	0.137
	Within Groups	0.053	8	0.007		
	Total	0.102	11			
day5	Between Groups	0.090	3	0.030	3.600	0.065
	Within Groups	0.067	8	0.008		
	Total	0.157	11			
day10	Between Groups	0.043	3	0.014	2.833	0.106
	Within Groups	0.040	8	0.005		
	Total	0.083	11			
day15	Between Groups	0.070	3	0.023	2.800	0.109
	Within Groups	0.067	8	0.008		
	Total	0.137	11			
Day20	Between Groups	0.049	3	0.016	3.933	0.054
	Within Groups	0.033	8	0.004		
	Total	0.083	11			

2H: Effect of treatment on the pH of tomato fruits during storage

		Sum of Squares	df	Mean Square	F	Sig
70%	Between Groups	0.003	4	0.001	0.143	0.962
	Within Groups	0.047	10	0.005		
	Total	0.049	14			
80%	Between Groups	0.077	4	0.019	2.900	0.078
	Within Groups	0.067	10	0.007		
	Total	0.144	14			
90%	Between Groups	0.063	4	0.016	1.469	0.283
	Within Groups	0.107	10	0.011		
	Total	0.169	14			
100%	Between Groups	0.057	4	0.014	3.583	0.046
	Within Groups	0.040	10	0.004		
	Total	0.097	14			

APPENDIX 3: ANOVA TABLES FOR NUTRITIONAL QUALITY OF TOMATO FRUITS (p<0.05)

3A: Effects of treatment on Moisture content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	24.790	3	8.263	608.722	0.000
	Within Groups	0.109	8	0.014		
	Total	24.899	11			
day5	Between Groups	7.279	3	2.426	53.447	0.001
	Within Groups	0.363	8	0.045		
	Total	7.643	11			
day10	Between Groups	3.957	3	1.319	44.861	0.000
	Within Groups	0.235	8	0.029		
	Total	4.192	11			
day15	Between Groups	5.699	3	1.900	75.157	0.001
	Within Groups	0.202	8	0.025		
	Total	5.901	11			
Day20	Between Groups	3.132	3	1.044	23.756	0.000
	Within Groups	0.352	8	0.044		
	Total	3.484	11			

3B: Effect of treatment on the Moisture content of tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	13.922	4	3.481	60.405	0.000
	Within Groups	0.576	10	0.058		
	Total	14.498	14			
90%	Between Groups	18.556	4	4.639	142.565	0.000
	Within Groups	0.325	10	0.033		
	Total	18.882	14			
80%	Between Groups	23.545	4	5.886	234.701	0.000
	Within Groups	0.251	10	0.025		
	Total	23.796	14			
70%	Between Groups	54.138	4	13.535	1248.578	0.000
	Within Groups	0.108	10	0.011		
	Total	54.247	14			

3C: Effects of treatment on Ash content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.440	3	0.147	133.334	.000
	Within Groups	0.009	8	0.001		
day5	Between Groups	0.416	3	0.139	109.101	0.001
	Within Groups	0.010	8	0.001		
day10	Between Groups	0.414	3	0.138	152.938	0.000
	Within Groups	0.007	8	0.001		
day15	Between Groups	0.539	3	0.180	173.198	0.001
	Within Groups	0.008	8	0.001		
	Total	0.548	11			
Day20	Between Groups	0.621	3	0.207	281.714	0.000
	Within Groups	0.006	8	0.001		
	Total	0.627	11			

3D: Effect of treatment on the Ash content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	2.535	4	0.634	265.542	0.000
	Within Groups	0.024	10	0.002		
	Total	2.559	14			
90%	Between Groups	0.009	4	0.002	4.075	0.033
	Within Groups	0.005	10	0.001		
	Total	0.014	14			
80%	Between Groups	0.034	4	0.009	8.339	0.003
	Within Groups	0.010	10	0.001		
	Total	0.045	14			
70%	Between Groups	0.081	4	0.020	30.490	0.000
	Within Groups	0.007	10	0.001		
	Total	0.088	14			

3E: Effects of treatment on Protein content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.018	3	0.006	2.228	0.162
	Within Groups	0.022	8	0.003		
	Total	0.041	11			
Day 5	Between Groups	0.024	3	0.008	5.192	0.028
	Within Groups	0.012	8	0.002		
	Total	0.036	11			
Day 10	Between Groups	0.101	3	0.034	29.236	0.000
	Within Groups	0.009	8	0.001		
	Total	0.110	11			
Day 15	Between Groups	0.316	3	0.105	16.366	0.001
	Within Groups	0.051	8	0.006		
	Total	0.367	11			
Day 20	Between Groups	0.276	3	0.092	14.704	0.001
	Within Groups	0.050	8	0.006		
	Total	0.327	11			

3F: Effect of treatment on the Protein content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	1.101	4	0.275	149.046	0.000
	Within Groups	0.018	10	0.002		
	Total	1.120	14			
90%	Between Groups	1.276	4	0.319	108.736	0.000
	Within Groups	0.029	10	0.003		
	Total	1.305	14			
80%	Between Groups	0.564	4	0.141	230.416	0.000
	Within Groups	0.006	10	0.001		
	Total	0.570	14			
70%	Between Groups	0.599	3	0.200	29.835	0.000
	Within Groups	0.054	8	0.007		
	Total	0.653	11			

3G: Effects of treatment on Fat content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day0	Between Groups	0.007	3	0.002	1286.608	0.004
	Within Groups	0.000	8	0.000		
	Total	0.007	11			
day5	Between Groups	0.001	3	0.000	75.643	0.005
	Within Groups	0.000	8	0.000		
	Total	0.001	11			
day10	Between Groups	0.002	3	0.001	571.846	0.015
	Within Groups	0.000	8	0.000		
	Total	0.002	11			
day15	Between Groups	0.005	3	0.002	943.095	0.005
	Within Groups	0.000	8	0.000		
	Total	0.005	11			
Day20	Between Groups	0.007	3	0.002	503.638	0.016
	Within Groups	0.000	8	0.000		
	Total	0.007	11			

3H: Effect of treatment on the Fat content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.010	4	0.002	537.213	0.000
	Within Groups	0.000	10	0.000		
90%	Between Groups	0.006	4	0.002	1947.026	0.000
	Within Groups	0.000	10	0.000		
80%	Between Groups	0.001	4	0.000	224.688	0.000
	Within Groups	0.000	10	0.000		
70%	Between Groups	0.007	4	0.002	433.426	0.000
	Within Groups	0.000	10	0.000		

3I: Effects of treatment on Fibre content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.271	3	0.090	7.818	0.009
	Within Groups	0.093	8	0.012		
	Total	0.364	11			
day5	Between Groups	0.307	3	0.102	153.294	0.000
	Within Groups	0.005	8	0.001		
	Total	0.313	11			
day10	Between Groups	0.379	3	0.126	10.662	0.004
	Within Groups	0.095	8	0.012		
	Total	0.474	11			
day15	Between Groups	0.324	3	0.108	333.682	0.000
	Within Groups	0.003	8	0.000		
	Total	0.326	11			
Day20	Between Groups	0.392	3	0.131	49.855	0.000
	Within Groups	0.021	8	0.003		
	Total	0.413	11			

3J: Effect of treatment on the Fibre content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.001	4	0.000	1.036	0.001
	Within Groups	0.003	10	0.000		
90%	Between Groups	0.053	4	0.013	0.775	0.000
	Within Groups	0.170	10	0.017		
80%	Between Groups	0.081	4	0.020	10.389	0.001
	Within Groups	0.020	10	0.002		
70%	Between Groups	0.018	4	0.005	1.871	0.000
	Within Groups	0.024	10	0.002		

3K: Effects of treatment on Carbohydrate content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	26.346	3	8.782	204.468	0.001
	Within Groups	0.344	8	0.043		
	Total	26.689	11			
day5	Between Groups	7.190	3	2.397	67.505	0.001
	Within Groups	0.284	8	0.036		
	Total	7.474	11			
day10	Between Groups	4.847	3	1.616	48.993	0.003
	Within Groups	0.264	8	0.033		
	Total	5.110	11			
day15	Between Groups	8.404	3	2.801	53.339	0.000
	Within Groups	0.420	8	0.053		
	Total	8.824	11			
Day20	Between Groups	1.984	3	0.661	16.608	0.001
	Within Groups	0.319	8	0.040		
	Total	2.302	11			

3L: Effect of treatment on the Carbohydrate content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	33.391	4	8.348	5080.570	0.000
	Within Groups	0.016	10	0.002		
90%	Between Groups	27.787	4	6.947	4848.393	0.000
	Within Groups	0.014	10	0.001		
80%	Between Groups	30.238	4	7.560	15990.794	0.000
	Within Groups	0.005	10	0.000		
70%	Between Groups	69.800	4	17.450	36859.026	0.000
	Within Groups	0.005	10	0.000		

APPENDIX 4: ANOVA TABLES FOR MINERAL CONTENT OF TOMATO FRUITS ($p<0.05$)

4A: Effects of treatment on calcium content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.000	3	0.000	14.410	0.001
	Within Groups	0.000	8	0.000		
day5	Between Groups	0.000	3	0.000	15.207	0.001
	Within Groups	0.000	8	0.000		
day10	Between Groups	0.000	3	0.000	14.776	0.001
	Within Groups	0.000	8	0.000		
day15	Between Groups	0.000	3	0.000	11.613	0.003
	Within Groups	0.000	8	0.000		
Day20	Between Groups	0.000	3	0.000	24.444	0.000
	Within Groups	0.000	8	0.000		
	Total	0.000	11			

4B: Effect of treatment on the Calcium content of the tomato fruit across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.000	4	0.000	0.941	0.479
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
90%	Between Groups	0.000	4	0.000	0.949	0.476
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
80%	Between Groups	0.000	4	0.000	1.957	0.178
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
70%	Between Groups	0.000	4	0.000	0.000	1.000
	Within Groups	0.000	10	0.000		
	Total	0.000	14			

4C: Effects of treatment on Magnesium content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.000	3	0.000	33.333	0.029
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day5	Between Groups	0.000	3	0.000	33.333	0.029
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day10	Between Groups	0.000	3	0.000	20.000	0.033
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day15	Between Groups	0.000	3	0.000	50.000	0.033
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
Day20	Between Groups	0.000	3	0.000	9.094	0.032
	Within Groups	0.000	8	0.000		
	Total	0.000	11			

4D: Effect of treatment on the Magnesium content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.000	4	0.000	0.923	0.488
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
90%	Between Groups	0.000	4	0.000	0.545	0.707
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
80%	Between Groups	0.000	4	0.000	0.000	1.000
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
70%	Between Groups	0.000	4	0.000	0.000	1.000
	Within Groups	0.000	10	0.000		
	Total	0.000	14			

4E: Effects of treatment on Sodium content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	17.890	3	5.963	334.047	0.000
	Within Groups	0.143	8	0.018		
	Total	18.033	11			
day5	Between Groups	17.943	3	5.981	299.070	0.000
	Within Groups	0.160	8	0.020		
	Total	18.103	11			
day10	Between Groups	17.716	3	5.905	218.870	0.001
	Within Groups	0.216	8	0.027		
	Total	17.932	11			
day15	Between Groups	15.342	3	5.114	237.306	0.000
	Within Groups	0.172	8	0.022		
	Total	15.515	11			
Day20	Between Groups	15.263	3	5.088	77.091	0.000
	Within Groups	0.528	8	0.066		
	Total	15.791	11			

4F: Effect of treatment on the Sodium content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.311	4	0.078	3.329	0.056
	Within Groups	0.234	10	0.023		
	Total	0.545	14			
90%	Between Groups	0.541	4	0.135	4.164	0.031
	Within Groups	0.325	10	0.032		
	Total	0.865	14			
80%	Between Groups	0.028	4	0.007	0.164	0.952
	Within Groups	0.424	10	0.042		
	Total	0.452	14			
70%	Between Groups	0.000	4	0.000	0.001	1.000
	Within Groups	0.237	10	0.024		
	Total	0.237	14			

4G: Effects of treatment on Potassium content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	31.382	3	10.461	428.092	0.001
	Within Groups	0.195	8	0.024		
	Total	31.577	11			
day5	Between Groups	28.311	3	9.437	729.822	0.000
	Within Groups	0.103	8	0.013		
	Total	28.415	11			
day10	Between Groups	25.720	3	8.573	436.856	0.001
	Within Groups	0.157	8	0.020		
	Total	25.877	11			
day15	Between Groups	28.754	3	9.585	366.532	0.012
	Within Groups	0.209	8	0.026		
	Total	28.964	11			
Day20	Between Groups	18.780	3	6.260	66.512	0.025
	Within Groups	0.753	8	0.094		
	Total	19.533	11			

4H: Effect of treatment on the potassium content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	7.837	4	1.959	100.695	0.000
	Within Groups	0.195	10	0.019		
	Total	8.031	14			
90%	Between Groups	0.428	4	0.107	4.991	0.018
	Within Groups	0.214	10	0.021		
	Total	0.642	14			
80%	Between Groups	0.497	4	0.124	22.408	0.000
	Within Groups	0.055	10	0.006		
	Total	0.552	14			
70%	Between Groups	4.265	4	1.066	11.179	0.001
	Within Groups	0.954	10	0.095		
	Total	5.219	14			

4I: Effects of treatment on Iron content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.099	3	0.033	73.877	0.001
	Within Groups	0.004	8	0.000		
	Total	0.102	11			
day5	Between Groups	0.093	3	0.031	80.183	0.000
	Within Groups	0.003	8	0.000		
	Total	0.096	11			
day10	Between Groups	0.096	3	0.032	82.213	0.000
	Within Groups	0.003	8	0.000		
	Total	0.099	11			
day15	Between Groups	0.092	3	0.031	127.347	0.000
	Within Groups	0.002	8	0.000		
	Total	0.094	11			
Day20	Between Groups	0.086	3	0.029	147.561	0.001
	Within Groups	0.002	8	0.000		
	Total	0.087	11			

4J: Effect of treatment on the Iron content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.003	4	0.001	1.829	0.200
	Within Groups	0.004	10	0.000		
	Total	0.006	14			
90%	Between Groups	0.004	4	0.001	2.461	0.113
	Within Groups	0.005	10	0.000		
	Total	0.009	14			
80%	Between Groups	0.003	4	0.001	8.679	0.003
	Within Groups	0.001	10	0.000		
	Total	0.003	14			
70%	Between Groups	0.001	4	0.000	0.759	0.575
	Within Groups	0.004	10	0.000		
	Total	0.006	14			

4K: Effects of treatment on Copper content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.000	3	0.000	13.667	0.002
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day5	Between Groups	0.000	3	0.000	26.268	0.000
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day10	Between Groups	0.000	3	0.000	20.068	0.000
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
day15	Between Groups	0.000	3	0.000	6.532	0.015
	Within Groups	0.000	8	0.000		
	Total	0.000	11			
Day20	Between Groups	0.000	3	0.000	21.754	0.000
	Within Groups	0.000	8	0.000		
	Total	0.000	11			

4L: Effect of treatment on the Copper content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.000	4	0.000	0.500	0.737
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
90%	Between Groups	0.000	4	0.000	1.742	0.217
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
80%	Between Groups	0.000	4	0.000	0.472	0.755
	Within Groups	0.000	10	0.000		
	Total	0.000	14			
70%	Between Groups	0.000	4	0.000	1.009	0.447
	Within Groups	0.000	10	0.000		
	Total	0.000	14			

4M: Effects of treatment on Zinc content of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.009	3	0.003	20.505	0.010
	Within Groups	0.001	8	0.000		
	Total	0.011	11			
day5	Between Groups	0.009	3	0.003	58.807	0.021
	Within Groups	0.000	8	0.000		
	Total	0.010	11			
day10	Between Groups	0.009	3	0.003	77.750	0.002
	Within Groups	0.000	8	0.000		
	Total	0.009	11			
day15	Between Groups	0.006	3	0.002	51.491	0.001
	Within Groups	0.000	8	0.000		
	Total	0.006	11			
Day20	Between Groups	0.003	3	0.001	15.502	0.001
	Within Groups	0.001	8	0.000		
	Total	0.004	11			

4N: Effect of treatment on the Zinc content of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.002	4	0.001	4.811	0.020
	Within Groups	0.001	10	0.000		
	Total	0.003	14			
90%	Between Groups	0.002	4	0.001	13.077	0.001
	Within Groups	0.000	10	0.000		
	Total	0.002	14			
80%	Between Groups	0.000	4	0.000	0.503	0.735
	Within Groups	0.001	10	0.000		
	Total	0.001	14			
70%	Between Groups	0.000	4	0.000	0.043	0.996
	Within Groups	0.000	10	0.000		
	Total	0.000	14			

APPENDIX 5 : ANOVA TABLES FOR ANTIOXIDANTS COMPONENTS ($p<0.05$)

5A: Effects of treatment on Lycopene concentration of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	24.474	3	8.158	4.896	0.032
	Within Groups	24.979	8	1.710		
	Total	49.453	11			
Day 5	Between Groups	9.462	3	3.154	0.469	0.712
	Within Groups	53.839	8	6.730		
	Total	63.300	11			
Day 10	Between Groups	2.522	3	0.841	0.350	0.791
	Within Groups	19.237	8	2.405		
	Total	21.759	11			
Day 15	Between Groups	6.379	3	2.126	0.563	0.654
	Within Groups	30.191	8	3.774		
	Total	36.571	11			
Day20	Between Groups	7.761	3	2.587	0.425	0.740
	Within Groups	48.651	8	6.081		
	Total	56.411	11			

5B: Effect of treatment on the lycopene concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	73.365	4	18.341	4.210	0.030
	Within Groups	43.568	10	4.357		
	Total	116.933	14			
90%	Between Groups	87.637	4	21.909	10.334	0.001
	Within Groups	21.202	10	2.120		
	Total	108.838	14			
80%	Between Groups	78.378	4	19.595	7.171	0.005
	Within Groups	27.325	10	2.732		
	Total	105.703	14			
70%	Between Groups	41.700	4	10.425	1.229	0.359
	Within Groups	84.802	10	8.480		
	Total	126.501	14			

5C: Effects of treatment on Beta Carotene concentration of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.164	3	0.055	116.048	0.000
	Within Groups	0.004	8	0.000		
	Total	0.168	11			
day5	Between Groups	0.220	3	0.073	130.670	0.000
	Within Groups	0.004	8	0.001		
	Total	0.224	11			
day10	Between Groups	0.224	3	0.075	619.156	0.000
	Within Groups	0.001	8	0.000		
	Total	0.225	11			
day15	Between Groups	0.250	3	0.083	616.347	0.000
	Within Groups	0.001	8	0.000		
	Total	0.251	11			
Day20	Between Groups	0.144	3	0.048	143.898	0.000
	Within Groups	0.003	8	0.000		
	Total	0.146	11			

5D: Effect of treatment on the Beta carotene concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.142	4	0.035	83.526	0.000
	Within Groups	0.004	10	0.000		
	Total	0.146	14			
90%	Between Groups	0.113	4	0.028	76.024	0.001
	Within Groups	0.004	10	0.000		
	Total	0.117	14			
80%	Between Groups	0.141	4	0.035	225.693	0.000
	Within Groups	0.002	10	0.000		
	Total	0.143	14			
70%	Between Groups	0.163	4	0.041	2.777	0.087
	Within Groups	0.147	10	0.015		
	Total	0.310	14			

5E: Effect of treatment on Ascorbic Acid concentration of tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	4.601	3	1.534	0.114	0.949
	Within Groups	107.501	8	13.438		
	Total	112.102	11			
day5	Between Groups	33.738	3	11.246	4.609	0.087
	Within Groups	9.759	4	2.440		
	Total	43.497	7			
day10	Between Groups	1.707	3	.569	0.182	0.904
	Within Groups	15.629	5	3.126		
	Total	17.336	8			
day15	Between Groups	2.118	3	.706	0.168	0.914
	Within Groups	21.075	5	4.215		
	Total	23.193	8			
day20	Between Groups	4.834	3	1.611	1.723	0.300
	Within Groups	3.742	4	.935		
	Total	8.576	7			

5F: Effect of treatment on the Ascorbic acid concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	500.053	4	125.013	29.124	0.000
	Within Groups	30.047	7	4.292		
	Total	530.100	11			
90%	Between Groups	432.598	4	108.150	36.097	0.000
	Within Groups	17.976	6	2.996		
	Total	450.575	10			
80%	Between Groups	351.847	4	87.962	6.412	0.017
	Within Groups	96.023	7	13.718		
	Total	447.870	11			
70%	Between Groups	379.113	4	94.778	41.635	0.000
	Within Groups	13.659	6	2.276		
	Total	392.772	10			

5G: Effect of treatment on vitamin E concentration of the tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
Day 0	Between Groups	0.689	3	0.230	0.625	0.619
	Within Groups	2.941	8	0.368		
	Total	3.630	11			
day5	Between Groups	0.421	3	0.140	1.263	0.368
	Within Groups	0.666	6	0.111		
	Total	1.087	9			
day10	Between Groups	0.056	3	0.019	0.792	0.548
	Within Groups	0.119	5	0.024		
	Total	0.175	8			
day15	Between Groups	0.025	3	0.008	0.556	0.667
	Within Groups	0.075	5	0.015		
	Total	0.100	8			
Day20	Between Groups	0.042	3	0.014	0.344	0.796
	Within Groups	0.163	4	0.041		
	Total	0.204	7			

5H: Effect of treatment on the Vitamin E concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.392	4	0.098	0.551	0.705
	Within Groups	1.245	7	0.178		
	Total	1.637	11			
90%	Between Groups	0.890	4	0.222	5.681	0.023
	Within Groups	0.274	7	0.039		
	Total	1.164	11			
80%	Between Groups	1.560	4	0.390	2.962	0.114
	Within Groups	0.790	6	0.132		
	Total	2.349	10			
70%	Between Groups	2.413	4	0.603	2.233	0.181
	Within Groups	1.621	6	0.270		
	Total	4.034	10			

5I: Effect of treatment on flavonoid concentration of the tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day 0	Between Groups	37.578	3	12.526	0.919	0.474
	Within Groups	109.069	8	13.634		
	Total	146.647	11			
day5	Between Groups	67.004	3	22.335	1.232	0.377
	Within Groups	108.764	6	18.127		
	Total	175.769	9			
day10	Between Groups	1.362	3	0.454	0.136	0.934
	Within Groups	13.366	4	3.341		
	Total	14.727	7			
day15	Between Groups	2.140	3	0.713	5.843	0.061
	Within Groups	0.488	4	0.122		
	Total	2.628	7			
Day20	Between Groups	1.872	3	0.624	14.712	0.013
	Within Groups	0.170	4	0.042		
	Total	2.042	7			

5J: Effect of treatment on the flavonoids concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
70%	Between Groups	48.356	4	12.089	1.305	0.332
	Within Groups	92.629	10	9.263		
	Total	140.985	14			
80%	Between Groups	24.810	4	6.202	0.681	0.621
	Within Groups	91.105	10	9.110		
	Total	115.914	14			
90%	Between Groups	34.573	4	8.643	2.221	0.140
	Within Groups	38.909	10	3.891		
	Total	73.482	14			
100%	Between Groups	25.601	4	6.400	1.848	0.196
	Within Groups	34.635	10	3.464		
	Total	60.237	14			

5K: Effect of treatment on total phenolics concentration of the tomato fruits

		Sum of Squares	df	Mean Square	F	Sig.
day 0	Between Groups	0.312	3	0.104	19.856	0.000
	Within Groups	0.042	8	0.005		
	Total	0.354	11			
day5	Between Groups	0.071	3	0.024	6.512	0.015
	Within Groups	0.029	8	0.004		
	Total	0.100	11			
day10	Between Groups	0.029	3	0.010	1.433	0.303
	Within Groups	0.054	8	0.007		
	Total	0.083	11			
day15	Between Groups	0.031	3	0.010	3.821	0.057
	Within Groups	0.022	8	0.003		
	Total	0.053	11			
Day20	Between Groups	0.014	3	0.005	0.967	0.454
	Within Groups	0.039	8	0.005		
	Total	0.053	11			

5L: Effect of each treatment on the Total phenolics concentration of the tomato fruits across the storage period

		Sum of Squares	df	Mean Square	F	Sig.
100%	Between Groups	0.321	4	0.080	61.921	0.000
	Within Groups	0.013	10	0.001		
	Total	0.334	14			
90%	Between Groups	0.043	4	0.011	1.320	0.328
	Within Groups	0.081	10	0.008		
	Total	0.123	14			
80%	Between Groups	0.060	4	0.015	2.074	0.159
	Within Groups	0.072	10	0.007		
	Total	0.131	14			
70%	Between Groups	0.008	4	0.002	1.138	0.393
	Within Groups	0.017	10	0.002		
	Total	0.025	14			

APPENDIX 6 : TRANSPLANTS IN PLASTIC BUCKET UNDER A RAIN SHELTER

6A: PLATE 1: Tomato plants under the rain shelter during the Initial stage (21DAT)

6B: PLATE 2: Weighing and measurement of the amount of irrigation water.

6C: PLATE 3: Tomato plants at the beginning of the mid-season stage (43DAT)