YIELD AND QUALITY PARAMETERS OF TOMATO CULTIVARS AS AFFECTED BY DIFFERENT SOILLESS PRODUCTION SYSTEMS AND BENEFICIAL MICRO-ORGANISMS

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DECLARATION

I, Martin Makgose Maboko, declare that the research reported in this thesis, except where otherwise indicated, is my original work. This thesis has not been submitted for any degree or examination at any other University.

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I certify that the above statement is correct.

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Abstract

Most tomato cultivars used for commercial food production are imported into South Africa. Optimal growing conditions for these specific cultivars need to be determined, as wrong cultivar choices can lead to great financial losses. Lack of information on selecting well-performing cultivars may lead to lower yield or unacceptable fruit quality. Information on the performance of tomato cultivars under South African conditions, utilizing plastic tunnels or shadenet structures under soilless cultivation is still very limited. Soilless cultivation of vegetables is becoming a preferable over in-soil cultivation due to the improved yield and quality of produce, efficient water and nutrients usage by the crop; furthermore, the grower can regulate nutrient solution, electrical conductivity and pH of the nutrient solution.

To identify the optimal system for growing tomatoes hydroponically, the performance of four tomato cultivars ('FA593', 'Miramar', 'FiveOFive' and 'Malory') under different growing conditions was evaluated: directly planted in soil under 40% shadenet with drip irrigation, a closed hydroponic system under 40% shadenet, an open bag system under 40% shadenet, or an open-bag system in a temperature controlled as well as a non-temperature controlled tunnel. The study revealed that 'Miramar' performed better than the other cultivars in all production systems, with the exception of soil cultivation where there were no differences amongst the four cultivars. Fruit cracking was found to be directly correlated with fruit size, as the large-sized cultivars 'Malory' and 'FA593' were more susceptible than the other two cultivars. Plants grown under shadenet were prone to fruit cracking and raincheck as well as early blight. Higher yields were obtained when plants were produced in the open bag system under temperature controlled conditions and in the closed system under shadenet. Growing tomatoes in the non-temperature controlled tunnel resulted in high incidences of fruit cracking, poor yield and pre-mature fruit ripening probably due to high and fluctuating temperatures under such conditions. The average marketable yield was 88% and 59% of the total yield in the temperature controlled and non-temperature controlled tunnels, respectively.

A further experiment was carried out to improve yield and quality of tunnel tomatoes using beneficial micro-organisms, i.e., arbuscular mycorrhiza fungi (AMF) at different

nutrient concentrations. Tomato seedlings were treated with Mycoroot™ containing four mycorrhiza species (*Glomus etunicatum*, *Paraglomus occultum*, *Glomus clarum* and *Glomus mossea*) at transplanting and subsequently transferred to either a temperature controlled or a non-temperature controlled tunnel under the recommended (100%) or reduced (75 and 50%) nutrient concentrations. Sawdust was used as a growing medium in this experiment. Application of AMF neither enhanced plant growth, yield, nor fruit mineral nutrient concentrations; although fruit Mn and Zn concentrations in the temperature controlled tunnel increased significantly following AMF application. Plants grown in the non-temperature controlled tunnel had significantly poorer plant growth, and lower yield and lower fruit mineral concentrations, compared with fruit from plants in the temperature controlled tunnel. Tomato plants in the non-temperature controlled tunnel had higher levels of micro-elements in leaf tissue, compared with those in the temperature controlled tunnel. The highest yields were obtained from plants fertigated with 75% of the recommended nutrient concentration, as compared with the 100 and 50% nutrient concentrations.

When coir was subsequently used as the growing medium, Mycoroot™ applied at seeding and transplanting did not enhance mycorrhizal colonization or fruit quality. Growing tomatoes under reduced nutrient supply reduced the total soluble solids in the juice of the fruit, but improved total and marketable yield, as well as the number of marketable fruit. This effect was more substantial in the temperature controlled than in the non-temperature controlled tunnel. Fruit firmness and leaf chlorophyll concentrations were significantly higher in plants grown in the temperature controlled tunnel. Growing tomatoes in sawdust improved the leaf Mn and Ca concentration over that of tomato plants grown in coir. Mycorrhizal colonisation did not have a beneficial effect on tomato yield and quality.

The study indicated that cultivar selection was important in obtaining the highest yield and quality of tomato using the closed hydroponic system under shadenet and the open bag hydroponic system in the temperature controlled tunnel. Temperature controlled tunnels with a pad–and-fan cooling system are still an effective way of cooling the tunnel environment which resulted in high yield and high quality of tomatoes with a higher fruit mineral content than that obtained under non-temperature controlled conditions where only natural ventilation is relied on. Results also demonstrated that mycorrhizal colonization in soilless condition has limited beneficial effects in allowing for better nutrient uptake and thereby for improved yield and quality of tomatoes. Further studies, including different media, nutrient composition and concentrations, need to be carried out to investigate the possible causes of AMF failure to improve yield, despite good AMF root colonization.

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CHAPTER 1
GENERAL INTRODUCTION

In South Africa, with its diverse climatic conditions and soil types, growing plants in soil is unpredictable. There is a wide range of challenges, such as variations in temperature, water holding capacity, cation exchange capacity, soils contaminated with heavy metals, available nutrient supply, proper root aeration as well as disease and pest control (du Plooy *et al*., 2012). Soilless production may alleviate some of these problems, while giving the farmer better control over plant growth and development. Soilless production of vegetables, as compared with traditional field and greenhouse production in soil, allows the efficient use of water and nutrients by crops (Resh, 1997). Advantages of soilless cultures include more efficient regulation of nutrient and water supply, electrical conductivity and pH of the nutrient solution, and temperature by the grower. Soilless culture therefore provides an ideal environment for growth and development of plants which often results in higher yield and quality compared to traditional cultivation methods. Growers in South Africa are faced with the challenge of producing high yields combined with good quality, in order to satisfy local consumer demand (Maboko *et al*., 2011). Rarely is this demand met, mainly due to poor cultivation methods, poor cultivar choice, inadequate plant nutrition, adverse climatic conditions, or pest and disease infestation (Maboko *et al*., 2011).

The pioneer of commercial greenhouse crop production in South Africa, Don Bilton, adapted the ‘Nutrient film technique’ (NFT) in the late 1970’s by using gravel in plastic lined beds instead of pure nutrient solution. The technique was named 'Gravel Film Technique' (GFT), the first commercial hydroponic system in South Africa and still utilised on a commercial scale in the country. Although vegetable production (including tomatoes) in South Africa is mainly open field cultivation, soilless cultivation in a protected environment has gained popularity due to improved yield and quality (Niederwieser, 2001; Maboko *et al*., 2009). Unfavourable weather conditions, such as hail and high temperatures during the summer season, have resulted in farmers trying to optimise yield and quality of tomatoes by using soilless production systems under shadenet structures (Maboko *et al*., 2011) while other vegetable growers are under the impression that only greenhouse (tunnels) are suitable to ensure good yield and quality (Combrink, 2005).

Hydroponically grown vegetables are high value crops and play a major role in income generation for small scale and commercial farmers in South Africa. Two hydroponic systems are applied commercially in South Africa (open bag and closed hydroponic system), with the majority of hydroponic farmers using plastic tunnels in open bag system (OBS) for production of crops such as tomatoes, sweet pepper, runner beans and cucumber, while leafy vegetables, such as lettuce, herbs, Swiss chard and spring onion are produced in tunnels or shade net structures using closed hydroponic system. The majority of vegetables are still produced seasonally in the open field, resulting in an inconsistent availability and affordability of vegetables in South Africa. Because of the diverse climatic conditions in South Africa, production of vegetables under protection plays a major role in increasing yield, quality and availability (Maboko *et al*., 2009; 2011).

Recently, the use of beneficial micro-organisms, such as arbuscular mycorrhizal fungi (AMF), has increased in agricultural production due to their ability to increase water and nutrient uptake, thereby increasing production efficiency (Sardi *et al*., 1992). These micro-organisms provide an important tool to enhance plant growth, yield and nutrient uptake under various environmental stress conditions, such as high salinity, drought and low fertility supply (Azcon-Aguilar and Barea, 1997; Abdel-Rahman *et al*., 2011). Arbuscular mycorrhizal fungi (AMF) form mutualistic associations with the majority of plant species (Smith and Read, 1997). Only a small number of plant species belonging mainly to the Cyperaceae, Chenopodiaceae, Juncaceae and Proteaceae are reported to be non-mycorrhizal or show restricted susceptibility to the mutualists (Azcon-Aguilar and Barea, 1997). These AMF increase the effective absorptive area of roots by formation of an extensive extraradical hyphae network that enhances efficiency in absorption of nutrients. Arbuscular mycorrhizae fungi (AMF) grow in close association with plant roots, and play an important symbiotic role in the uptake and transfer of water and nutrients by the root system. In exchange, the plant supplies the fungus with sugars. The hyphae of AMF penetrate roots, and grow extensively between and within living cortical cells, forming a very large and dynamic interface between symbionts (Farahani *et al*., 2008).

The fungus colonises the root cortex and develop an extra-mycelium that helps the plant to acquire mineral nutrients from soil (Harley and Smith, 1983). As the internal colonisation spreads, the extra-radical hyphae ramify, and grow along the root surface forming more penetration points. They also grow outwards, into the surrounding soil, thus developing an externsive tri-dimensional network of mycelium which interfaces with soil particles. The mycelial network can extend several centimeters outward from the root surface, bridging over the zone of nutrient depletion around roots to absorb low mobile elements from the bulk soil (Azcon and Barea, 1997). Once the hyphae reach the inner cortex, they will grow into the cells and, by means of repeated dichotomous branching, form tree-like structures called 'arbuscules'. Arbuscules formation, therefore, represents a large surface of cellular contact between symbionts. This facilitates the exchange of metabolites between host and fungus (Azcon and Barea, 1997). The arbuscules are the main transfer sit of mineral nutrients from fungus to plant and C compounds to the fungus (Smith and Gianinazzi-Pearson, 1988; Smith and Smith, 1990).

There is a growing interest from hydroponic vegetable growers on biologically based approaches to plant production in order to reduce the utilisation of high amounts of fertilisers and pesticides. Plant growth and yield are improved by AMF inoculation, particularly under conditions of limited water supply, low-quality irrigation water, low soil fertility, high daytime temperatures with high evapotranspiration rates, or soil salinity (Copeman *et al*., 1996; Al-Karaki, 2000; Abdel-Rahman *et al*., 2011). Amongst numerous benefits to plants, AMF increases the absorption of mineral elements, enhances defence against pathogens and drought conditions (Jeffries *et al*., 2003). By increasing the surface area of the root system of the host plant AMF support stronger, healthier, higher-yielding plants through increased nutrient acquisition (Miller, 2000), reduced levels of water stress (Auge, 2001), lower disease incidence and increased phytohormone production (Shaul-Keinan *et al*., 2002). Seedlings colonized by AMF often have better growth, improved water relations, greater tolerance to environmental stresses, resulting in better transplant survival when compared with similar non-colonised plants (Varma and Schuepp, 1995). However, mycorrhizal root colonisation can be affected by various factors or influencing growth of plant as reported below:

Crop improvement

In contrast to natural ecosystems, where mycorrhizae are common, soilless mixes used in hydroponics for vegetable production do not contain propagules of mycorrhizal fungi. Mycorrhiza inoculation in soilless media has been found to increase tomato and pepper seedling growth in nurseries (Oseni *et al*., 2010; Ortas *et al*., 2011), yield of peppers (Ikiz *et al*., 2009) and tomato (Dasgan, 2008). Inoculation with mycorrhiza in seedling growing medium at seeding stage before transplanting can be a successful strategy to enhance mycorrhiza root colonisation (Ikiz *et al*., 2009; Ortas *et al*., 2011). Inoculation with AMF in soilless systems did not positively influence plant growth and nutrient uptake of the tomato cultivar M19 (Dasgan *et al*., 2008). In field grown tomatoes, however, AMF inoculation enhances yield and quality (Subramanian *et al*., 2006); similarly, growth of pepper under saline conditions was improved following AMF inoculation (Kaya *et al*., 2009).

Growing media

Substrates (e.g. sawdust, coir, perlite, rockwool, etc.) are commonly used in hydroponic vegetable production where soil is not incorporated. In such soilless growing media AMF are absent, therefore addition of AMF to substrate culture is often beneficial (Cekic and Yilmaz, 2011), promoting plant growth and yield of soillessly grown peppers (Ikiz, 2003; Ikiz *et al*., 2009) and melons (Rehber, 2004), when cultivated in open bag hydroponic system. Dasgan *et al*. (2008) investigated mycorrhizal response on tomato when cultivated in a recycling hydroponic system. Pulatkan *et al*. (2010) reported the highest percentage (52.78%) mycorrhiza colonization on the ornamental *Forsythia x intermedia* when grown in soil combined with river sand and organic matter compared with plants grown in soil (31%), soil plus river sand (28%), indicating that the medium and its organic matter are important factors for successful AMF colonization. Zucchini plants inoculated with AMF and grown in sand culture under saline condition had higher leaf chlorophyll and relative water content than zucchini plants without AMF (Colla *et al*., 2008), underlining the potential benefits of AMF to plant growth and development, particularly under stressful conditions. Successful mycorrhizal colonisation has been reported in substrates containing sand, gravel, peat, expanded clay, pumice, perlite, bark, sawdust, vermiculite or mixtures of these (Gianinazzi *et al*., 1990).

Drought

Mycorrhizal fungi have been reported to improve water use efficiency in Rosa hybrids (Henderson and Davies, 1990) as well as in safflower and wheat (Bryla and Duniway, 1997). Mycorrhizal inoculation may directly enhance water uptake by the roots, providing adequate water to preserve physiological activity in plants, especially under severe drought conditions (Faber *et al*., 1991; Smith and Read, 1997). Plant roots colonized with mycorrhiza were found to have significantly higher biomass and fruit yield compared with non-mycorrhizal plants, whether plants were water-stressed or not (Kaya *et al*., 2003). Furthermore, these authors reported that mycorrhizal colonization of water-stressed plants was able to restore leaf nutrient concentrations to levels similar to well-watered plants (Kaya *et al*., 2003). Plants colonised by AMF showed high photosynthetic activity and high proline accumulation. These mechanisms are important in adaptation to drought stress (Azcon *et al*., 1996).

Temperature

Temperature is an important factor influencing mycorrhizal development and function (Jakobsen and Andersen, 1982; Liu *et al*., 2004). Mycorrhizal development is usually optimal in cool temperature climates, with temperatures ranging from 20 to 25^{o}C (Matsubara *et al*., 2000); maximal spore germination occurs between 20 and 28^{o}C, depending on the species (Wang *et al*., 1997). Carpio *et al*. (2005) found that AMF are able to colonise and survive in the medium of containerised bush morning glory (*Ipomoea carnea* ssp. *fistulosa*) plants at a temperature of 44.8^{o}C. Newman and Davies (1988) reported that AMF are known to enhance nursery crop resistance to high temperatures. Wu and Zou (2010) stated that three month citrus seedlings grown at a temperature of 15^{o}C showed less mycorrhiza root colonisation than those grown at a warmer temperature of 25^{o}C. These authors concluded that mycorrhizal colonisation has beneficial effects on plant growth, photosynthetic activity, root morphology and nutrient uptake (specifically P, Ca and Mg) of citrus seedlings when grown at moderate temperature (25^{o}C) compared with lower temperature (15^{o}C).

Diseases

Currently AMF are studied as biological control agents of root diseases caused by soil-borne pathogens (Norman and Hooker, 2000; Giri *et al*., 2003). In greenhouse studies, protection of muskmelon fruit, *Cucumis melo* L., from *Meloidogyne incognita* under infested conditions was reported to be due to AMF (Heald *et al*., 1989). Inoculation of tomato seedlings with AMF (i.e., *Glomus macrocarpum* or *Glomus fasciculatum*) 20 days after infection with *Fusarium oxysporum* f. sp. *lycopersici* reduced pathogen spread and disease severity by 75 and 78%, respectively (Kapoor, 2008). Tomato plants inoculated with AMF (*Glomus monosporum* and *Glomus mosseae*) showed lower *Fusarium oxysporum* f. sp. *radicis-lycopersici* root infection than untreated plants in a hydroponic system under greenhouse conditions (Utkhede, 2006). Several studies reported that mycorrhizal protection of tomato plants against soil-borne pests, like nematodes and various root diseases, is commonly observed (Cordier *et al*., 1996; Boedker *et al*., 1998). In contrast, Lindermann (1994) reported the susceptibility of tomato plants to leaf pathogens to be higher in mycorrhizal than non-mycorrhizal plants. Fritz and Kakobsen (2006) found the presence of AMF to significantly reduce *Alternaria solani* symptoms in tomato plants.

Salinity

Arbuscular mycorrhiza fungi can provide the host plant with resistance against high salinity by optimising the hormonal balance (Danneberg *et al*., 1992) or by enhancing water uptake (Ruiz-Lozano and Azcon, 1995). Results of glasshouse studies have shown that AMF can increase salinity tolerance resulting in higher yield under saline conditions (Hirrel and Gerdemann, 1980; Tian *et al*., 2004; Asghari *et al*., 2005; Al-Karaki, 2006; Zuccarini and Okaurowska, 2008). High salinity may, however, have negative effects on AMF growth and hyphal extension (Juniper and Abbott, 1993; Asghari *et al*., 2008). Asghari *et al*. (2008) reported that high soil salinity (45 dS m^{-1}) inhibited mycorrhizal root colonization, possibly due to inhibition of spore germination, hyphal growth and hyphal spreading after initial infection (McMillen *et al*., 1998). Reduction of arbuscules in high saline environment has also been observed (Pfeiffer and Bloss, 1988). Under saline conditions, a certain degree of tolerance is afforded by utitilisation of AMF as reported in eggplants grown in pumice (Yilmaz, 2005) and pepper grown in a perlite/ sand mixture (1:1; v/v). Grafted tomato plants inoculated with mycorrhiza also showed tolerance to soil salinity (Oztekin *et al*., 2012).

Nutrient uptake

In symbiotic relationships, AMF can alleviate certain mineral elements deficiencies in plants by increasing nutrient uptake (Ortas and Akpinar, 2006; Ciftci *et al*., 2010). The primary effect of AMF symbiosis is to increase the supply of mineral nutrients to the plant, particularly those whose ionic forms have poor mobility or are present at low concentration in the soil solution. This mainly applies to P, NH_4, Zn and Cu (Barea, 1991). Mycorrhizal hyphae extending into soil or substrate increase nutrient absorption (i.e. P, Zn, Cu, and Fe) (Al-Karaki, 2006) by penetrating into small particles. Mycorrhizal inoculation reduces the quantity of fertilizer applied to achieve a certain response (Charron *et al*., 2001; Ortas *et al*., 2011). Cimen *et al*. (2010) reported an increase in tomato leaf mineral concentrations, i.e. P, K, Mg, Fe, Mn, Zn and Cu following inoculated of plants with AMF.

Associations between plants and AMF improve plant performance in low fertility soils (Tran and Cavagnaro, 2010). Bush morning glory plants inoculated with AMF were larger than non–treated ones and were subsequently able to absorb a greater amount of ions, potentially minimizing nutrient leaching and runoff (Carpio *et al*., 2005). High P supply is known to inhibit mycorrhiza colonisation at the root system (Dasgan *et al*., 2008; Cwala *et al*., 2010). A concentration as low as 7 mg kg^{-1} P soil was reported to inhibit root colonisation by AMF (Brundrett *et al*., 1996) while other authors (Schubert *et al*., 1990) reported tolerance to much higher P concentration in soil. Ryan and Graham (2002) reported that highly available P often limits AMF colonization. Cekic and Yilmaz (2011) reported a non-significant effect of P level applied to hydroponically grown strawberry cultivars on mycorrhiza root colonization, when applying three levels of phosphorus (10, 30 and 60 ppm P). However, plants inoculated with mycorrhiza had a significant increase in strawberry yield compared with non-inoculated plants, possibly due to the increased plant growth through enhanced nutrient uptake. Nasim (2005) calculated that a root system associated with mycorrhizal fungi can transport phosphorus at a rate more than four times higher than that of a root not associated with mycorrhiza.

Growing vegetables under protection has gained the interest of many vegetable growers in South Africa. Among environmental factors, temperature during fruit development plays the main role in determining fruit quantity and quality (Dorais *et al*., 2001). Tomato plants are susceptible to damages when exposed to high solar radiation and high temperature. Some of the effects of such radiation and temperature conditions are transplant shock, low pollination, flower abortion or sunburn (Peet, 1992). While there are several beneficial effects of protected cultivation, the choice of an appropriate cultivar is important to maximise profit. Genetic factors linked to the tomato cultivar can have considerable influence on important economic parameters such as yield potential, resistance to disease and fruit quality (Gould, 1983; Dumas *et al*., 2003). Growers are constantly in search of cultivars that will improve yield and quality in their production systems. Most of the tomato cultivars grown in southern Africa are imported into the region and distributed by international seed companies. It is imperative to evaluate the performance of tomato cultivars in different production systems since these cultivars probably have different abilities to adapt to various environmental conditions. There is little or no information available on the optimal soilless production system for good yield and quality of tomato, with no such information existing for South African conditions. The use of AMF could potentially play an important role in natural as well as agricultural ecosystems, opening opportunities, particularly for low–input farming. Although AMF has been tested in soilless cultivation (Dasgan *et al*., 2008; Ikiz *et al*., 2009), there is limited information on the effect of mycorrhiza in reducing fertiliser application rates as well as improving tomato growth and yield in non-temperature controlled tunnels, often associated with heat stress.

AIM OF THE STUDY

Improvement of tomato production involves the use of improved cultivars, cultivars adapted to a particular production system, and the use of soilless media. The inclusion of microbial organisms in such media might enhance nutrient uptake by plants grown hydroponically. In order to ascertain if tomato production and quality can be improved under soilless cultivation the following set of objectives was followed:

- To compare yield and quality parameters of tomato cultivars grown in soil to those maintained under a shadenet structure using an open bag hydroponic system in a plastic tunnel
- To compare the performance of commonly grown cultivars, with regard to yield and quality when grown in two different production systems, viz. an open-bag hydroponic or a closed hydroponic (gravel-film technique) system.
- To compare the performance of four tomato cultivars commonly grown in southern Africa with regard to yield and quality when grown in soilless systems in non-temperature and temperature controlled tunnels
- To investigate whether AMF can colonize tomato plants in hydroponic fertigation systems and enhance nutrient uptake, thereby reducing the fertilization rate
- To investigate the effect of mycorrhiza, growing media and nutrient concentration in a temperature controlled and a non-temperature controlled tunnel on hydroponically grown tomato yield and quality

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CHAPTER 2

COMPARATIVE PERFORMANCE OF TOMATO CULTIVARS IN SOILLESS VS IN-SOIL PRODUCTION SYSTEMS

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Abstract

A study was conducted to compare yield and quality parameters of tomato cultivars cultivated in-soil under a shadenet structure with an open bag hydroponic (soilless) system in a plastic tunnel. Four tomato cultivars, namely, FA593, Malory, Miramar and FiveOFive were included using a randomized complete block design with four replicates for both trials. Total, marketable and unmarketable yield, plant height, total soluble solids (%Brix) as well as the pH of the tomato juice were determined. Results showed that plants in the soilless system developed faster with higher total yield compared with in-soil cultivation. The average marketable yield using soilless cultivation was 92.1%, while in-soil cultivation was only 77.0%. There was no significant difference in %Brix between cultivars under in-soil cultivation, while under soilless conditions 'Malory' and 'FiveOFive' had a higher %Brix than 'FA 593' and 'Miramar'. The pH of tomato juice was highest in 'Miramar' and 'FA593' under both production systems. The most promising cultivars with regard to yield and quality were 'Miramar', followed by 'FA593' when grown in the soilless system, while there were no significant differences between any of the tested cultivars under in-soil cultivation. Results indicate that soilless cultivation can improve yield and quality, with cultivar selection playing an important role when utilizing this production system.

INTRODUCTION

Tomatoes are widely grown in South Africa and rank second after potato as a vegetable commodity. Growers in South Africa are faced with the challenge of producing high yield combined with good quality in order to satisfy the local demand. Very often this demand is not met, mainly due to inadequate plant nutrition, adverse climatic conditions, or pest and disease infestation (Johnson et al., 1975).

The population increase in South Africa and improvement of the standard of living have resulted in an increased demand for high value foods of high quality. Although the majority of tomato production in South Africa is open field production, a small amount is also produced under protection (greenhouse and shadenet structures). Many vegetable growers in and around South Africa utilizing a variety of soilless production systems have become interested in the greenhouse cultivation of vegetables. Little to no comparative information is available on in-soil vs soilless production systems for tomatoes under local conditions. The objective of this study was to compare two different production systems, i.e. soilless and in-soil cultivation using four tomato cultivars.

MATERIALS AND METHODS

Two trials were conducted at the ARC-VOPI, Roodeplaat, South Africa (25^{o} 59' S, 28^{o} 35' E at an altitude of 1200 m.a.s.l.). Trials were conducted separately in different production systems, namely plants cultivated in soil under a 40% shadenet structure and in an open-bag system in a temperature controlled plastic tunnel. The following four cultivars were evaluated in each production system: 'FiveOFive', 'Malory', 'Miramar' and 'FA593'. Seed trays were filled with a commercial growth medium, Hygromix® (Hygrotech, South Africa), and covered with a thin layer of vermiculite after seeding. As soon as the first two true leaves were fully developed, foliar fertilizer (Multifeed® at 1 g/L water) was applied every second day, followed by irrigation with tap water to reduce the build-up of salts. Seedlings were transplanted 35 days after seeding. Each experiment was laid out as a randomized complete block design. Data loggers placed 15 cm above plant canopy (unprotected from sunrays) were used for temperature recording. Mean monthly temperature and rainfall and for the experimental sites during the experimental period are presented in Table 1, although rainfall was only applicable to the shadenet structure.

In-soil production

Seedlings were transplanted to 25 cm high and 70 cm wide soil ridges. Ridges were 1 m apart and seedlings were transplanted to a double row on the 70 cm wide ridges, resulting in a plant population of 2.5 plants/m^2. Pre-plant fertilizer application (63 kg/ha N and 100 kg/ha K) was applied based on soil analysis results. The soil type was a sandy clay loam comprising of 52.1% sand, 21.9% silt and 26.0% clay, with a bulk density of 1.39 g/cm^3. Plants where then irrigated with drippers (discharge rate of 2.1 L/hour) placed in the soil next to each plant. The plants were irrigated when 50% of the available water was depleted in the soil profile with the use of a neutron probe. The pH of the irrigation water was kept in a range of 5.8-6.8 by adding nitric acid. Every fourth week, plants were top-dressed through fertigation to a total application of 177 kg/ha of nitrogen and 100 kg/ha potassium.

Soilless production

A plastic tunnel (30 m x 10 m) was equipped with a fan and pad cooling system to maintain the temperature between 9.7 to 47.9^{o}C (Table 1). Seedlings were transplanted into 10 L black plastic bags filled with sawdust as growing medium. Plants were irrigated through a dripper system with one dripper per plant delivering 2.1 L/h nutrient solution. Bags were placed as double rows at a distance of 50 cm between bags of the double row and 100 cm between double rows, with an intra-row spacing of 50 cm. Therefore, a plant density of 2.5 plants/m^2 was also achieved in the tunnel trial. The electrical conductivity (EC) of the nutrient solution was kept between 2.1 and 2.3 mS/cm. The volume applied per irrigation was gradually increased as the plant developed to ensure that 10-15% of the applied water would leach out to reduce salt build-up in the growth medium. The pH was measured and maintained within a range of 5.8 to 6.1.

Cultural practices

Plants in both trials were trained to a single stem by twisting trellis twine around the main stem and fixing it to a strain wire 2 m above soil surface to support the plant. Lateral branches were removed weekly to maintain a single stem system. When plants had reached the horizontal wire at 2 m, the growing point was removed to stop further plant growth.

Data collection

Plant height measurements were made from four weeks after transplanting onwards on a 14 day basis until the plant reached a 2 m height and the growing point was removed. Fruits were harvested weekly at the breaker stage from December 2007 to February 2008.

Data were collected from ten plants per treatment. The performance of the cultivars under the two systems was evaluated using total, marketable and unmarketable yield, as well as pathological and physiological disorders as parameters. Fruits were regarded as unmarketable when they exhibited cracking, zippering, rotting, blossom end rot (BER), catface or fell into the extra small size category. All harvested fruit were graded into classes according to fruit diameter, namely extra large (XL) (> 70 mm), large (L) (60-70 mm), medium (M) (50-60 mm), small (S) (40-50 mm) and extra small (XS) (< 40 mm).

For the determination of total soluble solids (%Brix) and pH, four ripe fruits per treatment were placed in a blender to produce a puree. The puree was then filtered through Whatman No. 4 filter paper, and the total soluble solids (%Brix) and pH of the tomato juice determined.

Data was subjected to analysis of variance (ANOVA) using *GenStat* (2003). Treatment means were separated using Fisher's protected T-test least significant difference (LSD) at the 5% level of significance (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

The marketable and unmarketable yields are presented in Table 2. Under soilless cultivation conditions, the cultivars 'Miramar', 'FA593' and 'Malory' had a higher total yield compared to 'FiveOFive', with 'Miramar' having the significantly highest marketable yield. With in-soil cultivation there were no significant differences in total and marketable yield within the cultivars tested. However, 'Malory' had a tendency towards lower marketable yield than the other cultivars when cultivated in soil. 'FiveOFive' had the lowest unmarketable fruit yield under in-soil production, followed by 'Miramar', which had the lowest unmarketable yield under soilless cultivation. Under soilless cultivation 'Malory' had the highest unmarketable fruit yield, while under in-soil cultivation 'FA593' had the highest percentage of unmarketable fruit. Comparison of soilless and in-soil cultivation in the conditions of the experiments indicates that total as well as marketable yield can be improved under soilless cultivation.

Generally retail markets in South Africa accept tomatoes of L, M and S fruit size. Fruit size is a quality parameter that influences consumer acceptance of, and preference for tomatoes. Results show significant differences in fruit size among the cultivars under the two production systems. Soilless cultivation had 22% of M to S-sized fruit while in-soil cultivation had 19%. Soilless cultivation of 'Malory' produced significantly more XL fruit than the other cultivars except for cultivar FA593 (Table 3). High significant percentages of XS fruit (unmarketable size) were found in soilless cultivation for 'FiveOFive', with the same tendency under in-soil cultivation.

Significant differences in the number and weight of cracked fruit were observed among cultivars in both cultivation systems (Tables 4 and 5). In both cultivation systems 'Malory' had the highest number and weight of cracked fruit, with 'FA593' in second place, although it should be noted that the number of cracked fruit was not significantly different between 'Malory' and 'FA593' in both systems. The higher number of cracked fruit in the latter lines could possibly be due to the fact that 'Malory' and 'FA593' produced larger sized fruit which were seemingly predisposed to cracking. The cracked fruit weight of 'Miramar' was least under both cultivation systems, possibly due to the low ratio of fruit weight to fruit number. Peet (1992), however, reported that tomato cultivars of large fruit size are prone to fruit cracking. The lack of resistance to cracking has also been reported to exacerbate the incidence of fruit cracking (Dorais et al., 2001). The higher incidence of fruit cracking under in-soil cultivation might have been exacerbated by high soil moisture content caused by rain, since the shadenet was not waterproof, while the plastic tunnel was.

In agreement with Peet (1992), rainfall during the ripening stage drastically affected the incidence of fruit cracking. Furthermore, early blight (*Alternaria solani*) was observed under in-soil cultivation, resulting in leaf and fruit drop, and eventually death of the entire plant. High rainfall during December 2007 and January 2008 (Table 1) might have favoured the incidence and spread of fungal spores in the production system. Although preventative fungicides were applied on a weekly basis, rainfall might have washed off the applied fungicides. In soilless cultivation with a cooling system the harvesting period was longer compared with in-soil cultivation.

Neither cultivars nor the cultivation systems had any significant effect on the development of blossom end rot. However, cultivars responded differently with respect to the occurrence of a further physiological disorder, zippering. Under in-soil cultivation, 'FiveOFive' showed the highest number of 'zip-fruit' (Table 4), while under soilless cultivation 'Malory' had the highest number and weight of such fruit (Table 5). Under in-soil cultivation 'Miramar' had a higher number of rotten fruit than 'Malory' and 'FiveOFive', compared to the other cultivars in soil cultivation (Table 4). Lastly, no significant differences could be determined with respect to the number and weight of fruit affected by catface in both cultivation systems.

The pH of the extracted tomato juice was lower in 'Malory' and 'FiveOFive', compared to the other two cultivars under in-soil cultivation, while 'FiveOFive' had a lower pH than 'Miramar' in the soilless system (Figure 1). Total soluble solids (%Brix) were not significantly affected by cultivar under in-soil cultivation; however, under soilless cultivation 'Miramar' had the lowest %Brix. As total soluble solids (TSS) is an indication of sweetness, although sugars are not the sole soluble components, it is clear that an alteration in taste can be achieved by soilless tomato cultivation. The flavour of tomatoes is closely related to the concentration of TSS in the fruit (Cornish, 1992). Giordano et al. (2000) reported that tomato fruit processors have adopted a bonus system based on quality, whereby 5% bonus is given for produce with soluble solids content ranging between 4.8 and 5.2 %Brix. 'Miramar' had the lowest soluble solids content of 4.6 %Brix, compared to other cultivars in both production systems. However, production of this cultivar under soilless conditions could also not raise the %Brix above 4.6%.

With in-soil cultivation, cultivars did not show any significant cultivar effect on plant height. Although no significant effect was found, 'Miramar' had a tendency to grow slower than the other cultivars. The slower increase in the height of plants under in-soil cultivation compared with soilless cultivation might have been a transplant shock reaction. Under soilless cultivation 'FiveOFive' and 'Miramar' developed slower than 'FA593' and 'Malory'. As these two cultivars produced a higher marketable yield under soilless cultivation, it seems that the more intense vegetative growth reduced the yield potential of these cultivars.

CONCLUSIONS

Soilless cultivation of tomato can improve quality, total and marketable yield compared with in-soil cultivation. Of the tested cultivars, 'Miramar' was the most promising one under soilless cultivation, followed by 'FA593'. In-soil cultivation resulted in higher incidence of physiological disorders and diseases such as early blight. These conditions were favoured in the shadenet structure by high rainfall during the experiment. If these could be controlled efficiently in soil cultivation under shadenet structure might have the potential to outperform those in soilless cultivation.

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Tables

Table 1. Mean monthly temperature and rainfall during the 2007 trial at the experimental sites

Month	Plastic tunnel Ambient temperature (°C)			40% Shade-net Ambient temperature (°C)			Rainfall (mm)
	Min	Average	Max	Min	Average	Max	
October	9.7	22.4	43.7	7.6	20.2	45.6	189.4
November	10.5	23.5	42.6	7.3	22.6	45.4	73.6
December	13.2	23.5	39.5	9.2	23.5	44.2	187.0
January	13.2	23.9	47.9	10.5	23.1	46.0	331.0
February	11.0	25.3	47.9	8.9	24.9	45.4	23.2

Table 2. Effect of cultivation system on yield (g/10 plants) of four tomato cultivars

Cultivar	Cultivation systems							
	Soilless				Soil			
	Yield (g)/10 plants							
	Total	Marketable	Marketable (%)	Unmarketable	Total	Marketable	Marketable (%)	Unmarketable
Miramar	78440a	76342a	97.3	2098c	51181	43991	85.9	9255c
FA593	75314a	69854b	92.8	5460b	53688	40623	75.7	18968a
Malory	73516ab	62943c	85.6	10573a	53217	34249	64.4	13065b
FiveOFive	68714b	63620c	92.6	5094b	51135	41880	81.9	7190d
LSD $_{0.05}$	6224.3	5170.4		2357.6	ns	ns		1527.8

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fisher’s protected T-test.

Table 3. Influence of production systems on fruit size (g/10 plants) of four tomato cultivars

Cultivar	Soil					Soilless				
	Weight of fruits (g)/10 plants									
	XL	L	M	S	XS	XL	L	M	S	XS
FiveOFive	18676	14286a	7418ab	1500	476	24251c	19926b	14485ab	4958a	1234a
Malory	22132	8517b	2951c	650	169	39805a	16125c	5878d	1136c	203b
FA 593	16775	13314a	8800a	1734	244	34078ab	22131b	10640c	3005ab	596b
Miramar	19734	15752a	6419b	2086	140	30150bc	26090a	15691a	4411a	445b
$LSD_{0.05}$	ns	4322.1	2043.4	ns	Ns	7729.8	3414.70	4380	2220.2	581.3

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fishers' protected T-test.

Table 4. Incidence of physiological disorders of four tomato cultivars under in-soil cultivation

Cultivar	Cracking		Blossom-end rot		Zippering		Catface		Rotten	
	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)
FiveOFive	32.5b	5024c	10.8	515	9.5a	1178	3.0	394	17.0b	1669
Malory	82.0a	13513a	4.3	742	6.0b	1174	5.8	1358	16.2b	2011
FA 593	70.5a	9167b	6.5	371	3.8b	466	0.5	44	30.5ab	2772
Miramar	15.5b	2246d	10.8	565	5.8b	991	2.0	242	41.5a	3006
$LSD_{0.05}$	19.33	2615.1	ns	ns	3.287	ns	ns	ns	14.40	ns

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fisher's protected T-test.

Table 5. Incidence of physiological disorders of four tomato cultivars under soilless cultivation

Cultivar	Cracking		Blossom-end rot		Zippering		Catface		Rotten	
	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)
FiveOFive	9.3b	1260bc	8.2	768	4.5b	414b	5.3	488	16.0	930
Malory	46.2a	7151a	1.8	134	10.8a	1502a	6.3	984	7.0	600
FA 593	31.8a	3602b	4.8	332	3.0b	557b	1.5	120	3.5	252
Miramar	3.2b	406c	2.0	102	5.0b	404b	4.3	316	5.0	395
LSD $_{0.05}$	15.46	2614.8	ns	ns	5.03	777.6	Ns	ns	ns	ns

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fisher’s protected T-test.

Figures

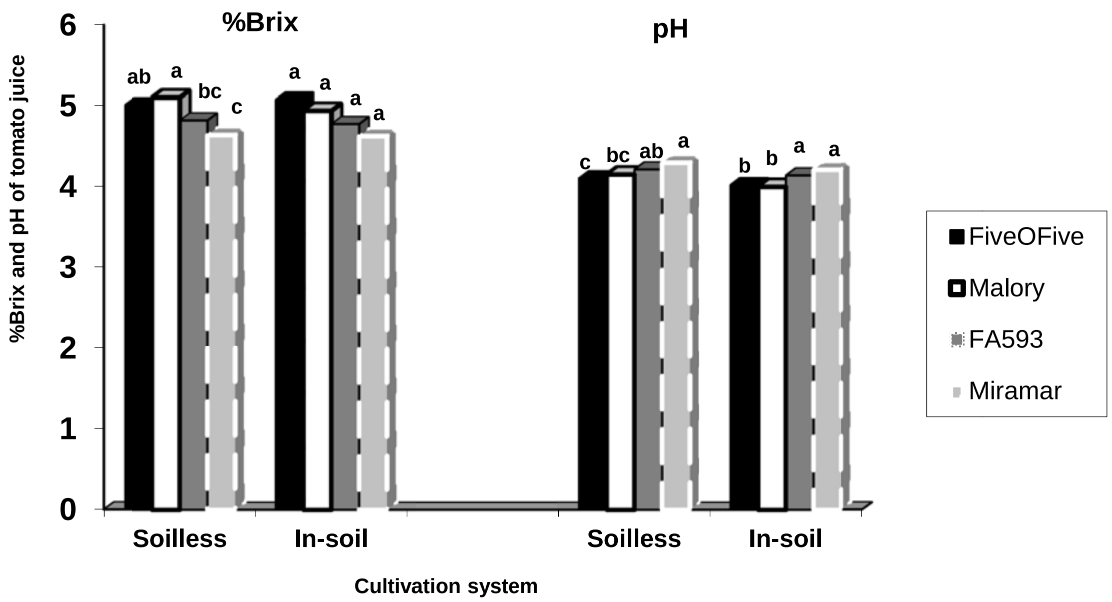

Fig. 1. Effect of cultivation systems on %Brix and pH of four tomato cultivars.

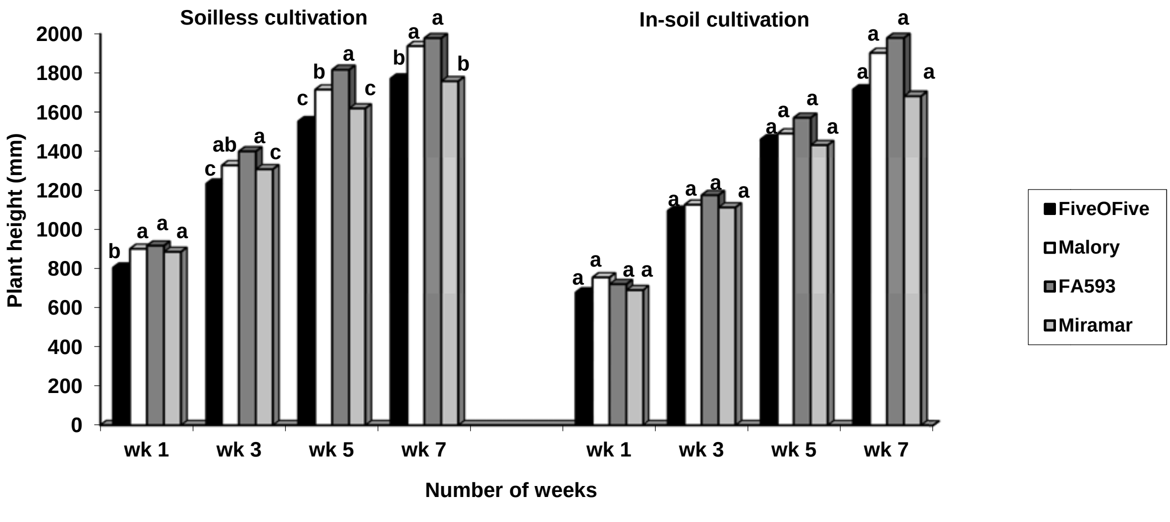

Fig. 2. Effect of cultivation systems on plant height of four tomato cultivars.

CHAPTER 3

COMPARATIVE PERFORMANCE OF TOMATO CULTIVARS CULTIVATED IN TWO HYDROPONIC PRODUCTION SYSTEMS

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Abstract

Cultivar selection for different hydroponic production systems is an important management decision, potentially impacting the tomato grower's profitability. Knowledge on the performance of tomato cultivars, in specific hydroponic systems (open-bag and closed system) under South African conditions, is still very limited. The performance of four cultivars was evaluated in an open and a closed hydroponic (gravel-film technique) system. The commonly grown cultivars evaluated in each of the two hydroponic systems were 'FA593', 'Malory', 'Miramar' and 'FiveOFive'. For each experimental, randomized complete block design was used with four replicates. Total, marketable and unmarketable yields, as well as internal fruit quality characteristics (total soluble solids (ºBrix) and pH) were determined. Although no significant differences in total yield could be established - neither in the open nor in the closed hydroponic system - differences in marketable yield were observed. 'Miramar' and 'FiveOFive' produced the highest marketable yield in the closed system; the high unmarketable yield of 'FA593' and 'Malory' in the closed hydroponic system could be attributed to the high number of cracked fruit due to their inherent larger fruit size. There were no significant differences in ºBrix between cultivars in the closed system. Cultivar 'FiveOFive', 'FA593' and 'Miramar' produced higher marketable yields than cultivar 'Malory' when grown in the open-bag system. 'Malory' and 'FA593' produced the highest number of fruit exhibiting fruit cracking in the open bag system. In the open system, only cultivar 'Malory' had a higher ºBrix than 'Miramar' and 'FiveOFive'. The most promising cultivars for local hydroponic tomato production, with regard to yield and quality, were identified as 'Miramar' and 'FiveOFive', with 'FA593'

performing equally in the open system only. Further studies need to be undertaken on economical comparison of the two production systems.

Keywords: closed hydroponic system, fruit cracking, open hydroponic system, marketable yield

Introduction

Tomatoes are the third most consumed vegetable, following potato and onion, and the most consumed fruit vegetable in South Africa (Department of Agriculture, 2010). Worldwide tomato production extends over 5.2 million ha, producing more than 130 million tons annually. In terms of tomato production, South Africa ranks 39th in the world, with a total of 421 000 tons tomatoes produced annually (FAOSTAT, 2009).

Soilless cultivation of fresh-market tomatoes has gained popularity in recent years in South Africa due to improved growth, yield and quality of commodities grown in such systems (Maboko *et al*., 2009). The majority of South African producers cultivate tomato in the open field, while a small number are producing in soilless systems under protection (Maboko *et al*., 2009). There is, however, an increase in soilless vegetable production (Raviv & Lieth, 2008) because typical field-based monoculture systems often result in disease built-up, making soil a less suitable cultivation medium.

Many new tomato cultivars are released annually in South Africa and internationally. This result in a fast turnover rate of cultivars that can complicate cultivar choice. Different cultivars have different characteristics, including sensitivity to temperature extremes, tolerance or susceptibility to insects and diseases, fruit quality and size as well as yield (Niederwieser, 2001). Most tomato cultivars are imported into South Africa and, therefore, knowledge on the optimal growing conditions for specific cultivars needs to be determined, as a wrong cultivar choice can lead to large financial losses.

In South Africa, the most popular are the open-bag hydroponic system and the closed hydroponic system using the gravel-film technique (Niederwieser, 2001). In closed systems, the excess nutrient solution is recovered, sometimes filtered, replenished and re-circulated, while open systems do not re-circulate the nutrient solution after it has passed the plant rooting zone. The open-bag system is generally used for production of crops with an indeterminate growth habit, like tomatoes, sweet peppers, cucumbers and runner beans, while the closed system (using the gravel-film technique) is generally used for leafy vegetables, such as lettuce, Swiss chard, spring onions, as well as herbs.

Soilless cultivation has recently tended towards closed systems to avoid nutrient losses and thereby reducing potentially negative environmental impact (Schwarz *et al*., 2009). No information is available on the performance of indeterminate fresh-market tomato cultivars in a closed hydroponic system under local conditions. The objective of the study was, hence, to compare the performance of four tomato cultivars, commonly grown in southern Africa, with regards to yield and quality when grown in an open-bag hydroponic system or a closed hydroponic (gravel-film technique) system, to aid producers in the choice of tomato cultivars when using systems.

Material and methods

Two experiments were conducted using a 40% shade-net (black and white) at the Agricultural Research Council - Vegetable and Ornamental Plant Institute (ARC-VOPI), Roodeplaat, South Africa (25°59' S; 28°35' E, altitude 1 200 m.a.s.l.). In one experiment an open-bag hydroponic system was used and in the second experiment a closed system (gravel-film technique) was used. Four indeterminate fresh-market tomato cultivars, commonly grown in South Africa, were evaluated in each production system: ‘FiveOFive’ and ‘Miramar’ (Hygrotech Seed Pty. Ltd., South Africa), as well as ‘Malory’ and ‘FA593’ (Sakata Seed, Southern Africa, Pty. Ltd). Cultivar ‘FA593’ is regarded as the standard cultivar grown hydroponically in South Africa, while ‘Malory’, ‘Miramar’ and ‘FiveOFive’ are fairly new introductions. Both experiments were laid out in a randomized complete block design with four replicates. Maximum, minimum and mean monthly ambient temperatures and rainfall for the experimental sites (weather station) during the experimental period were recorded at the intake (top) and the end of the gullies (Table 1) using a Digi-Senser® Thermometer (EUTECH Instruments, Singapore) to determine the possible temperature differences due to radiation.

Cultural practices

Plants in both systems were trained to a single stem by twisting trellis twine around the main stem and fixing it to a stray wire, 2 m above medium surface to support the plant. Side branches were removed weekly to maintain a single stem. When plants had reached the horizontal wire at 2 m, the growing point was removed to restrict further vertical growth.

Open-bag hydroponic system

Five-week-old tomato seedlings were transplanted into 10 L black plastic bags filled with sawdust as growing medium. Bags were placed in double rows with 50 cm intra-row spacing, a distance of 120 cm between double-rows and 47 cm between the double rows (2.5 plants m^{-2}). Plants were irrigated with a dripper system with one dripper per plant delivering 2.1 L nutrient solution h^{-1}. Plants were irrigated seven times a day, every two hours between 5:15 and 17:15. The irrigation volume was gradually increased as plants developed to ensure that 10-15% of the applied water leached out to reduce salt build-up in the growing medium. The pH and electrical conductivity (EC) of the nutrient solution were measured using a handheld 'HANNA' EC and pH meter (Hanna Instruments, Mauritius) when the fresh nutrient solution was topped up in a 5000 L container and maintained within a pH and EC range of 5.8 to 6.1and 1.9 to 2.3 mS cm^{-1}, respectively. The composition and chemical concentration of fertilizers used for tomato production, were: Hygroponic® (Hygrotech Seed Pty. Ltd., South Africa) comprising of N (68 g kg^{-1}), P (42 g kg^{-1}), K (208 g kg^{-1}), Mg (30 g kg^{-1}), S (64 g kg^{-1}), Fe (1.254 mg kg^{-1}), Cu (0.022 mg kg^{-1}), Zn (0.149 mg kg^{-1}), Mn (0.299 mg kg^{-1}), B (0.373 mg kg^{-1}) and Mo (0.037 mg kg^{-1}), calcium nitrate [$Ca(NO_3)_2$] comprising of N (117 g kg^{-1}) and Ca (166 g kg^{-1}), and potassium nitrate (KNO_3) comprising of K (38.6 g kg^{-1}) and N (13.8 g kg^{-1}). An amount of 800 g Hygroponic® and 600 g $Ca(NO_3)_2$ was diluted in 1000 L water and applied from transplanting until the first flower trusses appeared. During development of the first to third flower truss, 900 g Hygroponic® and 700 g calcium nitrate, diluted in 1000 L water, was applied; 1000 g Hygroponic®, 900 g $Ca(NO_3)_2$ and 200 g KNO_3 per 1000 L water was applied from the third flower truss to termination of the experiment.

Closed hydroponic system

A gravel-film technique hydroponic system was used to perform the experiment as described by Maboko and du Plooy (2008a). Each 6 cm deep, 1 m wide and 17 m long gully had a slope of 2.5 to 3% to allow efficient nutrient solution flow and was separated by a 70 cm path-row. Five-week-old tomato seedlings were transplanted 6 cm deep into gullies filled with crushed granite rocks of irregular shape with a diameter ranging from 16 to 19 mm. Plants were arranged in double rows with 40 cm intra-row spacing, 130 cm between double rows and 47 cm within double rows (2.5 plants m^{-2}). The gravel-film technique is based on the nutrient-film technique system, where the nutrient solution flows down gullies by gravitation. The nutrient solution was pumped to the top of the gullies resulting in a thin layer of nutrient solution flowing downwards by gravitation into the reservoir at the bottom of the gullies, from where it was continuously pumped back to the top of the gullies. At the top of the gullies four tubes released the nutrient solution at a rate of 700 ml min^{-1} per tube, on a continuous basis. The nutrient solution was completely renewed on a weekly basis as reported for the open-bag system. Similarly, the pH and the EC of the nutrient solution were measured and maintained within a range of 5.8 to 6.1 and 1.9 to 2.3 mS cm^{-1}, respectively, when the fresh nutrients were added into the 5000 L container.

Data collection

Fruit were harvested weekly at the breaker stage (Jones, 2008) from December to February. Data were collected from ten plants per replicate for each cultivar and the performance of the cultivars was evaluated using total yield, marketable and unmarketable yield, as well as physiological and pathological disorders. Fruit were regarded as unmarketable when they exhibited pathological disorders or exhibited cracking (Peet, 1992), zippering (Niederwieser, 2001), blossom-end rot (Saure, 2001), rain-check (Niederwieser, 2001; Huang & Snapp, 2004), cat-face (Jones, 2008) or fell into the extra small size category (< 40 mm diameter). For the determination of total soluble solids (ºBrix) and pH of the tomato juice, four fruit were harvested per replicate for each cultivar from the fourth truss and placed in a blender to produce a puree that was then filtered through a cheese-cloth. The ºBrix and pH was determined using a pocket refractometer PAL-1 (ATAGO®, Japan) and a pH meter (Hanna Instruments, Mauritius), respectively.

Data for each production system were subjected to analysis of variance (ANOVA) using *GenStat* (2003). Treatment means were separated using Fisher's protected T-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980).

Results and Discussion

Closed hydroponic system

No significant difference in total yield between the cultivars tested could be established. However, 'Miramar' and 'FiveOFive' had a significantly higher marketable yield compared with 'Malory' and 'FA593'. Significant differences in the number of marketable fruit were observed among cultivars (Table 2). 'Miramar' had a tendency to bear the highest number of marketable fruit, although it was not significantly different from 'FiveOFive'. 'Malory' had the lowest number of marketable fruit compared with the other cultivars, while 'FA593' had the tendency to be the second lowest producer judging on the number of marketable fruit produced. ‘Malory’ and ‘FA593’ showed a significantly higher unmarketable yield compared with other cultivars.

Significant differences in the number and mass of cracked fruit were observed between cultivars (Table 3). The incidence of fruit cracking might have been exacerbated by high rainfall, especially in January, as well as by high temperatures (Table 1), since shade-net structures are not water-proof and do not provide temperature-controlled environments. This is in agreement with Peet (1992) who indicated that overhead irrigation and high temperatures increase the incidence of fruit cracking. Rain-check was observed among all cultivars, with the exception of ‘FiveOFive’. Rain-check incidences were significantly higher in ‘Miramar’ and ‘FA593’ compared with ‘FiveOFive’ and ‘Malory’. The disorder was not observed in the open-bag system, possibly because fruit in this system were harvested before those in the closed system exhibited symptoms. The cause of rain-check is not known, but heavy rain might alter fruit temperature and/or water uptake, which could disrupt epidermal development, causing cracks on fruit shoulders (Maboko, 2008; Huang & Snapp, 2004). Cultivars did not show any significant differences in number and mass of fruit exhibiting blossom-end rot and zippering. ‘Malory’ had a high incidence of cat-face, but not significantly different from ‘FA593’ and ‘Miramar’. Cultivar ‘Miramar’ and ‘FA593’ produced a higher number of diseased fruit in the closed system than the other two cultivars. No significant differences in °Brix were observed between cultivars; however, ‘Miramar’ had the highest fruit juice pH (Figure 1).

Open-bag hydroponic system

No significant differences in total yield between the cultivars tested could be established (Table 2). ‘Malory’ produced significantly lower marketable yield as well as higher unmarketable yield than the other cultivars. The same trend was established for this cultivar in the closed system. Differences in marketable yield were due to differences in the number of marketable fruits among cultivars (Table 2). ‘Malory’ produced the lowest number of marketable fruit in this system, followed by ‘FA593’, ‘Miramar’ and ‘FiveOFive’.

Significant differences in pathological and physiological disorders and the number and mass of cracked fruit were observed among cultivars (Table 4). ‘Malory’ and ‘FA593’ had the highest number of cracked fruit; this could possibly be due to the large-sized fruit of both cultivars which seemingly predisposed them to cracking (Maboko *et al*., 2009). According to Cheryld *et al*. (1997) and Guichard *et al*. (2001), the lack of epidermis elasticity, when fruit expand, results in its rupturing. This lack of elasticity has been reported to increase the incidence of fruit cracking among tomato cultivars (Abbott *et al*., 1986; Dorais *et al*., 2001; Maboko & Du Plooy, 2008b). The cultivars evaluated did not show any significant differences in number or mass of fruit exhibiting blossom-end rot and zippering. ‘Miramar’ had a higher number of diseased fruit than ‘Malory’ and ‘FA593’. °Brix is the most common flavour index associated directly with sugars and organic acid concentrations in tomato juice (Cornish, 1992; Young *et al*., 1993). The °Brix was highest in ‘Malory’ fruit, followed by ‘FA593’, while the lowest °Brix was recorded for ‘FiveOFive’ and ‘Miramar’ in the open-bag system (Figure 1). ‘Miramar’ had the highest fruit juice pH in the open-bag production system, while ‘Malory’ juice had 5.0 °Brix followed by ‘FA593’ and ‘FiveOFive’ juice, both with 4.7 °Brix. The quality of the fruit of these cultivars is still acceptable, as the °Brix for tomatoes grown in greenhouses, using the nutrient film technique, can vary from 4.7 to 5.1 °Brix (Dorais *et al*., 2001). The pH of 'Malory', 'FA593' and 'FiveOFive' tomato juice was lower than that of 'Malory' fruit (Figure 1). Cultivars with a high juice pH generally had lower °Brix, indicating that the acidity of these fruit was lower. Jones (1999) reported that the lower the pH the greater the tartness of the fruit, a factor by which some consumers judge the quality of tomato fruit. According to the same author (Jones 1999; 2008) the acceptable pH range of tomato juice averages between 4.0 and 4.5, and for most fruits pH was 4.0 to 4.4.

Conclusions

The results demonstrate that tomato cultivars respond differently regarding marketable yield, °Brix and pH, and resistance to disorders when grown in an open-bag system or in a re-circulating hydroponic system. Of the tested cultivars, 'Miramar', 'FiveOFive' and 'FA593' outperformed 'Malory' in the open-bag system with the same tendency in the closed system. Although the closed cultivation system is not commonly utilized for tomato production, this system might improve the number of marketable fruit, as well as total and marketable yield of tomato. However, such a cultivation system seems to induce low °Brix, which is invariably linked to lower product quality. The most promising cultivars for local hydroponic tomato production, with regard to yield and quality, were identified as 'Miramar' and 'FiveOFive'.

Acknowledgements

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Table 1 Monthly mean ambient and nutrient solution temperatures, and rainfall at the experimental site, Agricultural Research Council-Vegetable and Ornamental Plant Institute (ARC-VOPI), Roodeplaat, South Africa

Month	Mean ambient temperature (^{o}C)			Closed hydroponic system (gravel-film technique)						Rainfall (mm)
				Mean nutrient solution temperature (^{o}C)						
				Top of gullies			Bottom of gullies			
	Max	Avg	Min	Max	Av	Min	Max	Avg	Min	
Oct	31.0	21.73	13.0	25.0	22.2	17.0	27.0	23.1	17.0	189.4
Nov	29.1	21.99	15.7	26.0	23.1	18.0	28.0	23.5	19.0	73.6
Dec	30.6	23.10	16.5	25.0	23.1	19.0	26.0	23.9	20.0	187.0
Jan	29.2	22.81	17.8	27.0	23.2	19.0	28.0	23.7	18.0	331.0
Feb	27.6	21.34	16.5	27.0	25.6	24.0	30.0	27.0	25.0	23.2

Table 2 Yield parameters (of 10 plants per cultivar) of four tomato cultivars in different hydroponic cultivation systems

	Closed hydroponic system (gravel-film technique)				Open-bag hydroponic system			
Cultivar	Total (kg)	Marketable (kg)	Unmarketable (kg)	Number of marketable fruit	Total (kg)	Marketable (kg)	Unmarketable (kg)	Number of marketable fruit
FiveOFive	74.74	69.27ab	5.47b	549ab	65.60	56.75a	8.85c	456.8a
Malory	79.42	57.36c	22.06a	332c	60.20	42.77b	17.42a	253.2c
FA593	83.13	65.11bc	18.02a	463b	68.37	54.40a	13.98b	407.2b
Miramar	87.05	76.08a	10.97b	577a	68.08	55.45a	12.63b	437.2ab
LSD $_{0.05}$	ns	10.69	6.34	86.5	ns	5.55	3.25	41.18

Figures within columns followed by the same letter are not significantly different ($P > 0.05$), using Fishers' protected t-test.

Table 3 Incidence of physiological and pathological (rotten fruits) disorders (of 10 plants per cultivar) on four tomato cultivars cultivated under closed hydroponic gravel-film technique

Cultivar	Cracking		Blossom-end rot		Zippering		Cat-face		Rotten fruit		Rain-check	
	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)
FiveOFive	27.0b	3.03c	3.8	0.28	12.2	1.11	0.8	0.09b	13.5ab	0.72b	0.0c	0.00c
Malory	95.2a	16.81a	3.5	0.29	15.5	2.35	7.3	0.99a	7.0b	1.01b	4.2bc	0.52bc
FA 593	88.2a	11.91b	5.0	0.40	9.5	0.85	3.5	0.46ab	24.2a	2.51a	14.2ab	1.62ab
Miramar	25.0b	3.06c	11.3	0.73	11.2	1.72	4.75	0.53ab	27.0a	2.84a	17.8a	1.93a
$LSD_{0.05}$	34.75	4.91	ns	ns	ns	Ns	ns	0.60	13.6	1.39	12.03	1.13

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fishers' protected t-test.

Table 4 Incidence of physiological and pathological (rotten fruits) disorders (of 10 plants per cultivar) on four tomato cultivars cultivated in an open-bag hydroponic system

Cultivar	Cracking		Blossom-end rot		Zippering		Cat-face		Rotten fruits	
	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)	Number	Mass (kg)
FiveOFive	51.0c	5.16d	5.5	0.362	10.5	1.062	4.50	0.490	16.2	1.15ab
Malory	110.2a	14.60a	0.50	0.073	6.75	1.134	4.50	0.833	8.0	0.63b
FA 593	100.2a	11.79b	1.75	0.110	4.25	0.557	1.50	0.265	9.0	0.73b
Miramar	75.5b	8.47c	1.50	0.090	10.75	1.343	1.25	0.124	20.2	1.66a
$LSD_{0.05}$	21.14	2.62	ns	ns	ns	ns	ns	ns	ns	0.68

Figures in a column followed by the same letter are not significantly different (P > 0.05), using Fishers' protected t-test.

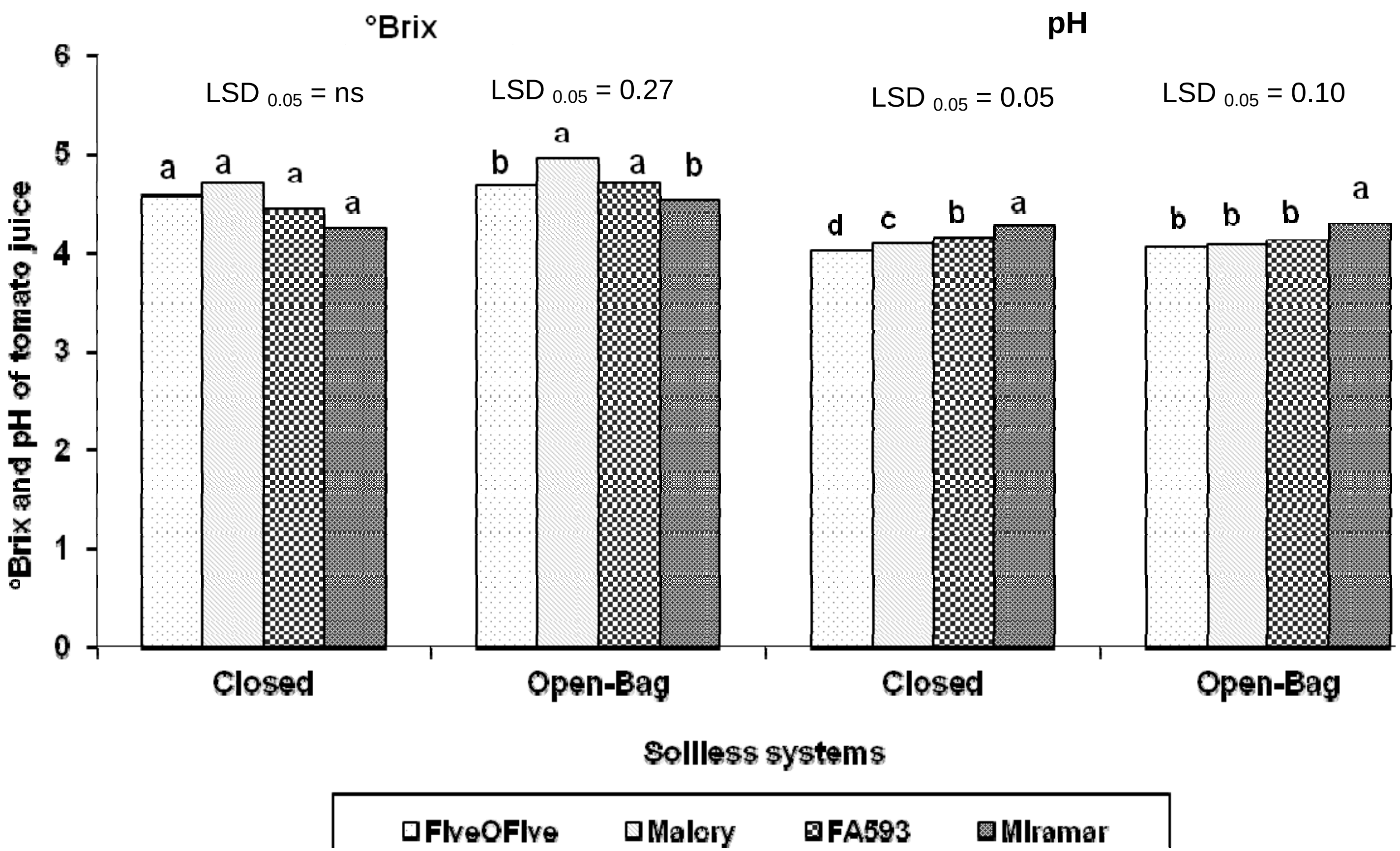

Figure 1 Total soluble solids (°Brix) and pH of four tomato cultivars in different hydroponic production systems

CHAPTER 4

Performance of Tomato Cultivars in Temperature and Non-Temperature Controlled Plastic Tunnels

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Abstract

The majority of tunnel production in South Africa is carried out in standard (non-temperature controlled) tunnels, while utilization of temperature controlled tunnels is increasing. Knowledge on the performance of common tomato cultivars utilizing tunnels is still very limited. Four tomato cultivars, namely, 'FA593', 'Malory', 'Miramar' and 'FiveOFive' were grown in an open-bag system with sawdust as growing medium in non-temperature controlled and temperature controlled tunnels. The latter was equipped with a fan-and-pad cooling system, while the non-temperature controlled tunnel relied on natural ventilation. A randomised complete block design with four cultivars replicated four times was used for both conditions. Fruit number and mass, as well as total marketable and unmarketable yield per plant were calculated for each cultivar. 'Miramar' and 'FiveOFive' produced the highest marketable yield in both structures. The average marketable yield was 88% and 59% of the total yield in the temperature controlled and non-temperature controlled tunnel, respectively. All cultivars produced a higher marketable yield in the temperature controlled tunnel than in the non-temperature controlled tunnel. The lower marketable yield in the non-temperature controlled tunnel was caused by the higher number of small-sized fruits and higher number of fruit cracking. This disorder was found to be directly correlated with fruit size, with cultivars 'Malory' and 'FA593' more susceptible than the other two cultivars. Results emphasize the importance of cultivar selection, while illustrating that temperature control can improve yield and quality of tomatoes produced in tunnels.

Keywords: cultivar, fruit cracking, fruit size, temperature, tunnel, quality, yield

INTRODUCTION

Cultivation of fresh market tomatoes in a protected environment has gained popularity in recent years in South Africa due to improved growth, yield and quality of commodities grown in such a manner. The majority of producers cultivate tomato in the open field, while a smaller amount is produced in soilless production systems under protected environments (Maboko et al., 2009). There is, however, an increase in soilless production systems for vegetables (Raviv and Lieth, 2008) because typical field-based monoculture systems often result in disease build-up, making soil a less suitable cultivation medium. Unfavourable weather conditions, such as high rainfall and high temperature fluctuations, have resulted in farmers trying to optimise yield and quality of tomatoes by using soilless production systems under protection.

The majority of tunnel production in southern Africa is still carried out in standard (non-temperature controlled) tunnels, while utilization of temperature controlled tunnels is continuously increasing. Producing vegetables successfully in such tunnels during the summer season requires cooling or ventilation to maintain a suitable microclimate. Tunnel growers and designers of protected cultivation systems are faced with the challenge to choose between installations of natural ventilations or expensive fans providing evaporative cooling (Teitel et al., 2007). Although such fan-and-pad cooling systems are efficient in reducing the heat load inside tunnels (Mutwiwa et al., 2007), such cooling systems are not widely used in South Africa due to high initial costs, high maintenance, as well as the high electricity costs. Farmers prefer non-temperature controlled tunnels due to their low cost and simplicity, and are relying on natural ventilation in order to reduce the temperature in tunnels. However, Perdigones et al. (2005) reported that natural ventilation is not sufficient to reduce heat load in protected cultivation.

Many new tomato cultivars are released annually on the South African and the international markets. This results in a fast turnover rate of cultivars and can severely complicate cultivar choice. Farmers are relying on the description of cultivars in pamphlets released by seed companies or breeders. New farmers often communicate with well-established commercial farmers when selecting a good cultivar. Lack of information in selecting good cultivars may lead to lower yield or unacceptable fruit quality. Cultivars differ in characteristics, including sensitivity to temperature extremes, tolerance or susceptibility to pests and diseases, fruit quality, size and yield (Niederwieser, 2001). Most tomato cultivars are imported into South Africa and therefore optimal growing conditions for specific cultivars need to be determined, as wrong cultivar choices can lead to great financial losses.

The objective of the study was to compare the performance of four tomato cultivars commonly grown in southern Africa with regard to yield and quality when grown under soilless systems in non-temperature controlled tunnel and temperature controlled tunnels.

MATERIALS AND METHODS

An experiment was conducted using a temperature controlled tunnel and a non-temperature controlled tunnel at the Agricultural Research Council - Vegetable and Ornamental Plant Institute (ARC-VOPI), Roodeplaat, South Africa ($25^{o}59^{'}$ S; $28^{o}35^{'}$ E, altitude 1 200 m.a.s.l.). A temperature controlled tunnel was equipped with a wet-wall (1.7m x 8m) and two extraction fans (1.1 kW fans, 1300 mm diameter), whereas the non-temperature controlled tunnel relied on natural ventilation by means of a flap and door that could be opened on opposite sides. The size of the tunnel was 10 m width x 30 m length x 4.2 m height covered with a UV resistant 200 µm thick plastic (Chris Hefer Construction, South Africa). The following four hydroponically grown indeterminate fresh market tomato cultivars were evaluated in each production system: ‘FiveOFive’ and ‘Miramar’ (Hygrotech Seed Pty. Ltd., South Africa), and ‘Malory’ and ‘FA593’ (Sakata Seed, Southern Africa, Pty.). Cultivar ‘FA593’ is regarded as the standard cultivar grown hydroponically in South Africa, while cultivars ‘Malory’, ‘Miramar’ and ‘FiveOFive’ are new introductions. A randomised complete block design experiment was performed for each of the two systems (non-temperature controlled tunnel and temperature controlled tunnel). For each production system, four tomato cultivars were randomly replicated within four blocks.

Data-loggers (Gemini Data Loggers, United Kingdom), placed under a Stevenson-type screen (ACS-5050), were used to record temperature (Table 1).

Cultural Practices

Five-week-old tomato seedlings were transplanted into 10 L black plastic bags filled with sawdust as growing medium. Plants in both production systems were trained to a single stem by twisting trellis twine around the main stem and fixing it to a stray wire 2 m above ground surface to support the plant. Side branches were removed weekly to maintain a single stem system. When plants had reached the horizontal wire at 2 m (on average eight trusses), the growing point was removed to restrict further plant growth.

Open-bag System

Bags were placed as double rows with a distance of 50 cm intra-row spacing, a distance of 120 cm between double rows and 47 cm between the individual rows of a double row (2.5 plants/m^2). Plants were irrigated through a dripper system with one dripper per plant delivering 2.1 L/h nutrient solution. Plants were irrigated seven times a day for every two hours. The irrigation volume was gradually increased as plants developed to ensure that 10-15% of the applied water leached out to reduce salt build-up in the growth medium. The pH was measured using a handheld 'HANNA' EC and pH meter (Hanna Instruments, Mauritius) and maintained within a range of 5.8 to 6.1 and 1.9 to 2.3 mS/cm. The composition and chemical concentration of fertilizers used for tomato production were: Hygroponic® (Hygrotech Pty Ltd, South Africa) comprising of N (68 mg/kg), P (42 mg/kg), K (208 mg/kg), Mg (30 mg/kg), S (64 mg/kg), Fe (1.254 mg/kg), Cu (0.022 mg/kg), Zn (0.149 mg/kg), Mn (0.299 mg/kg), B (0.373 mg/kg) and Mo (0.037 mg/kg); calcium nitrate ($CaNO_3$) comprising of N (117 mg/kg) and Ca (166 mg/kg); and potassium nitrate (KNO_3) comprising of K (38.6 mg/kg) and N (13.8 mg/kg). An amount of 800 g Hygroponic® and 600 g $CaNO_3$ was applied in 1000 L water at transplanting until the first flower truss appeared. During development of the first to third flower trusses, 900 g Hygroponic® and 700 g calcium nitrate were applied in 1000 L water. Fertiliser applied from the third flower truss to end of the experiment was 1000 g Hygroponic®, 900 g $CaNO_3$ and 200 g KNO_3 per 1000 L of water.

Data Collection

Fruit were harvested weekly at the breaker stage (Jones, 2008) from December 2008 to February 2009. Data were collected from 10 plants per cultivar per replicate, and the performance of the cultivars was evaluated using total yield, marketable and unmarketable yield, as well as physiological and pathological disorders. Fruit were regarded as unmarketable when they exhibited pathological disorders or cracking, zippering, rotting, blossom-end rot, rain-check, cat-face or fell into the 'extra small size' category (less than 40 mm diameter).

The data of the two production systems were tested for homogeneity of variances using Bartlett's test with SAS v9.2 statistical software (SAS, 1999). In cases where the variability in the observations of the two production systems were of comparable magnitude, an analysis of variance for the two systems' observations together could be validly carried out. In cases where there were strong evidence against homogeneity, a weighted analysis of variance was carried out on the two systems' observations together using the inverse of the pooled variances of each system as weight (John, 1977). The data was acceptably normal and Student's t-Least Significant Differences were calculated at the 5% level to compare treatment means of significant effects (Snedecor and Cochran, 1980). Analysis of variance was carried out using GenStat® (2010).

RESULTS AND DISCUSSION

Effect of Production System

Yield and number of marketable fruit per plant were significantly higher under temperature controlled than non-temperature controlled conditions (Figure 1, Table 2). This was probably due to air temperatures in the temperature controlled and non-temperature controlled tunnel differing (Table 1), ranging from 13.2 to 38.0˚C in the temperature controlled and 14.6 to 44.2˚C in the non-temperature controlled tunnel. The optimal temperature range for growing tomatoes has been identified as 18.5 to 26.5˚C (Jones 1998). Hence, the temperature controlled tunnel was better suited to tomato plant growth and development than the non-temperature controlled tunnel.

The marketable yield of tomatoes grown in the temperature controlled tunnel was at least 29% higher than in the non-temperature controlled tunnel (Figure 1). Total yield and marketable yield, as well as number of marketable fruits were significantly high in the temperature controlled tunnel than in the non-temperature controlled tunnel (Table 2). Conversely, unmarketable yield, number and mass of fruit cracking were significantly higher in the non-temperature controlled tunnel compared to the temperature controlled tunnel.

Larger temperature differences (Table 1) in the non-temperature controlled tunnel, as compared to the temperature controlled tunnel might have contributed to reduced fruit set in the former tunnel. Nonviable pollen and failure to set tomato fruit can result from temperatures above 29^{o}C (Abdul-Baki and Stommel, 1995; Peet and Bartholomew, 1996, Sato et al., 2000). According to Perdigones et al. (2005) natural ventilation is not sufficient for extracting warm air during the sunny days. Comparison of temperature controlled and non-temperature controlled facilities indicates that total, as well as marketable yield can be improved in temperature controlled tunnels (Table 2, Figure 1). Similarly, Peet et al. (1997), as well as Mutwiwa et al. (2007) reported that fan-and-pad cooling systems can improve fruit set of tomatoes.

Effect of Cultivar

Total yield, marketable yield and number of marketable fruits were significantly higher with ‘Miramar’ and ‘Five-O-Five’ as compared to ‘Malory’ and ‘FA593’ (Table 2). ‘FiveOFive’ and ‘Miramar’ produced the highest number of marketable fruit, followed by ‘FA593’, while the lowest number was recorded for ‘Malory’. ‘Malory’ and ‘FA593’ produced a higher unmarketable yield than ‘Miramar’ and ‘FiveOFive’. ‘FA593’, followed by ‘Malory’, produced the highest number of fruit exhibiting cracking, higher than ‘Five-O-Five’ and ‘Miramar’ (Table 2).

Interaction Effect of Cultivar and Production System

There was a significant interaction between production system and cultivar with regard to unmarketable yield, number of marketable fruits and mass of fruit with cracking (Table 3). The number of marketable fruits was significantly higher in ‘Miramar’ and ‘FiveOFive’, followed by ‘‘FA593’ in the temperature controlled tunnel, while ‘Malory’ and ‘FA593’ recorded the lowest in the non-temperature controlled tunnel. In the non-temperature controlled tunnel the highest unmarketable yield was recorded for ‘FA593’, followed by ‘Malory’, with the lowest unmarketable yield recorded for ‘Miramar’ and ‘FiveOFive’ in the temperature controlled tunnel. This is in agreement with Maboko et al. (2009) who observed tomato cultivars responding differently when grown in different production systems. ‘Miramar’ and ‘FiveOFive’ produced the highest number of marketable fruits, compared to the other cultivars in the temperature controlled tunnel, while in the non-temperature controlled tunnel ‘Five-O-Five’ and ‘Miramar’ produced the highest number of marketable fruits, compared to ‘Malory’ and ‘FA593’.

‘Malory’ produced significantly the highest number of cracked fruit, with ‘FA593’ recording the second highest, compared to the other cultivars in the non-temperature controlled tunnel than in the temperature controlled tunnel. This higher number of cracked fruit could be due 'Malory' and 'FA593' producing larger-sized fruit, a feature which predisposes such fruit to cracking (Maboko and Du Plooy, 2008; Maboko et al., 2009). The lack of exocarp elasticity when fruit expand can result in rupturing of the epidermis (Peet, 1992; Cheryld et al., 1997). The higher incidence of cracked fruit among cultivars grown in the non temperature controlled tunnel might have been caused by higher temperatures, as well as higher temperature fluctuations than in the temperature controlled tunnel. Peet (1992) reported that higher temperatures increase the incidence of tomato fruit cracking. Relying on natural ventilation to counteract heat build-up in tunnels seems insufficient to improve tomato yield. However, cultivars that tolerate warm air or heat stress could be introduced to improve fruit set, yield and quality of tomato in non-temperature controlled tunnels.

CONCLUSIONS

Results emphasize the importance of cultivar selection, while illustrating that temperature control can improve yield and quality of tomatoes produced in tunnels. 'Miramar' and 'FiveOFive' were the most promising cultivars in both systems with regard to yield and quality. Use of the recommended cultivars can help tunnel production growers to positively compete with imported tomatoes.

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Figures

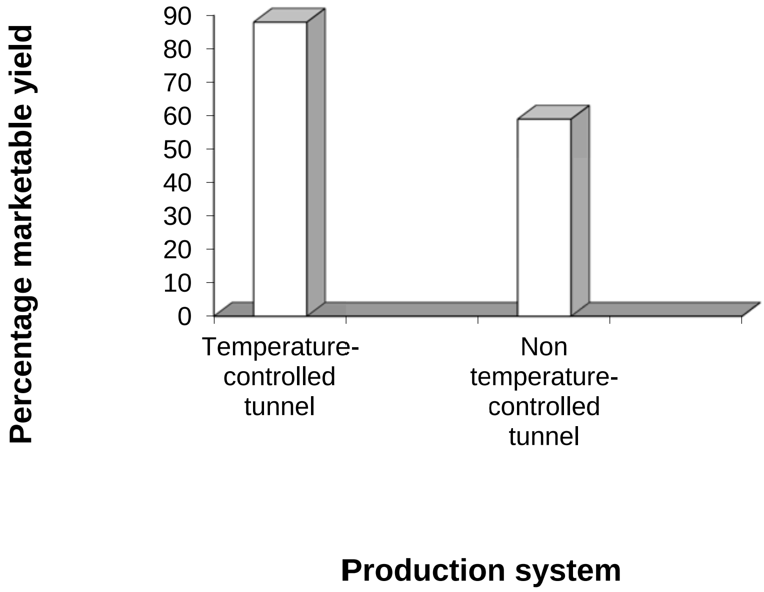

Fig. 1. Percentage marketable yield in temperature and non-temperature controlled tunnels.

Tables

Table 1. Mean monthly temperature during the 2008/9 experimental period

Month	Non-temperature controlled tunnel			Temperature controlled tunnel		
	Min	Ave	Max	Min	Ave	Max
Oct	15.9	25.7	44.2	13.2	23.1	38.0
Nov	16.1	25.8	44.2	14.1	21.8	35.6
Dec	15.8	26.9	44.2	13.8	23.0	32.9
Jan	17.2	25.6	44.2	15.5	21.7	30.9
Feb	14.6	24.3	41.5	13.5	19.9	27.5

Table 2. Yield and number of marketable fruit of tomato cultivars (g/plant, fruit/plant) in the temperature controlled tunnel and non-temperature controlled tunnel

Treatment	Total yield	Marketable yield	Number of marketable fruits	Unmarketable yield	Number of marketable fruits	Number of fruit cracking	Mass of cracked fruit
Production System							
C28	3978b	2349b	25.31b	1629a	25.31b	14.36a	1358a
C29	6619a	5799a	45.20a	820b	45.20a	4.14b	616b
Lsd 0.05	299.1	309.4	1.99	187.6	1.99	1.3	171.8
Cultivars							
Five-O-Five	5596ab	4835a	43.40a	761b	43.40a	2.92c	413c
Malory	4748c	3100b	23.41c	1648a	23.41c	9.64b	1424b
FA593	5193b	3352b	28.89b	1841a	28.89b	12.85a	1671a
Miramar	5657a	5007a	45.31a	650b	45.31a	3.07c	440c
LSD 0.05	422.9	147.3	2.81	265.3	2.81	1.675	243

Figures in a column followed by the same letter are not significantly different ($P > 0.05$), using Fisher's protected t-test.
C28 = non-temperature controlled tunnel; C29 = temperature controlled tunnel