EFFECTS OF PHOTO-SELECTIVE NETS ON TOMATO (*Solanum lycopersicum*)
PLANT GROWTH AND FRUIT QUALITY AT HARVEST

By

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FACULTY OF SCIENCES

TSHWANE UNIVERSITY OF TECHNOLOGY

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Co-supervisor: Prof P Soundy

November 2013
DECLARATION

I hereby declare that the work herein submitted as a dissertation for the degree M Tech: Agriculture, at the Tshwane University of Technology, is the results of my own investigation and has not previously been submitted to any other institution of higher education. Work by other authors that served as sources of information have fully been acknowledged by means of a comprehensive list of references.

_________________________  _________________________
Mr P.P TINYANE               DATE
DEDICATION

This thesis is dedicated to my late father, Mr Lekgoo Wilson Tinyane, with much love and appreciation.
AKNOWLEDGEMENTS

First I would like to give thanks to GOD Almighty, for he has provided me strength and wisdom during the period of my studies.

I am grateful to my supervisor, Prof D Sivakumar, for her leadership, expertise and excellent contributions throughout the course of my study, and my co-supervisor, Prof P Soundy, thanks for your assistance.

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Finally and most importantly, I would like to acknowledge the financial assistance from the National Research Foundation and the Tshwane University of Technology postgraduate scholarship.
LIST OF PUBLICATIONS AND PRESENTATIONS

1 PUBLICATIONS

1.1 Article online


1.2 Farmers communication-Transfer of technology


2 PRESENTATIONS

2.1 International Conference

Postharvest Africa 2012, 7\textsuperscript{th} International CIGR Technical Symposium

Tinyane, P.P., Sivakumar, D. & Soundy, P. Influence of photo-selective netting on fruit quality parameters and bioactive compounds in tomatoes.

2.2 National Conference

Combined Crops, Soils, Horticulture and Weeds Congress 2013, South Africa.

Tomatoes (*Solanum lycopersicum*) are rich in carotenoids (especially lycopene, and β-carotene, a precursor of vitamin A), phenolics (flavonoids) and vitamin C. However, growth, yield, fruit quality, and nutritional content of tomato plants are affected not only by genetics (cultivars), but also by environmental conditions, including abiotic and biotic factors such as pests and diseases. Therefore, a study was conducted to investigate the influence of photo-selective nets (*ChromatiNet™*) (red, pearl and yellow) with 40% shading on the plant growth, yield, and production of good quality fruits that contain improved bioactive compounds. A commercial black net with 25% shading was as a control. Three indeterminate tomato cultivars (AlfaV, Irit, and SCX 248) were planted. The photosynthetically active radiation, air temperature and relative humidity were monitored throughout the growing period. The following parameters such as plant height, stem diameter, leaf area, leaf chlorophyll, flowering, fruit trusses and numbers of fruits per plant were measured during the growing period. The fruit mass, fruit marketable yield, fruit firmness and colour, titratable acidity, soluble solids content, and bioactive compounds (ascorbic acid, lycopene content, β-carotene, total phenols and flavonoids, and total antioxidant activity) were determined at harvest maturity (pink colour stage). Photo-selective nets indicated a higher air temperature and a lower relative humidity, while the black (control) net accumulated a higher photosynthetically active radiation. The results of the study demonstrated that the two photo-selective nets (red and yellow) had a great influence on plant height and leaf area, while the stem diameter measurements were greater in plants grown under the red net. High intensities of flowering were noted in plants produced under photo-selective red, pearl and yellow
nets, whereas the number of fruits per plant was higher for plants grown under the pearl and yellow nets. Marketable fruit yields were higher in cultivar AlfaV grown under the pearl net. Furthermore, no significant differences were noted among the shade nets with regard to disease and pest incidences. The three cultivars grown under the black net revealed a lower plant height, less fruit mass, and lower fruit marketable yields. Principle component analysis demonstrated that cultivar AlfaV fruits produced under black nets were lower in mass, less firm, and higher in bioactive compounds but lower in titratable acidity and more intense in red colour. However, under pearl nets cultivar AlfaV exhibited a higher fruit mass, more firmness and moderately higher bioactive compounds. Pearl and red photo-selective nets improved the overall fruit yield and quality parameters such as fruit mass, fruit firmness and bioactive components in AlfaV and SCX 248.

**Keywords:** Environmental conditions, bioactive compounds, plant growth, tomatoes, yield, fruit quality
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<tr>
<td>% w/v</td>
<td>Percentage weight per volume</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>°C</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>µg</td>
<td>Microgram</td>
</tr>
<tr>
<td>µl</td>
<td>Microlitre</td>
</tr>
<tr>
<td>a*</td>
<td>+a refers to the red colour, while –a refers to the green colour</td>
</tr>
<tr>
<td>AA</td>
<td>Ascorbic acid</td>
</tr>
<tr>
<td>AlCl&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Aluminium chloride</td>
</tr>
<tr>
<td>AT</td>
<td>Air temperature</td>
</tr>
<tr>
<td>b*</td>
<td>+b refers to yellow colour, while –b refers to blue colour</td>
</tr>
<tr>
<td>B</td>
<td>Boron</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
<tr>
<td>Ca(NO&lt;sub&gt;3&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Calcium nitrate</td>
</tr>
<tr>
<td>CEA</td>
<td>Controlled environment agriculture</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>CMV</td>
<td>Cucumber mosaic virus</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Carbon dioxide</td>
</tr>
</tbody>
</table>
Cu  Copper

cv.  Cultivar

DPPH  2, 2-diphenyl-1-picrylhydrazyl

DRI  Recommended daily intake

DV  Daily value

E  East

E  Environment

e.g.  For instance

etc.  And so forth

FAO  Food and Agriculture Organisation

Fe  Iron

FR  Far red

g kg\(^{-1}\)  grams per kilogram

\(g\ L^{-1}\)  Grams per litre

G  Genotype

g  Gram

\(g^{-1}\ FW\)  Per gram fresh weight

GAE  Gallic acid equivalents

h  Hour
<table>
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<td>$h^\circ$</td>
<td>Hue</td>
</tr>
<tr>
<td>IU</td>
<td>International unit</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>kcal</td>
<td>Kilocalorie</td>
</tr>
<tr>
<td>$kg \ m^{-2}$</td>
<td>Kilogram per meter squared</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>$kg^{-1} \ FW$</td>
<td>Per kilogram fresh weight</td>
</tr>
<tr>
<td>KNO$_3$</td>
<td>Potassium nitrate</td>
</tr>
<tr>
<td>$L^*$</td>
<td>Lightness,</td>
</tr>
<tr>
<td>L</td>
<td>Litre</td>
</tr>
<tr>
<td>LSD</td>
<td>Least significant difference</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>M</td>
<td>Mole</td>
</tr>
<tr>
<td>$mg \ g^{-1}$</td>
<td>Milligrams per gram</td>
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<td>$mg \ kg^{-1} \ FW$</td>
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<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>min</td>
<td>Minute</td>
</tr>
<tr>
<td>ml</td>
<td>Milliliter</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>mM</td>
<td>Millimolar</td>
</tr>
<tr>
<td>mm²</td>
<td>Millimeter squared</td>
</tr>
<tr>
<td>Mo</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>N</td>
<td>Normality</td>
</tr>
<tr>
<td>n</td>
<td>Number</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>Sodium carbonate</td>
</tr>
<tr>
<td>NaNO₂</td>
<td>Sodium nitrite</td>
</tr>
<tr>
<td>NaOH</td>
<td>Sodium hydroxide</td>
</tr>
<tr>
<td>NH₄</td>
<td>Ammonium</td>
</tr>
<tr>
<td>nm</td>
<td>Nanometer</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>PAR</td>
<td>Photosynthetically active radiation</td>
</tr>
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<td>PARo</td>
<td>Photosynthetically Active Radiation outside the net house</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal Component Analysis</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts per million</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>PVY</td>
<td>Potato virus Y</td>
</tr>
<tr>
<td>R</td>
<td>Red</td>
</tr>
<tr>
<td>RDA</td>
<td>Recommended daily allowance</td>
</tr>
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<td>RH</td>
<td>Relative humidity</td>
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<td>S</td>
<td>South</td>
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<tr>
<td>S</td>
<td>Sulfur</td>
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<tr>
<td>S&lt;sub&gt;PAR&lt;/sub&gt;</td>
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<tr>
<td>SSC</td>
<td>Soluble solids content</td>
</tr>
<tr>
<td>TA</td>
<td>Titratable acidity</td>
</tr>
<tr>
<td>TF</td>
<td>Total flavonoids</td>
</tr>
<tr>
<td>TP</td>
<td>Total phenolics</td>
</tr>
<tr>
<td>TYLCV</td>
<td>Tomato yellow leaf curl virus</td>
</tr>
<tr>
<td>™</td>
<td>Trade mark</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
</tr>
<tr>
<td>UV</td>
<td>Ultra violet</td>
</tr>
<tr>
<td>v/v</td>
<td>Volume per volume</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc</td>
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</table>
\[ \beta \quad \text{Beta} \]

\[ \mu \text{mol m}^{-2} \text{s}^{-1} \quad \text{Micromole per meter squared per second} \]
CHAPTER ONE

1 GENERAL INTRODUCTION

Tomato (*Solanum lycopersicum*) is the most important and the most popular vegetable crop in South Africa. The tomato has also been recognised as the most important source of lycopene, a red coloured carotenoid associated with several health benefits (Ilahy *et al.*, 2011:588). In addition to lycopene, the tomato contains a number of flavonoids and phenolic acids that can contribute to a healthy diet (Anza, Riga & Garbisu, 2006:17). However, the yield and quality of tomatoes is limited due to varying climatic conditions characterised by high solar radiation and temperatures, and pests which cause direct feeding damage and often transmit viruses during the growing periods (Ben-Yakir *et al.*, 2013:249, Higashide, 2009:1874, De Koning, 1989:329). It is a well-known fact that climatic conditions and tomato variety have an effect on yield and fruit quality (Davies & Hobson, 1981:205, Tshiala & Olwoch, 2010:2945). Tomato is sensitive to temperature in different physiological aspects (Picken, 1984:1); hence, it also plays a role in determining floral quality. In comparison to the vegetative parts, the reproductive parts of the tomato plant are more vulnerable to higher temperatures (32/26 °C day and night) (Sakata *et al.*, 2000:395). On the other hand, tomatoes grown at higher day temperatures (>24 °C) as well as at lower night temperatures (<18 °C) were reported to have a negative effect on fruit quality during harvest and postharvest (Ohio Vegetable Production Guide, 2010). Aspects relating to loss of fruit quality incurred under excessive preharvest temperatures include alterations in the colour, shape and texture of the
tomato fruits (Ziplevish et al., 2000:431). Furthermore, tomato yields are determined by the amount of intercepted light (Newton et al., 1999:43) and assimilate partitioning (Ho, 1996:1239). Temperature significantly affect the partitioning of assimilates between vegetative and generative parts (De Koning, 1989:329; Adams et al., 2001:869).

At higher temperatures, fruit trusses appear faster (Hurd & Graves, 1985:359; Adams et al., 2001:869), resulting in more fruits per plant. These fruits will grow at the expense of vegetative growth, and may also cause a delay in the growth of newly set fruit or may even lead to flower or fruit abortion (De Koning, 1989:329), as the newly developed and flowering trusses are weaker sinks than fruiting trusses (Ho & Hewitt, 1986:201). A loss of firmness and fruit damage that can be noted at light intensity levels above photosynthetic saturation, particularly under intense light exposure, have been associated with an increase in the temperature of fruit (Adegoroye & Jolliffe, 1987:297; Sams, 1999:249).

The lycopene content of tomato fruits is influenced by fruit variety as well as by cultivation methods and environmental conditions. In the fruit, chlorophyll breaks down and carotenoids, mostly lycopene, accumulate during the ripening process (Brandt et al. 2006; Helyes, 1999). Fruit exposure to excessive sunlight was reported to inhibit lycopene synthesis (Brandt et al., 2006:568). Fruits exposed to strong solar radiation may have a temperature which is 10 °C higher than that of fruits protected by leaves. According to Brandt et al. (2006:568), when the temperature of the fruits exceeds 30 °C, the formation of lycopene is inhibited. Lycopene develops best when the temperature is between 12 °C and 21 °C (Tomes, 1963:180). Raymundo,
Chichester and Simpson (1976:59) reported that a low light intensity results in an uneven fruit colour due to a decrease in lycopene accumulation, but on the other hand, direct radiation is too strong and therefore harmful to fruits. The accumulation of phenolic compounds such as flavonoids and phenylpropanoids is, however, induced by thermal stress (Helyes, Lugasi & Pek, 2012:703). According to George et al. (2004:45), the polyphenol level in tomatoes produced at 35 °C is double the amount of that produced at 25 °C. A higher temperature also favours ascorbic acid synthesis (Helyes, Lugasi & Pek, 2012:703). Large parts of land in Africa and the world at large have shown high irradiation; with temperatures having risen by over 0.7 °C in the last 100 years, and 11 of the last 12 years (1995-2006) having been the warmest on record (Allali et al., 2001:490). As a result, the need for crop cultivation in protected environments has become essential so as to improve the quality and yield of agricultural produce by minimising thermal stress on heat sensitive traits. Netting has the potential to offer an effective solution, because it (a) provides protection from environmental hazards (e.g., excessive solar radiation, wind, hail, flying pests); (b) improves the plant microclimate (thus reducing heat or chill, drought stresses); (c) moderates rapid climatic stresses; and (d) is cheaper and less energy consuming than greenhouses.

Photo-selective nets (ChromatiNet™), are light-dispersive shade with potential benefits for crop production in protected culture. Unlike the common black and white nets, photo-selective nets have the ability to modify the quality of transmitted light, in addition to their basic protective function (from hail, wind, pests, or excessive solar radiation) (Shahak et al., 2004a:144). Photo-selective nets are composed of semitransparent threads that selectively screen out the defined spectral bands of
light, generally transmitted through them in UV or visible spectral ranges, together with transforming direct light into scattered or diffused light (Shahak, 2004b:610). Such spectral manipulation can trigger a wide range of physiological responses, while the scattering improves the penetration of spectrally modified light into the inner plant canopy, thus increasing the efficiency of light-dependent processes (Rajapakse & Shahak, 2007:290, Shahak, 2004b:609).

The implementation of net protection using photo-selective technology is gaining popularity around the world. Photo-selective nets have been tested with various perennial crops in order to improve their fruit yield and quality, particularly in high irradiance environments (Jifon & Syvertsen, 2001:177, Oren-Shamir et al., 2001:353, Pastenes et al., 2003:71, Raveh et al., 2003:365, Shahak et al., 2004b:609, Shahak et al., 2004a:143). Previous research has shown that photo-selective nets have a positive effect on fruit yield (in relation to full sun conditions) in some varieties of *Vaccinium corymbosum* L., depending on the colour and shade percentage used (Lobos et al., 2009:465, Retamales et al., 2008:193). In bell pepper cultivars grown in the Besor (semi-arid) region of Israel under 35% shading, the red, yellow, and pearl nets were found to markedly increase the productivity and improve the fruit quality (both pre- and postharvest) compared with the black nets commonly used (Fallik et al., 2009:37). Growing fruit trees in stressed environments (high irradiances and temperatures) could reduce their photosynthetic rate, carbohydrate accumulation and fruit yields (Darnell, 1991:856, Darnell & Birkhold, 1996:1132).
In summary, researchers have widely used photo-selective nets as a: biological control against the key pests of protected crops (the whitefly *B. tabaci*, and the aphids *M. persicae* and *M. euphorbiae*) and two of the main natural enemies of *B. tabaci* (*O. laevigatus* and *A. swirskii*) (Legarrea *et al*., 2012:523); light manipulation to improve various aspects of fruit tree performance (flowering intensity, fruit setting, productivity, fruit maturation rate, fruit size, vegetative vigour) (Shahak *et al*., 2004b:609, Takeda *et al*., 2010:134); and a method to improve yields as well as quality in tomato fruits and sweet peppers (Ilic *et al*., 2012:90, Kong *et al*., 2013:290). However, the effects of light quality on plants are well known and the response of different species to light management is variable; therefore, it is clearly important to treat plants with the correct type of light filters (McMahon & Kelly, 1995:203), especially those with economic benefits.

In the present study, the effects of three photo-selective nets (red, pearl, and yellow) and a black net (control) on growth, yield and fruit quality of three tomato cultivars were investigated. A major concern in agricultural productivity is heat stress and pest infestation which have a direct effect on the product quality and postharvest storage of fresh produce. High temperatures can increase the capacity of air to absorb water vapour and consequently generate a higher demand for water. Higher evapotranspiration indices could lower or deplete the water reservoir in soils, creating water stress in plants during the dry seasons. It is well documented that water stress not only reduces crop productivity but also tends to accelerate fruit ripening (Henson, 2008:384). Exposure to elevated temperatures can cause morphological, anatomical, physiological, and, ultimately, biochemical changes in
plant tissues and can consequently affect the growth and development of different plant organs. These events can cause drastic reductions in crop yields. Based on previous positive results of coloured shade nets on plant development, we investigated the hypothesis that the light quality of the red, pearl and yellow photo-selective net spectrum, rather than the light intensity (common black net), is responsible for the major plant development related to the growth parameters, yield and product quality in tomato cultivars.

1.1 AIM AND OBJECTIVES

1.1.1 Aim

The aim of this project was to determine a suitable photo-selective net (ChromatiNet™), a suitable cultivar type and the cultivar versus photo-selective net interaction necessary to improve crop yields, product quality and bioactive compounds.

1.1.2 Objectives

Firstly, to investigate the effect of photo-selective nets on plant growth parameters (plant height, leaf area, leaf chlorophyll, stem diameter, flowering intensity, and fruit
setting), pest and disease incidence, and yield (number of fruits per plant) in three selected cultivars.

Secondly, to investigate the effect of shading on fruit quality parameters (fruit mass, firmness, colour, soluble solids content, and titratable acidity) and health promoting compounds (ascorbic acid, lycopene content, β-carotene, total phenols and flavonoids, and antioxidant scavenging activity) in three selected tomato cultivars.

1.2 THESIS STRUCTURE

This thesis is organised into five chapters. The literature review on tomato production and photo-selective netting is presented in Chapter 2, and covers information on the crop origin and description of tomato fruit, varieties, production and trade, fruit structure and nutritional composition, maturity indices for harvesting tomatoes, physiological disorders and common tomato diseases, hydroponic culture and conventional production practices, and production under photo-selective nets. Chapter 3 illustrates the effect of three photo-selective nets (red, pearl and yellow) (ChromatiNet™) and a black net (control) on plant growth parameters (plant height, leaf area, stem diameter, leaf chlorophyll and flowering), yield (number of fruits per plant, fruit trusses, and marketable fruits), PAR and microclimatic conditions, pest infestation and disease occurrences. Chapter 4 describes the effect of shading on tomato fruit quality (fruit mass and firmness, colour, soluble solids content, titratable acidity) and health promoting compounds in tomatoes (lycopene, β-carotene, ascorbic acid, total phenols and flavonoids, and antioxidant scavenging activities). A general conclusion is furnished in Chapter 5 and the conclusions obtained from
2 LITERATURE REVIEW

2.1 TOMATO (Solanum lycopersicum)

Tomatoes are one of the most widely produced and consumed vegetables in the world. The tomato belongs to the Solanaceae family (also known as the nightshade family), genus Lycopersicon, subfamily Solanoideae and tribe Solaneae (Taylor, 1986:1). The Solanaceae family includes other well-known important species such as chilli and bell peppers (Capsicum spp.), potato (Solanum tuberosum), aubergine (Solanum melongena), tomatillo (Physalis ixocarpa) and tobacco (Nicotiana tabacum) (Naika et al., 2005:6). Some common names for the tomato of different regions are: tomate (Spain, France), tomat (Indonesia), faan ke’e (China), tomati (West Africa), tomatl (Nahuatl), jitomate (Mexico), pomodoro (Italy), nyanya (Swahili) (Naika et al., 2005:6).

2.1.1 Origin, history and uses

Tomatoes originated from the South American Andes, specifically in Peru, Bolivia and Ecuador (Costa & Heuvelink, 2005:2). According to the available literature, wild plants of Lycopersicon esculentum were more widespread and have been distributed to other South American regions and into Mexico (Naika et al., 2005:6; Peralta &
Spooner, 2001:1902). Archaeological, ethnobotanical and linguistic evidence suggests that the tomato was domesticated in Mexico (outside its centre of origin) from where a variety of fruit sizes and colours were selected (Van der Vossen, Nono-Womdim & Messiaen, 2004). The Spanish brought the cultivated tomatoes to Europe in the early 16th century (Harvey, Quilley & Beynon, 2002:304). According to Naika et al. (2005:6), the tomatoes were then introduced to Southern and Eastern Asia, Africa and the Middle Eastern countries from Europe.

According to Orzolek et al. (2006:1), commercial tomato production was initiated after the 1860s. More recently, through tomato breeding, many tomato varieties have been developed and adopted for consumption around the world. Tomatoes have become one of the most important and widely eaten vegetables in the world today (Costa & Heuvelink, 2005.ix). Tomatoes are eaten either fresh (salads) or in cooked form in sauces, soups and meat or in processed forms (purees, juices, ketchup, canned or dried tomatoes). The worldwide production of tomatoes totalled 159,023,383 tonnes in 2011, with the top producers being China, followed by India, the United States, Turkey, Egypt and Italy (FAOSTAT, 2013).

2.1.2 Nutritional content and health benefits

Tomatoes can contribute to a healthy, well-balanced diet. They are rich sources of minerals, vitamins (A, B and C), essential amino acids, sugars and dietary fibres (Bhowmik et al., 2012:34). Tomatoes also contain high levels of potassium,
phosphorus, magnesium and iron (Beecher, 1998:98). They are further regarded as the most important source of fibre in the human diet (Bhowmik et al., 2012:40). Both fibre and vitamins possess the ability to neutralise dangerous free radicals and lower high cholesterol levels (Bhowmik et al., 2012:40; Gahler, Otto & Bohm, 2003:7962). According to Carr and Frei (1999:1086), Nagy and Smoot (1977:135), and Watada, Aulenbach and Worthington (1976:856), 60 mg of vitamin C per day is the recommended daily allowance (RDA) for maintaining good health. Although the vitamin content of tomatoes differ due to varying cultural practices, cultivars and postharvest handling practices, Hamner and Maynard (1942), and Bhowmik et al. (2012:38) reported that tomatoes provide 40% of the daily value (DV) of vitamin C, 15% DV of vitamin A, 8% DV of potassium and 7% of the RDA of iron for women and 10% RDA for men.

Tomatoes are the major source of dietary lycopene. Unlike nutrients in most fresh produce, tomatoes have greater bioavailability with regard to dietary lycopene after cooking and processing (Bhowmik et al., 2012:34). Lycopene is a powerful antioxidant with a high oxygen-radical scavenging and quenching capacity, which helps in the fight against cancerous cell formation and other kinds of health complications and diseases (Beecher, 1998:98; Di Mascio, Kaiser & Sies, 1989:533; Levy et al., 1995:258; Clinton et al., 1996:824). Tomatoes are also rich in antioxidant micronutrients such as lutein, phytoene, phytofluene, β-carotene, vitamin E and phenolic compounds (Bhowmik et al., 2012:36). Several of these constituents may, therefore, contribute to the health-giving properties of tomatoes. They contribute more to human nutrition than other vegetables because large quantities of tomato
products are widely available, relatively cheap and consumed in so many different ways by people of all ages and cultures.

Table 2.1: Tomato (raw) nutritional value per 100 g

<table>
<thead>
<tr>
<th>Principle</th>
<th>Unit</th>
<th>Nutritional Value Per 100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>kcal</td>
<td>18</td>
</tr>
<tr>
<td>Proteins</td>
<td>g</td>
<td>0.88</td>
</tr>
<tr>
<td>Total lipid (fat)</td>
<td>g</td>
<td>0.20</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>g</td>
<td>3.89</td>
</tr>
<tr>
<td>Dietary fibre</td>
<td>g</td>
<td>1.2</td>
</tr>
<tr>
<td>Sugars, total</td>
<td>g</td>
<td>2.63</td>
</tr>
<tr>
<td>Vitamins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td>mg</td>
<td>13.7</td>
</tr>
<tr>
<td>Thiamin</td>
<td>mg</td>
<td>0.037</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>mg</td>
<td>0.019</td>
</tr>
<tr>
<td>Niacin</td>
<td>mg</td>
<td>0.594</td>
</tr>
<tr>
<td>Vitamin B-6</td>
<td>mg</td>
<td>0.080</td>
</tr>
<tr>
<td>Folates</td>
<td>µg</td>
<td>15</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>IU</td>
<td>833</td>
</tr>
<tr>
<td>Vitamin E (alpha-</td>
<td>mg</td>
<td>0.54</td>
</tr>
<tr>
<td>tocopherol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin K</td>
<td>µg</td>
<td>7.9</td>
</tr>
<tr>
<td>Electrolytes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>mg</td>
<td>5</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg</td>
<td>237</td>
</tr>
<tr>
<td>Minerals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>mg</td>
<td>10</td>
</tr>
<tr>
<td>Iron</td>
<td>mg</td>
<td>0.3</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg</td>
<td>11</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg</td>
<td>24</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Source: USDA National Nutrient database
2.1.3 Plant morphology

The tomato is a perennial plant but is grown as an annual plant. A detailed description of the growth and development, botanical information, ecology, anatomy and histogenesis of the tomato is furnished by Van der Vossen, Nono-Womdim and Messiaen (2004), and Hayward (1938:39). These authors describe the plant as a branching, herbaceous plant with hairy, weak, trailing stems. The leaves are hairy and vary in size. The plant bears yellow flowers in clusters. Its fruits are round to lobed and vary in size and colour ranging from red, pink or yellow when ripe. Flat, slightly curved, hairy, light brown seeds are produced. The tomato plant has three different growth tendencies, namely indeterminate, semi-indeterminate and determinate types (Van der Vossen, Nono-Womdim & Messiaen, 2004; Hayward, 1938:39). Indeterminate and determinate types are entirely different kinds of crops. The indeterminate varieties are best suited to a long harvest period, because they keep growing even after flowering. However, under tropical conditions, their growth is limited by disease and insect attacks. The plants generally have more foliage which helps to keep the temperature within the crop lower, allowing the fruits to grow under the shade of the leaves. Shade protects the fruits from sun damage, and facilitates slow ripening (Van der Vossen, Nono-Womdim, Messiaen, 2004; Hayward, 1938:39). Slower ripening improves the taste and in particular the sweetness of the fruits. Indeterminate cultivars have a main stem which grows upwards indefinitely, reaching more than 10 m per year; therefore, these cultivars have to be trellised and they are best suited to greenhouse cultivation as well as hydroponic production (Costa & Heuvelink, 2005:3).
Determinate cultivars can grow to a height of 2 m, but they stop growing after flowering, thereby restricting fruiting. They require less labour; hence, they are popular in commercial cultivation (Costa & Heuvelink, 2005:3). They can be grown under field conditions and within greenhouses, have large fruit sets which last only for a short period and their fruits ripen faster than those of indeterminate cultivars (Naika et al., 2005:6).

2.1.4 Cultivars

The choice of cultivar to be planted depends on the local conditions and the purpose of growing them. There are local varieties and value added varieties available to farmers which result from a continuous process of selection of plants based on characteristics such as fruit type and size, type of plant, yield, vitality and resistance to specific diseases and pests, specific market and planting time, and also on factors related to climate and management (Naika et al., 2005:12). Farmers will most certainly choose cultivars that perform better under local conditions with minimum capital input. Tomato breeding companies have also developed F1-hybrids, and the advantage of these hybrids is that they combine high yield, disease resistance and other plant and fruit characteristics (Naika et al., 2005:12). Disease resistance is an added advantage because plants will require less spraying with pesticides. Hybrids are cost-effective, but farmers will have to purchase new seeds each season.
Popular cultivars in South Africa are: cultivars best suited to the fresh market, including Florodade, Heinz 1370, Karino, Rodade, Fortress, Hytec, Star 9001, Star 9003, Sundance and Zeal; fresh market cultivars with a long shelf life are Baldo, Blockbuster, Disco, P747 and Shirley; cultivars that are suitable for processing include HTX 14, Legato, Roma, VF, Rossol, Star 9056F, Sun 6216 and UC 82B; cultivars for cherry tomatoes are Bamby and Josephine; and lastly, cultivars suited to protected cultivation are Atletico, Daniella and Gabriella (Department of Agriculture Forestry and Fisheries, 2011).

2.1.5 The fruit

Tomato fruits develop from the ovary of flowers after fertilisation of the ovules. During the initial stages of fruit development, cell division and expansion delay fruit growth. After 2-3 weeks of slow growth, rapid growth commences and the cells continue to enlarge (Ho & Hewitt, 1986:201). Rapid growth takes 3-5 weeks resulting in mature green fruits. At the mature green stage, the fruit will accumulate most of its final weight (Ho & Hewitt, 1986:201). Within two days after the onset of the mature green stage, the colour of the fruit will begin to change (Ho & Hewitt, 1986:201). The green pigment will become lighter and a faint yellow-orange colour will appear. As the orange pigment accumulates on the outside, several metabolic changes will be occurring on the inside (Grierson & Kader, 1986:241). The pulp of the fruit will gradually become softer as a result of enzymatic digestion of the cell walls (Grierson & Kader, 1986:241). A placental tissue which fills much of the locular spaces and the areas around the ovules will be degraded and assume a gelatinous character.
(Grierson & Kader, 1986:241). When the fruit is fully matured, an abscission layer forms between the calyx and the fruit, causing the fruit to detach from the pedicel (Grierson & Kadar, 1986:241).

The tomato fruit can be bilocular or multilocular (Figure 2.1). The locules (cavities containing seeds that are derived from carpels) are surrounded by the pericarp. The pericarp includes the inner wall, columella; the radial wall, septa; and the outer wall. The pericarp and placenta comprise the fleshy tissue of the tomato. Seeds are located inside the locules and are enclosed in gelatinous membranes. There are vascular bundles that surround the outer wall of the pericarp and extend from the stem to the centre of the tomato, radiating to each seed (Ho & Hewitt, 1986:201).

**Figure 2.1:** Transverse section of a multilocular tomato fruit
2.1.6 Maturity of the fruit for harvesting

Harvesting tomatoes at the correct stage of maturity is very important and plays a key role in limiting instances of post-harvest damage (Davis & Gardner, 1994:613). Over-mature fruits are susceptible to bruising and injury and can also rot easily. Tomatoes, in particular, have a high water content which makes them more vulnerable to post-harvest losses (Eckert & Ogawa, 1988:433). Fruit maturity can be assessed by examining the external and internal indicators of maturity. External fruit maturity indices are based on skin colour, while internal indices are based on seed development and locular gel formation (Ministry of Fisheries, Crops and Livestock, New Guyana Marketing Corporation, National Agricultural Research Institute, 2003). The most widely used tomato maturity index is the skin colour (Batu, 2004:471). The latter remains green during fruit development on the plant, and as the fruit becomes mature, distinct changes occur in the external colour which can then be used to determine harvest maturity. Skin colouration in tomatoes follows a typical sequence with regards to ripening (Alexander & Grierson, 2002:2047). In red skinned cultivars, after the mature green stage, the tip of the blossom end will change to a pinkish-yellow colour, which is referred to as the breaker stage because lycopene begins to accumulate at this point (Fraser et al., 1994:405). The breaker stage usually occurs within a day after the mature green stage. The entire fruit then turns pink, followed by a light red and finally a deep red colour. The ripening stages of mature tomato fruit are categorised as being green, breaker, turning, pink, light red, and red (Figure 2.2) as described in Table 2.2.
Figure 2.2: Ripening stages of mature tomato fruit; from left to right: green, breaker, turning, pink, light red, and red

The internal fruit characteristics used to determine the harvest maturity of green fruits are seed development and locular jell formation (Kader & Morris, 1976). Mature green fruits have fully developed tan-coloured seeds whereas the seeds in immature green fruits are white and not adequately formed. The fruit cavities of mature green fruits are completely filled with jelly in each of the locules, while immature green fruits have one or more locules without jelly (Ministry of Fisheries, Crops and Livestock, New Guyana Marketing Corporation, National Agricultural Research Institute, 2003).
**Table 2.2**: Terms used to describe tomato colour as an indicator of ripening

<table>
<thead>
<tr>
<th>Colour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>The tomato surface is completely green. The shade of green may vary from light to dark</td>
</tr>
<tr>
<td>Breaker</td>
<td>There is a definite break of colour from green to yellow, with pink or red skin covering not more than 10% of the surface</td>
</tr>
<tr>
<td>Turning</td>
<td>Tannish-yellow, pink or red colour shows on over 10% but on not more than 30% of the tomato surface</td>
</tr>
<tr>
<td>Pink</td>
<td>Pink or red colour shows on over 30% but on not more than 90% of the tomato surface</td>
</tr>
<tr>
<td>Light red</td>
<td>Pinkish-red or red colour shows on over 60% but the red colour covers not more than 90% of the tomato surface</td>
</tr>
<tr>
<td>Red</td>
<td>More than 90% of the tomato surface, on aggregate, is red</td>
</tr>
</tbody>
</table>

Source: USDA

In practice, tomatoes are harvested at different stages of maturity depending on market specifications and the planted cultivar. Generally, the average time it takes to obtain the first harvest after sowing is 3-4 months (Valenzuela, Hamasaki & Hori, 1993). Fruits meant for the fresh market are harvested at the mature green to pale pink stage, depending on the distance and the time required to market them (Kader *et al.*, 1977:724). Green tomatoes can continue to ripen after picking, until they are completely red. A few ripe tomatoes in the harvest will help to speed up the ripening process. However, fruits harvested at the pre-ripe stages tend to have a lower quality (lower soluble solids, ascorbic acid, and reduced sugars) than fruits that have ripened on the plant (Naika *et al.*, 2005:60). In contrast to the fruits for the fresh market, processed fruits can be harvested when they are fully ripe. Tomatoes that are used to make pureed products (soup, juice, sauce) are usually left on the tree...
and picked when they are red and completely ripe (Department of Agriculture Forestry and Fisheries, 2011).

2.1.7 Physiological disorders

Tomato fruit quality is determined by appearance (colour, shape, size, freedom from physiological disorders and decay) firmness, dry matter and flavour, and health benefits (Fleisher et al., 2006:126). The absence of physiological disorders in tomatoes is very important not only for the sake of their appearance, but also because other attributes such as the nutritional status and shelf life may be affected (Masarirambi et al., 2009:123).

Physiological or abiotic disorders are caused by changing environmental conditions such as the temperature, moisture, unbalanced soil nutrients, inadequate or excessive soil minerals, extremes in soil pH and poor drainage (Jarvis & McKeen, 1991; Khavari-Nejad et al., 2009:209). Genetic factors are also involved; thus, there is a genetic (G) and an environmental (E) interaction (G x E). The physiological disorders found in tomatoes can be divided into groups, namely: nutrient imbalances between potassium (K) and nitrogen (N) or magnesium (Mg) (blotchy ripening, grey wall); amounts or movement of calcium (Ca) into the fruit (blossom-end rot); genetic sensitivity (green or yellow shoulder) and watering (cracking) (Peet, 2009:151); high irradiance and low temperature (sunscald, cat-facing) (Olson, 2004, Masarirambi et
These disorders drastically affect the production of tomatoes and result in severe economic losses.

2.1.8 Common tomato diseases

Tomato diseases are weather dependent and can spread rapidly. The diseases are caused by parasitic fungi, bacteria, viruses, nematodes and environmental conditions. Some of these diseases are more prevalent in outdoor tomato production while others are more prevalent in indoor production. The latter produces a physical environment which is favourable for the development of pathogens due to the ideal temperatures, high humidity and restricted air movement. Biotic diseases in tomatoes that favour these conditions include gray mould, leaf mould and powdery mildew (Elad et al., 2007:285). Common diseases occurring in outdoor tomato production are septoria leaf spot, early blight, fusarium wilt, verticillium wilt, late blight, bacteria spot, bacteria speck, viruses and nematodes (Gleason & Edmunds, 2006). These diseases are spread by insects, splashing water, leafhoppers and humans. Diseases can, however, be controlled by buying treated seeds, sterilising the soil before planting, spraying plants with appropriate pesticides, using resistant cultivars or soilless media and implementing sanitary measures (Jarvis & McKeen, 1991).
2.2 HYDROPONICS/SOILLESS VEGETABLE PRODUCTION

2.2.1 Definition

The term “soilless culture” is defined as the cultivation of crops of plants in a nutrient solution that supplies all the nutrient elements needed for optimum plant growth, with or without the use of an artificial growing medium (sand, gravel, vermiculite, rockwool, peat moss, sawdust, coir dust, coconut fibre, etc.) to provide mechanical support (Gruda, 2009:141). Liquid hydroponic systems have no supporting medium for the plant roots; whereas, aggregate systems offer a solid medium for support. Hydroponic systems can be either open (once the nutrient solution is delivered to the plant roots, it is not reused) or closed (surplus solution is recovered, replenished, and recycled). Hydroponics are employed in protected cultivation practices; either, inside greenhouses or under shade nets in order to provide temperature control, reduce evaporative water loss, provide better control of diseases and pests and to protect crops against weather elements such as wind and rain.

A major advantage of hydroponics is its isolation of the crops from the soil, which is often associated with problems such as diseases, salinity or poor structure and drainage (Abd-Elmoniem et al., 2006:1). Also, in hydroponics, continuous cultivation is possible, and a more efficient use of water and fertilisers is possible. The principal disadvantages of hydroponics, relative to conventional open-field practices, are firstly, its high initial input costs, which will increase if soilless culture is combined
with controlled environmental agriculture, and secondly, the energy inputs required to operate the system. A high level of management skills is also necessary to prepare the solutions, maintain the pH and EC values, judge and correct the nutrient deficiency, ensure aeration, and maintain favourable conditions inside the protected structure. Because of these significantly high input costs, the successful practical applications (e.g., for food production) of soilless culture are limited to the production of high economic value crops such as tomato, strawberry, cucumber, and so forth (Jenson & Collins, 1985:483). Greater emphasis is placed on aggregate (open) hydroponic system, as described below.

### 2.2.2 Closed and open hydroponic systems

Hydroponic systems of cultivation are classified according to the method of applying nutrient solutions to the plant roots, either in a “closed form” where the nutrient solution is recirculated, or an “open form” where the nutrient solution is not recirculated (Jensen & Collins, 1985:484). Closed hydroponic systems can be further divided into two methods; the circulating and non-circulating method. In the circulating method, the nutrient solution is pumped through the root system and any excess solution is collected, replenished and reused (Jensen & Collins, 1985:484). The nutrient solution is monitored for its salt concentration before it is recycled, and in some cases growers replace the nutrient solution every week with a fresh solution in order to ensure that sufficient nutrients are available to the plants. In the non-circulating method, the nutrient solution is not circulated, but used only once. The nutrient solution is replaced when its concentration declines or its pH or EC changes.
Therefore, the nutrient composition in the recirculated nutrient solution is continuously changing due to the plant uptake and evapotranspiration of water from the solution (Graves, 1985:1-44). Applying a closed system requires good management skills as the system is vulnerable to poor water quality, and toxic ions can accumulate in the water if the entire solution is not changed periodically.

In an open hydroponic system, a solid, inert medium provides support for the plants and like in closed systems, the nutrient solution is delivered directly to the plant roots through irrigation. Fertilisers can be provided through the proportioners or can be mixed with the irrigation water in a large tank. Irrigation is usually programmed using a timer, and in large installations, solenoid valves are used to allow only a section of the greenhouse or net house to be irrigated at a time. Compared to the “closed system”, the “open system” can be managed with less difficulty, nutritional management problems can be reduced, and incidences of nutritional deficiencies may also be lessened (Jensen & Collins, 1985:484).

2.2.3 Aggregate hydroponic system

This technique involves inert solid media (sand, gravel, rockwool, peat moss, sawdust, coconut fibre, coir dust, perlite, vermiculite) which provides support for the plants. The selected media material must be flexible and crumbly, with a water holding capacity that can be drained easily. In addition, the media must be free of toxic substances, pests, disease causing microorganisms, nematodes, and so forth.
The chosen media must also be thoroughly sterilised before use (Jensen & Collins, 1985:484). As in liquid systems, the nutrient solution is delivered directly to the plant roots. Aggregate systems can be closed or open, depending on whether the recovered excess solution is recirculated through the system or not. Aggregate hydroponic systems include the bag culture and the rockwool culture. For the purpose of this manuscript greater emphasis will be placed on the bag culture. However, the use of horticultural rockwool as the growing medium in open hydroponic systems is increasing rapidly. Rockwool was first developed as an acoustical and insulation material made from a mixture of diabase, limestone and coke which was melted at a high temperature, extruded in small threads, and finally pressed into lightweight sheets (Thiyagarajan, Umadevi & Ramesh, 2007). In the bag culture, the growing medium is placed into plastic bags which are placed in lines on the greenhouse floor, thus avoiding the cost of complex drainage systems. The bags can be used for at least two years, and can be sterilised by steam much more easily and cheaply than bare soil. The bags have a black interior and are composed of UV-resistant polyethylene, which will last for up to two years in controlled environment agriculture (CEA). The exterior of the bags should be white if they are placed in desert areas and other regions with high light intensities, so as to reflect radiation and minimise the heat reaching the growing medium. Conversely, a darker exterior colour is recommended in low-light latitudes in order to absorb winter heat. Growing media for use in the bag culture includes peat, vermiculite; a combination of these materials with perlite is often added to reduce costs. Bags are placed flat on the greenhouse floor at a normal spacing for vegetable production. It is beneficial, however, to first cover the entire floor with white polyethylene film so as to maximise the amount of light reflected back into the plant canopy. Such a covering may also
reduce the relative humidity and the incidence of some fungal diseases. The soil in the bag has to be moistened before planting. The use of the bag culture is largely dependent on the availability and cost of the growing media (Jensen & Collins, 1985:483; Thiyagarajan, Umadevi & Ramesh, 2007).

2.2.4 Nutrient solution

Unlike soil which stores nutrients, the growing media used in hydroponic systems have little effect on the nutrition of the plants. The only source of nutrients is the nutrient solution, and therefore all the nutrients required for plant growth have to be present in the circulating water of the hydroponic system. There are macro and micro nutrients that are essential for good plant growth. Macro elements: nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) are required in high concentrations, whereas micro elements: iron (Fe), boron (B), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum (Mo) are required in very low concentrations. These elements must be maintained at appropriate concentrations since the management of the nutrient solution is the key to success in a hydroponic culture, (see Table 2.3) (Marr, 1994).
Table 2.3: Recommended concentration ranges of essential elements in nutrient solution

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>200-236</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>60</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>300</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>50</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>170-185</td>
</tr>
<tr>
<td>Sulphur</td>
<td>S</td>
<td>68</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>12</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>0.1</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>0.1</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mg</td>
<td>2.0</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>0.3</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Source: Cooper, 1988

In an “open system” the nutrient solution is not recovered and recycled; as a result it does not require monitoring and adjustment. Once mixed, it is used until depleted. Growing media will, however, require constant monitoring, particularly if the irrigation water is relatively saline or if the hydroponic structures are located in a warm, high sunlight region. To avoid an accumulation of salt in the growing medium, some irrigation water can be used to allow a small amount of drainage or “leaching” from the bags. This drainage should be collected and tested periodically for total dissolved salts. If the salinity of the drainage water reaches 3,000 ppm or above, the bags must be leached free by using plain water in the irrigating system (Marr, 1994).
2.2.5 Nutritional disorders

Nutritional disorders are plant symptoms that result from either too much or too little of a specific nutrient element. There are no nutritional disorders unique to hydroponics or open field cultivation. Plants are more likely to show nutritional disorders in a closed hydroponic system than in an open system. In a closed system, levels of impurities or unwanted ions in the recycled liquid or from the chemicals used can interfere with the balance of the formulation and accumulate to toxic levels (Thiyagarajon, Umadevi & Ramesh, 2007). Common nutritional disorders in hydroponics are caused by high levels of ammonium (NH$_4$), zinc toxicity or low levels of potassium and calcium. Physiological disorders resulting from high levels of ammonium can be avoided by providing no more than 10% of the required nitrogen in an ammonium form. Low levels of potassium (less than 100 ppm in the nutrient solution) can affect tomato acidity and reduce the percentage of high-quality fruit (Marr, 1994). Low levels of calcium can induce blossom end rot in tomatoes (Taylor & Locascio, 2004:123) and tip burn in lettuce (Barta & Tibbitts, 2000:294). Zinc toxicity resulting from dissolution of the elements from galvanised pipes in the irrigation system can be prevented by using plastic or other non-corrosive materials suitable for agriculture. At toxic concentrations, ions of heavy metals act as efficient generators of reactive oxygen species (Luna, Gonzalez & Trippi, 1994:11; Assche & Clijsters, 1990:195).
2.2.6 Disease and insect control in hydroponic systems

Hydroponic systems were initially developed to control soil-borne diseases. However, diseases that are specific to hydroponics have been reported (Stanghellini & Rasmussen, 1994:1129). Nevertheless, a soilless culture provides several advantages such as greater production of crops, reduced energy consumption, better growth control and independence of soil quality. Sources of pathogens in hydroponic systems include the following: plant material, growth media, air, sand, soil, peat, and water from lakes, rivers and wells, and insect pests. Airborne spores of *Fusarium oxysporum* f. sp. *radicis-lycopersici* fungus have been identified as major sources of fungal attacks on both the roots and the crown of tomato plants (Rowe et al., 1977:1513). These spores are present in the soil introduced into the production facilities on the shoes of greenhouse personnel, and in nutrient solution reservoirs placed at ground level in most greenhouse facilities. To prevent soil borne pathogens, all soil within the greenhouse should be covered to prevent splash dispersal or generation of dust which may harbour soil borne pathogens and the nutrient reservoirs should be covered at all times. Washed river sand has been used in greenhouses as an aggregate substrate or as a ground cover pathway between production areas (Stanghellini & Rasmussen, 1994:1131). Washed river sand can be infested with many plant pathogens and has been identified as the source of introduction of *Pythium aphanidermatum* and *P. dissotocum* into hydroponic systems (Bates & Stanghellini, 1984:989). Crops affected by *Pythium aphanidermatum* and *P. dissotocum* show extensive root rot, wilt, severe stunting and death. Peat and peat mixtures are major sources for the introduction of plant pathogens. A survey conducted by Kim, Faorer and Longenecker (1975:124) revealed that 15 out of 52
randomly selected peat products contained *Pythium*, and all 52 contained *Fusarium* (which is a pathogenic fungal inocula). Fungus gnats (*Brady sia* spp.) and shore flies (*Scatella stagnalis*) are common greenhouse insect pests; both their larva and adult stages have been implicated as vectors of some of the root pathogens (Stanghellini & Rasmussen, 1994:1132).

### 2.3 PHOTO-SELECTIVE NETTING

#### 2.3.1 Introduction

Netting is frequently used in agriculture to protect crops from excessive solar radiation (shade-nets), thereby improving the thermal climate (Kittas *et al*., 2009:97), and minimizing environmental stresses (wind and hail) or flying pests (Teitel *et al*., 2008:99). The nets commonly used for the shading of ornamental crops and nurseries are black and offer from 40-80% shading (Shahak *et al*., 2004a:143). Anti-hail and insect proof nets are made of clear or white threads or a combination of both (Shahak *et al*., 2004a:143). The available netting products are mostly woven, knitted or embossed, and they may vary in their texture, design, mechanical properties and durability (Shahak *et al*., 2004a:143).

Photo-selective nets include “coloured-ColourNets” (red, yellow, green, and blue net products) as well as “neutral-ColourNets” (pearl, white and grey) absorbing spectral
bands shorter or longer than the visible range (Shahak et al., 2008:75). Photo-selective nets represent a new agro-technological concept which combines physical protection together with differential filtration of the solar radiation in order to specifically promote the desired physiological responses that are light regulated (Shahak et al., 2004a:144). The targeted responses are those that determine the commercial value of each crop, including yield, product quality and rate of maturation (Shahak et al., 2004a:143). The nets are based on the incorporation of various chromatic additives, and light dispersive and reflective elements into the netting materials during manufacturing.

Photo-selective nets also have an ability to transform direct light into scattered light, which improves the penetration of light into the inner plant canopy, prevents burning, offers a moderate cooling effect, and influences pest control (Shahak et al., 2008:75). Radiation use efficiency increases when the diffuse component of the incident radiation is enhanced under the shade (Healey et al., 1998:665). Shading of crops results in a number of changes in both the local microclimate and the crop activity. Changes in the local microclimate modify the assimilation of carbon dioxide (CO₂) and consequently affect crop growth and development (Kittas et al., 2009:97).

2.3.2 Plant growth and yield

Nettings, regardless of colour, possess the ability to reduce radiation from reaching the crops underneath them. With a higher shading factor, more radiation will be
blocked. Reductions in radiation resulting from the type of netting used affect the
temperatures (air, plant, soil) and the relative humidity (Stamps, 1994:35). However,
besides affecting the amount of radiation, netting can also influence the direction of
the radiation. The ability of the shade nets to influence the radiation direction induces
light penetration into the inner plant canopy. Diffuse light has been demonstrated to
increase radiation use efficiency, the yields and may even affect flowering (timing
and amounts) (Gu et al., 2002:1). Shade netting that maximises light scatterings
without affecting the light spectrum has also been shown to increase branching,
plant compactness, and the number of flowers per plant (Nissim-Levi et al., 2008:9).
Photo-selective nets prevent excess sunlight and retain soil moisture levels for
proper plant growth, which lead to an increase in productivity (yield) of the plants. Air
movement inside the nets is restricted, thus reducing wind damage to the crop and
evaporation of soil moisture. The nets also ensure that the air beneath the shade
cloth stays humid which is of further benefit to the plants.

According to Kasperbauer and Hamilton (1984:967), plants react to changes that
occur in the spectrum of electromagnetic radiation to which they are exposed
through adjustments in their morphology and physiological functions that result in
their adaptation to different environmental conditions. Such adjustments are
facilitated by the phytochromes, cryptochromes and phototropin photoreceptors
which have absorption peaks in the red and blue or ultraviolet regions of the
spectrum (Li et al., 2000:216). Photoreceptors are able to detect variations in light
composition and induce photo-morphogenetic responses that influence growth and
development, morphology, leaf and stem anatomy, distribution of photosynthetic
products, photosynthetic efficiency and chemical composition (Lee et al., 2000:447,
Kasperbauer, 1987:353; Lee et al., 1997:4; Schuerger et al., 1997:273; Brown et al., 1995:810; Kasperbauer & Peaslee, 1973:442; Macedo et al., 2004:517). These light-regulated signalling events are necessary for normal plant development, and they ensure that adaptive changes occur in response to environmental changes. Phytochromes are capable of detecting wavelengths from 300 nm to 800 nm, with a maximum sensitivity in the red (600 nm to 700 nm with peak absorption near 730 nm) wavelengths of the spectrum (Rajapakse & Shahak, 2007).

Plants produce new and structurally altered leaves as their primary means of responding to changes in the radiation environment. Costa et al. (2010:349) conducted an experiment to evaluate the effect of coloured shade nets (blue & red net, 50% shading) versus full sunlight on the vegetative growth and development of the medicinal plant Ocimum selloi. Results indicated that shade grown plants were taller when compared to plants grown in full sunlight; their total dry biomass, roots, stem and leaf tissue biomasses were lower. Plants exhibited a high degree of physiological, morphological and anatomical plasticity, as explained by the difference in total leaf area, specific leaf area, leaf area ratio and leaf weight ratio values recorded under the different light treatments. The quantity and the quality of light under shade nets induce optimal plant growth (shoot and stem elongation) in order to increase light interception and to facilitate photosynthetic processes (Kasperbauer, 1987:350). These processes result from the translocation of photosynthates from the leaves and root reserves (Brutnell, 2006:417; Marks & Simpson, 1999:133). Shade-grown plants also tend to have high inflorescences in comparison with field grown plants (Costa et al., 2010:352). This is a phenomenon
that can be viewed as a survival strategy; whereby under unfavourable conditions plants opt to minimise the energy spent on biomass production in order to support reproductive functions upon which the continued existence of the species depend (Costa et al., 2010:352).

Normally, shaded plants have low photosynthetic rates. Shading increases flower and fruit abortions, and reduces fruit set. The quantity of fruit produced is directly influenced by the number of flowers, flower abortions and fruit setting. However, covering the plants with ColourNets has been demonstrated to be beneficial in that they allow for the high transmission of red light which is essential for chlorophyll (663 nm), photosynthesis and phytochrome (666 nm, 730 nm) (Solomakhin & Blanke, 2008:211). Shahak et al. (2004:146a) found that even though the total photosynthetically active radiation (PAR) intensity was reduced by about 30%, the photosynthetic rates of exposed leaves of apple trees were improved during most of the day by the nets, parallel with stomatal conductance, and leaf cooling. The highest photosynthetic rates were obtained under the red net (55%). The daily time course of photosynthesis differed between the colour nets; common morning and afternoon peaks were recorded for the red and black (48%) nets, while there was no apparent mid-day drop in the grey (46%), pearl (54%) and blue (52%) nets. Similarly, the mid-day stem water potential was better under the red net, relative to the un-netted control, while being the best under the pearl, grey and blue nets. This indicates that the ColourNet approach can be adopted as a common practice, and presents a great opportunity to promote netting of crops which are not yet grown under nets.
Applying net houses under high sunlight intensities is more beneficial when compared with lower intensities both on a daily and seasonal basis. In the summer seasons, PAR (400 nm to 700 nm) that is transmitted through net covered structures usually fulfils crop growth requirements because the outside incidence of PAR is high. Shading in winter or in a cool and cloudy environment can be more deleterious due to low sunlight intensity. In a study conducted in England, 23% shading was sufficient to reduce tomato yield by 20% (Cockshull, Graves & Cave, 1992:11). Under intense sunlight in Spain, shading increased the marketable yield of tomatoes by 10% (Lorenzo et al., 2003:181). Fruit set in Hermosa peaches was increased by two treatments of netting compared with a no-net control; 30% red net enhanced the quality of fruit set, and fruit size was also greater under the nets, except under blue-coloured nets (Shahak et al., 2004b:612). Results to the contrary were reported by Gent (2007:514) and Sandri et al. (2003:642).

2.3.3 Disease and pest infestation

Insect pests are a major cause for the reduction in the quantity and quality of crop plant products. The most important ones under protected cultivation include aphids, whiteflies and thrips. Aphids and whiteflies feed by suckling fluids directly from the phloem vessels of plants, and thrips feed by breaking the epidermal cells of plants and sucking their contents. These pests cause injuries to plant tissue by the penetration of their mouthparts which can cause scars and often serve as ports of entry for bacterial and fungal pathogens. They also contaminate the surface of their host plants with their sticky sweet excrements (honeydew) that serve as a growing
substrate for fungi. Hence the majority of plant viruses are transmitted by these insect pests (Hogenhout et al., 2009:115). Insect-borne viral diseases often cause substantial economic damage to growers of agricultural crops worldwide. To protect the crop plants from these pests, growers usually apply insecticides. Frequent applications of insecticides, however, create health hazards for workers, consumers, and the environment. Moreover, frequent applications of insecticides often induce resistance in the treated pest populations. Therefore, alternative methods for protecting crop plants from pests are constantly being sought (Ben-Yakir et al., 2013). These pests use reflected sunlight as optical cues for finding hosts (Ben-Yakir et al., 2012:609). They are known to have receptors for UV light (peak sensitivity at 360 nm) and for green-yellow light (peak sensitivity at 520 nm to 540 nm) (Ben-Yakir et al., 2012:609). The latter colour induces landing and favours the settling (arresting) of these pests (Shahak et al., 2008:78). This attraction to colour can be enhanced by plant odour over a short distance. While, high levels of reflected sunlight (glare) deter these insects from landing, at temperatures between 20 °C and 25 °C, these insects complete their life cycle in 1-4 weeks and can build up high populations on plants (Ben-Yakir et al., 2013). Adult pests disperse to adjacent plants by walking or by short flights. Some of the adults migrate on long flight, aided by the wind, to colonise new areas (Byrne, 1999:310).

Traditionally, black shading nets have been used in the protected cultivation of plants. However, coloured (photo-selective) shading nets are currently being developed for improving crop production in addition to their protective function. In a study conducted by Ben-Yakir et al. (2008:205) and Shahak et al. (2009:79), yellow
and pearl nets protected crops from aphids and whiteflies, but not from thrips. The effects of coloured shading nets on the infestation of aphids and whiteflies and the incidence of viral diseases transmitted by these insects were studied by Ben-Yakir et al. (2012:249) from 2006 to 2010. The studies were conducted in the semi-arid Besor region in southern Israel. Plants were grown in “walk-in” tunnels that were covered by various coloured nets of 35% shading capacity. The nets had large holes that permitted free passage of sucking pests of 1-2 mm in length (Figure 2.3). Ben-Yakir et al. (2008:205) found that whiteflies landed on the yellow net 20 to 40 times more often than on the other nets. Despite that, the infestation level of aphids and whiteflies in the tunnels covered by either the yellow or pearl nets were consistently two to threefold lower than in tunnels covered by the black or red nets. The reduction in pests leads to a similar reduction in the incidences of viral diseases transmitted by them. When the incidence of the cucumber mosaic virus (CMV) in peppers grown under the black or red nets ranged between 35% and 89%, it was two to tenfold lower under the yellow or pearl nets (Ben-Yakir et al., 2012:249). Similarly, when the incidence of the necrotic strain of the potato virus Y (PVY) in tomatoes grown under black or red nets ranged between 42% and 50%, it was two to threefold lower under the yellow or pearl nets (Ben-Yakir et al., 2012:249). Also, when the incidence of the tomato yellow leaf curl virus (TYLCV) in tomatoes grown under the black or red nets ranged between 15% and 50%, it was two to fourfold lower under the yellow or pearl nets (Ben-Yakir et al., 2012:249).

The mechanism by which yellow and pearl nets provide protection against aphids and whiteflies is unclear, but it is believed that the optical properties of these nets,
light reflection and arrestment play a major role in this protection (Ben-Yakir et al., 2012:255; Shahak et al., 2008:78). The sunlight transmission and scattering characteristics of these nets were reported by Shahak et al. (2004a:143), and Rajapakse and Shahak (2007). Covering crops with shading nets may interfere with the ability of flying pests to see the host plants under the nets and to discern the plants from their background. Since the threads of the light coloured nets are more translucent than the black threads, light coloured nets have a higher thread density than black nets of the same shading capacity. Therefore, the light coloured nets probably block the view and hide the plants to a greater extent than do the black ones. However, the study conducted by Ben-Yakir et al. (2012:253) indicated that the red net did not provide any protection from pests, even though its thread density was about twice as thick as that of the yellow and pearl nets.

Figure 2.3: Photo-selective shade nets and the black commercial shade net
2.3.4 Physico-chemical properties in fruits

Fruit and vegetable consumption is growing globally. At the same time, consumers are becoming increasingly conscious of the quality of the fruit and vegetables that they consume. Satisfying consumer demands and assuring the markets of fresh fruit and vegetables, therefore, necessitates optimum quality in produce in terms of their state of ripeness and organoleptic quality. Sweetness and firmness are important components of fresh fruit quality, and they provide a good indication of the state of fruit ripeness and the potential shelf life. Firmness affects the susceptibility of fruit to physical damage and storability. Titratble acidity (TA) in fruits is used along with total soluble sugar content (SSC) (°Brix) as an indicator of maturity (Gonzalez-Cebrino et al., 2011:444). Acids tend to decrease with fruit maturity while sugar content increases; therefore, the SSC/TA ratio is often used as an index of maturity (Caliman et al., 2010:77). High acid levels are associated with lower pH values and vice-versa. They also play a significant role in the taste, colour and microbial stability of the juice; they prevent the growth of microorganisms that are harmful to the conservation of the fruit (Caliman et al., 2010:76).

Fruit pH increases with maturity and generally has an inverse relationship with titratable acidity (Gould, 1992) (Table 2.4). Sugars and acids and their interactions are important to the sweetness, sourness and overall flavour intensity of fruits (Debruyn, Garretsen & Kooistra, 1971:241). Fructose and citric acid were found to be more important to the sweetness and sourness than the glucose and malic acid in tomatoes (Kader, 1986:212). High sugar and relatively high acid levels are essential
for the best flavours in fruits (Kader et al., 1978:742; Mencarelli & Saltveit, 1988:742). High acid and low sugar levels produce a sour taste, while high sugar and low acid levels result in a bland taste (Kader, 1986:212). When both sugar and acid levels are low, they result in tasteless fruits (Kader, 1986:212).

The growth and development of plants under a protected environment depend on the intensity, quality and duration of solar radiation (Cockshull, Graves & Cave, 1992:11). The normal growth and development of crops occur when the amount of radiation received exceeds the trophic limit (Beckmann et al., 2006:86). Climatic variables such as air temperature, relative humidity and solar radiation are modified by shade structures, thereby influencing the growth, development and production of plants. Fruit growth and development depends on the translocation rates of the carbohydrate supply, and the sink strength in plants (Lowell, 1986). Temperature and light may influence these processes at any stage of the development of the fruit (Marsh, Richardson & Macrae, 1999:443), because the accumulation of carbohydrates depends largely on the photosynthetic activity in the plant.

Table 2.4: Tomato Fruit pH and TA ranges of different cultivars at red ripe maturity stage

<table>
<thead>
<tr>
<th>Tomato plant genotype</th>
<th>pH</th>
<th>Citric acid (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriset</td>
<td>4.21bc (0.05)</td>
<td>0.57a (0.03)</td>
</tr>
<tr>
<td>FL7692B</td>
<td>4.25ab (0.09)</td>
<td>0.44c (0.01)</td>
</tr>
<tr>
<td>FL7692D (og)</td>
<td>4.34a (0.06)</td>
<td>0.38d (0.05)</td>
</tr>
<tr>
<td>Suncoast (og)</td>
<td>4.19bc (0.02)</td>
<td>0.50b (0.04)</td>
</tr>
<tr>
<td>Equinox</td>
<td>4.09d (0.10)</td>
<td>0.57a (0.03)</td>
</tr>
<tr>
<td>97E212S (rin/)</td>
<td>4.13cd (0.08)</td>
<td>0.45b (0.02)</td>
</tr>
<tr>
<td>FL7655</td>
<td>4.16cd (0.06)</td>
<td>0.53b (0.04)</td>
</tr>
<tr>
<td>Solar Set</td>
<td>3.19e (0.04)</td>
<td>0.53ab (0.01)</td>
</tr>
</tbody>
</table>

Source: Thompson et al., 2000:719
In a previous study regarding the quality of tomatoes grown under a protected environment and under field conditions (Caliman et al., 2010:75), it was found that the field produced fruits were more acidic (greater TA) than those produced in a protected environment. The lower acidity levels of fruits grown in the protected environment may be due to the lower photosynthetic activity of the plants in that environment as well as the lower carbohydrate accumulation in the fruits (Caliman et al., 2010:77). In the same study, Caliman et al. (2010:77) also found that the SSC/TA ratios were greater in fruits produced in the field than those produced in protected environments (Table 2.5). Similar results were reported by Zoran & Milenkovic (2012:25); field produced fruits were more acidic (TA-0.37%) than those produced in a protected environment (0.34%).

Environmental effects on fruit acidity is a complex matter and many studies favour the hypothesis that organic acids are produced from stored carbohydrates in the fruit itself, although some of these acids may be translocated from the leaves and roots to the fruit (Bertin et al., 2000:749). According to Mahakun, Leeper and Burns (1979:241), genetic factors are the determinants of major acid content in tomato fruit, with a great variation occurring between genotypes (Stevens & Rick, 1986:34). When evaluating the hybrid ‘Carmen’, Loures (2001:31) found fruit titratable acidity (% citric acid) levels of 0.46% and 0.49% under greenhouse and field conditions respectively. Sakiyama (1968:67) reported that titratable acidity is increased by high air temperatures, but unaffected by shading.
The SSC content is mostly composed of sucrose as well as reducing sugars (Ho & Hewitt, 1986:201). Thus, any factor that alters a photosynthetic activity will affect the glucose and fructose accumulation in the fruit, thus altering the SSC content (Caliman et al., 2010:77). A lower SSC content was reported by Tombesi, Antognozzi and Palliotti (1993:88), Dussi et al. (2005:256), and Richard et al. (1991:386) for plants grown under protected cultivation as opposed to field cultivation. These authors attribute this phenomenon to the reduced light which the plants received, leading to poor carbohydrate accumulation in the fruit. Reduced light conditions are also likely to affect fruit firmness, as light is necessary for cell wall formation. ‘Fuerte’ avocados exposed to direct sunlight (32 °C) were 2.5 times firmer than those positioned on the shaded side (20 °C) of the tree. Changes in cell wall composition, cell number and cell turgor properties are influenced by temperature and sunlight exposure (Woolf et al., 2000:370).

Table 2.5: SSC/TA for different cultivars planted in field and protected environments

<table>
<thead>
<tr>
<th>Environment</th>
<th>Tomato plant genotype</th>
<th>BGH-320</th>
<th>Carmen</th>
<th>Santa Clara</th>
<th>Total average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected</td>
<td></td>
<td>10.33</td>
<td>12.17</td>
<td>13.72</td>
<td>12.07b</td>
</tr>
<tr>
<td>Field</td>
<td></td>
<td>13.59</td>
<td>17.07</td>
<td>19.81</td>
<td>16.82a</td>
</tr>
<tr>
<td>Total average</td>
<td></td>
<td>11.96b</td>
<td>14.62a</td>
<td>16.76a</td>
<td></td>
</tr>
</tbody>
</table>

Source: Caliman et al., 2010:78

2.3.5 Bioactive compounds in fruits

Fruit and vegetables are rich in phytochemicals (Olajire & Azeez, 2011:022). Phytochemicals mediate the interaction of plants with their environments; thus,
functioning as feeding deterrents, pollination attractants, protective compounds against pathogens or various abiotic stresses, antioxidants, or signalling molecules (Kennedy & Wightman, 2011:33). Maintaining a high level of phytochemicals in fruit and vegetables is therefore desirable. A high concentration of antioxidants in horticultural produce is also believed to improve its storability and reduce its rate of deterioration (Bergquist, 2006). These functional compounds can consist of a wide range of substances such as lycopene, carotenoids, ascorbic acid, phenolic acids, flavonoids, and other polyphenols such as glucosinolates, allylic sulphides, isothiocyanates, dietary fibres, phytosterols and monoterpenes (Schreiner & Huyskens-Keli, 2006:268; Lister, 1999:18; Kris-Etherton et al., 2002:71).

Antioxidants protect living cells against the harmful effects of free radicals and other reactive oxygen species (Bergquist, 2006). Some of these phytochemicals such as flavonoids and other phenolics, and carotenoids are marked by a broad spectrum of health promoting functions (Heinonen, Lehtonen & Hopia, 1998:25). The vitamins C (ascorbic acid) and E (tocopherols and tocotrienols) and some enzymes are also part of the antioxidant defence system (Lurie, 2003:131). Free radicals are mostly highly reactive and unstable due to their unpaired valence electrons (Bergquist, 2006). In the human body, an overproduction of free radicals may be triggered by radiation, pollutants, cigarette smoke, alcohol, exercise and stress (Bergquist, 2006). Free radicals have been found to be involved in ageing, several forms of cancer, heart disease, cardiovascular disease, Alzheimer’s disease, inflammatory conditions, rheumatism, insulin resistance and cataracts (Halliwell & Gutteridge, 1989; Houstis, Rosen & Lander, 2006:944), and increasing the antioxidant intake therefore purportedly decreases the risk of contracting these diseases (Berger, 2005:172). Bioactive compounds are also believed to affect the storability of the fruit and
vegetables that contain them. Reactive oxygen species are known to be involved in leaf senescence and the antioxidant defence system most likely plays an important role in determining the onset and rate of senescence (Philosoph-Hadas et al., 1994:2376; Meir et al., 1995:1813; Hodges & Forney, 2003:930). Bergquist (2006) opines that a product with a high concentration of antioxidants is well protected against oxidation and may therefore retain its quality longer. Thus, increasing the concentrations of the presumed beneficial compounds in fruit and vegetables may not only have positive health effects for consumers, but may also extend the shelf lives and increase their stress tolerance, leading to lower postharvest losses in produce. Furthermore, since a high antioxidant concentration may be associated with a fresh appearance, the freshness of a fruit or vegetable may to some extent be a marker of its food value regarding its content of bioactive compounds.

The concentrations of bioactive compounds in fruit and vegetables are clearly not constant and are affected by many pre- and postharvest factors which include genetic variations, climatic conditions, fertilisers, harvesting, storage conditions, temperature management and relative humidity. Some bioactive compounds are common among fruit and vegetables but may vary in concentration between species or cultivars (Lee & Kader, 2000:207). Genetic factors strongly influence the content of bioactive compounds in fruit and vegetables. Variations between cultivars of the same species may also be extensive (Mercadante & Rodriguez-Amaya, 1991:1094; DuPont et al., 2000:3957; Howard et al., 2002:5891). Climatic factors such as light and temperature are known to regulate not only plant growth and development, but also the biosynthesis of both primary and secondary metabolites (Hemm et al., 2004:765; Liu et al., 2002:581). Cultural practices, including nutrient and water
availability, influence these compounds, as do soil type variations in growing sites (Weston & Barth, 1997:812). Variation in concentrations of bioactive compounds resulting from the maturity stage are more evident in fruit ripening, particularly when the carotenoid or flavonoid content provide the colour of the ripe fruit (Kalt, 2005:11). The timing of the harvest during the day is also important, as there may be large variations in the concentrations during the day, possibly related to the water content (when concentrations are given on a fresh weight basis) or the light intensity (Mozafar, 1994; Veit et al., 1996:478). Temperature management is therefore crucial for maintaining the quality of harvested fruit and vegetables, both in terms of appearance and biochemical composition (Wills et al., 1998). Ascorbic acid rapidly decreases during storage in many plant products, whereas carotenoids and flavonoids appear to be more stable (Kalt, 2005:11).

2.3.5.1 Carotenoids

Carotenoids are yellow, orange or red pigments that are responsible for the colour of many fruits, vegetables and flowers. Carotenoids are tetraterpenoids, that is, they are built on a 5-carbon isoprenoid unit and are hydrophobic. There are two groups of carotenoid; the hydrocarbon carotenes and the oxygenated xanthophylls. Carotenes, such as α- and β-carotene and lycopene, are predominantly orange or red-orange pigments, whereas xanthophylls such as lutein, violaxanthin, zeaxanthin, antheraxanthin and neoxanthin are mainly yellow. Carotenoids have important functions in photosynthesis. Some of them are accessory pigments that absorb light energy and transfer it to chlorophyll, which can use the energy for photosynthesis.
Lycopene, like other carotenoids such as lutein and \( \beta \)-carotene, plays an important role as a free-radical scavenger in humans and plants (Jones & Porter, 1999:295). In plants, lycopene provides antioxidant protection for photosystem events and appears in chromoplasts during ripening, and it is further thought to improve the attraction of the fruit, its consumption and seed dispersal by herbivores (Collins, Perkins-Veazie & Roberts, 2006:1135). In humans, lycopene exhibits antioxidant activities (Di-Mascio, Kaiser & Sies, 1989:523), suppresses cell proliferation (Levy et al., 1995:257) and interferes with the growth of cancer cells (Clinton et al., 1996:823). In tomatoes, lycopene is responsible for the deep red colour in fully ripe fruit. The colour of the fruit forms an important property from the consumer's point of view; it is the first quality attribute that stimulates them to purchase, consume and enjoy the fruit. The lycopene content also adds a very important quality attribute to tomato processing (Barrett & Anthon, 2008:132); it constitutes 80% to 90% of the total pigments present in mature processing tomatoes (Shi & Le Maguer, 2000:293). Environmental conditions such as temperature and light, and cultivar type (Table 2.6) were reported to affect lycopene biosynthesis in plant materials (Dumas et al., 2003:369; Martinez-Valverde et al., 2002:323). Tomatoes exposed to direct sunlight accumulate high pulp temperatures which inhibit lycopene synthesis; hence the fruits
often develop poor colour under such conditions (McCollum, 1954:182). Fruits exposed to strong radiation may have a temperature of 10 °C higher than that of fruits grown in shaded areas. The temperature of the fruit (>32 °C) suppresses lycopene synthesis completely, but not β-carotene (Dumas et al., 2003:371). Tomes (1963:180) reported that lycopene develops best when the temperature is between 12 °C and 21 °C. Low light intensity results in an uneven fruit colour due to reduced lycopene accumulation, but intense direct radiation on fruits can be harmful (Raymundo, Chichester & Simpson, 1976:59). According to Adegoye and Jolliffe (1987:297), lycopene synthesis is inhibited when green fruit is exposed to ~2990 μmol m⁻² s⁻¹ for 1.5 to 4 h. However, fruit exposed to direct sunlight during its developmental stages accumulate higher carotene levels than shaded fruit (McCollum, 1954:182). Cabibel and Ferry (1980:27) reported that fruits grown under a glass or plastic tunnel yielded a lower β-carotene content than those in the open field. Similar results were obtained by Dorais, Papadopoulos and Gosselin (2001:239).

### Table 2.6: Lycopene content in tomato varieties (100% ripe stage), expressed as mg kg⁻¹ on a fresh weight basis

<table>
<thead>
<tr>
<th>Tomato plant variety</th>
<th>Lycopene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rambo</td>
<td>31.97±0.54c</td>
</tr>
<tr>
<td>Senior</td>
<td>32.24±0.55c</td>
</tr>
<tr>
<td>Ramilllete</td>
<td>31.49±1.17c</td>
</tr>
<tr>
<td>Liso</td>
<td>18.60±1.00e</td>
</tr>
<tr>
<td>Pera</td>
<td>63.37±3.21a</td>
</tr>
<tr>
<td>Canario</td>
<td>49.44±2.73b</td>
</tr>
<tr>
<td>Durina</td>
<td>64.98±5.12a</td>
</tr>
<tr>
<td>Daniella</td>
<td>36.32±3.52cd</td>
</tr>
<tr>
<td>Remate</td>
<td>42.96±3.29bc</td>
</tr>
</tbody>
</table>

*Source: Martinez-Valverde et al., 2002:325*
Ascorbic acid (AA) or vitamin C, was first discovered in citrus in 1928, and is a water soluble antioxidant (Lester, 2006:59). It is the most important vitamin in fruit and vegetables with regard to human nutrition. More than 90% of the vitamin C in human diets is supplied by fruit and vegetables (Lee & Kader, 2000:207). Vitamin C is required for the prevention of scurvy, the maintenance of healthy skin, gums and blood vessels (Lee & Kader, 2000:208), the maintenance of a healthy immune system, the reduction of colds by preventing secondary viral or bacterial infections, and the prevention of cardiovascular diseases and some forms of cancer (Eichholzer et al., 2001:5). AA is an important cofactor for some plant enzymes, including violaxanthin de-epoxidase, and is involved in photo-protection through the xanthophyll cycle and in photosynthesis as an electron donor to photosystem II (Smirnoff, 2000:1455). Furthermore, ascorbic acid has been implicated in the control of cell expansion and division in plants (Smirnoff, 1996:661).

Light and average temperatures have a strong influence on the chemical composition of horticultural crops. Light is not essential for the synthesis of AA in plants (Caliman et al., 2010:79). However, the amount and intensity of light during the growing period exert a great influence on the amount of AA formed. AA is synthesised from products of photosynthesis-produced (carbohydrates) in plants (Lee & Kader, 2000:210). Thus, those parts of the fruit that are exposed to maximum sunlight will contain higher amounts of vitamin C than those that are inside or shaded on the same plant (Table 2.7). In general, plants exposed to lower light intensities
during growth and development, yield a lower AA content in their plant tissues (Lee & Kader, 2000:210; Kalt, 2005:15). Makus and Lester (2002:23) reported a lower AA content in mustard greens planted under a 50% shade environment rather than in full sunlight. Similar results were reported by Lopez-Andreu et al. (1986:387) and Brown (1954:342). In a study conducted by Sayre, Robinson and Wishnetsky (1953:381), vine ripened tomato fruit grown at low versus medium, or high day or night temperatures presented altered concentrations of AA. Their results suggest that the AA content declined with increasing temperatures. Gautier et al. (2008:1241) reported similar results, where a temperature increase from 27 °C to 32 °C reduced the AA content of cherry tomato plants in greenhouse conditions. Elevated temperatures and increased solar exposure of fruits are known to cause ascorbic acid degradation (Torres, Andrews & Davies, 2006:1933).

**Table 2.7:** Ascorbic acid content in tomato varieties (100% ripe stage), expressed as mg 100 g⁻¹ fresh fruit

<table>
<thead>
<tr>
<th>Environment</th>
<th>Tomato plant genotype</th>
<th>Total average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected</td>
<td>BGH-320</td>
<td>12.70</td>
</tr>
<tr>
<td></td>
<td>Carmen</td>
<td>12.03</td>
</tr>
<tr>
<td></td>
<td>Santa Clara</td>
<td>13.76</td>
</tr>
<tr>
<td></td>
<td>Total average</td>
<td>12.83b</td>
</tr>
<tr>
<td>Field</td>
<td>15.23</td>
<td>14.17</td>
</tr>
<tr>
<td></td>
<td>21.66</td>
<td>17.02a</td>
</tr>
<tr>
<td>Total average</td>
<td>13.96b</td>
<td>13.10b</td>
</tr>
<tr>
<td></td>
<td>17.71a</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Caliman et al., 2010:78

2.3.5.3 Total Phenols and Flavonoids

Flavonoids and phenolics are the most important groups of secondary metabolites and bioactive compounds in plants. They contribute to the sensory qualities (colour,
flavour, taste) of fresh fruit, vegetables and their products. In addition, many phenolic compounds have antioxidative, anticarcinogenic, antimicrobial, antiallergic, antimutagenic and anti-inflammatory activities (Kim, Jeond & Lee, 2003:321). Flavonoids constitute a large family of polyphenols synthesised in plants; they have been labelled as high level natural antioxidants because of their abilities to scavenge free radicals and quench active oxygen with the inhibition of enzyme activity (Clifford & Cuppett, 2000:1063). High contents of natural phenols and flavonoids are found in green tea, fruit and vegetables, while some amounts of phenolics are present in red wine and coffee (Ghasemzadeh & Ghasemzadeh, 2011:2436). Epidemiological studies have found associations between a high risk of diseases and a low intake of fruit and vegetables or bioactive compounds (Knekt et al., 1996:478). Besides flavonoids, chlorogenic acids and related compounds are the main phenolic compounds found in tomatoes (Slimestad & Verheul, 2009:1255). Chlorogenic acids possess a number of beneficial health properties related to their potent antioxidant activity as well as their hepatoprotective, hypoglycemic and antiviral activities (Farah & Donangelo, 2006:23). These acids may also be responsible for a somewhat astringent taste in tomatoes (Walker, 1962:363; De Bruyn, Garresten & Kooistra, 1971:214).

Flavonoids occurring in tomatoes include: rutin, naringenin and quercitrin, kaempferol, aglycones, quercetin, myricetin, and chalconaringenin (Slimestad & Verheul, 2009:1257); they are found in abundance in the leaves, fruit skins, stem epidermis, cuticle of the fruit and in canned tomato paste. Phenolic acids present in the tomato skin, pulp and canned pastes are: hydroxycinnamic acids, ferulic, caffeic and chlorogenic acid, p-coumaric acid, sinapic acid, vanillic and salicylic acids, 5-p-
coumaroylquinic acid, $p$-coumaroylglucoside and feruloylglucoside, 4- and 3-
caffeoylquinic acids (Walker, 1962:363; Wardale, 1973:1523; Fleuriet & Macheix,
1976:407; Schmidtlein & Herrmann, 1975:213; El Khatib et al., 1974:23). The total
level of tomato phenolics varies significantly both with respect to the ripening stage
and the location within the fruit (Senter, Horvart & Forbus, 1988:639; Slimestad &
Verheul, 2005a:3114; Slimestad & Verheul, 2005b:7251). The highest concentration
has been found in the epidermal and placental tissues. Stewart et al. (2000:2663)
measured the distribution of flavonols (sum of free and conjugated kaempferol and
quercetin respectively) in Spanish cherry tomatoes. Each fruit was found to contain
25.3 mg kg$^{-1}$ FW of flavonols. Its peel or epidermis was found to contain 143.3 mg
kg$^{-1}$, the flesh 0.12 mg kg$^{-1}$, whereas the seeds were found to hold 1.5 mg kg$^{-1}$ FW
of flavonols; thus, more than 98% of total flavonols occurred in the skin. Of these,
conjugated quercetin, primarily rutin, was the main class of flavonols, with a content
of more than 94% of total flavonols in the tomatoes (Slimestad & Verheul,

The concentration of bioactive compounds in fruit and vegetables can be influenced
by environmental conditions such as light intensity and temperature (both in terms of
total or average temperature and the extremes during the growth period)
(Ghasemzadeh, Jaafar & Rahmat, 2010:4540). Stewart et al. (2000:2663) indicated
that the choice of cultivar was a major factor contributing to the total content of
phenolics in tomatoes when grown under similar environmental conditions. Two
normal-sized field grown tomatoes, cvs Bond and Havanera, grown alongside each
other in Spain contained 10.9 and 6.6 mg flavonol kg$^{-1}$ FW. Since 98% of the total
flavonols occur in the skin (Slimestad & Verheul, 2009:1264), tomato types with different fruit sizes, and thus different skin-volume ratio or different skin colours, are expected to present a different flavonol content. The total flavonol content of cv. Favorita, a red cherry tomato, was found to be 21.5 mg kg\(^{-1}\) FW, twice as high as the cv. Bond when grown under the same conditions. This findings were confirmed by Willcox, Catignani and Lazarus (2003:1) who found the total flavonoid content in normal sized tomatoes to be 5 mg kg\(^{-1}\) and 30 mg kg\(^{-1}\) FW in cherry tomatoes. Mineral nutrition can have a major influence on phenolic accumulation (Slimestad & Verheul, 2009:1266); a limited nitrogen supply was found to be associated with higher levels of phenolics in the plant (Parr & Bolwell, 2000:985; Lea et al., 2007:1245). Increases in flavonoids during nitrogen starvation could be due to increased deamination of phenylalanine (Slimestad & Verheul, 2009:1266). Under such conditions ammonia would be recycled for protein synthesis and cinnamic acid can constitute a substrate for the flavonoid metabolic pathway (Slimestad & Verheul, 2009:1266).

Phenolic biosynthesis requires light and is also enhanced by light (Ghasemzadeh et al., 2010:3887), and flavonoid formation is absolutely light dependent; its biosynthetic rate is related to light intensity and density (Xie & Wang, 2006:51). However, different plants have a different response to light intensity changes and the resulting total flavonoids (TF) and total phenolics (TP). Previous studies indicated that changes in light intensity were able to change the production of TF and TP in herbs (Graham, 1998:135). Chan et al. (2008:477) reported a much higher concentration of flavones and flavonols in the leaves of vegetables that were
exposed to shade. This finding is in agreement with Ghasemzadeh et al. (2010:3889), who indicated that the TF content of *Zingiber officinale* Roscoe can be increased by reducing the light intensity under the glasshouse shade. Bergquist et al. (2007:2464) also indicated that the use of shade netting is acceptable for the production of baby spinach in relation to flavonoid concentration and composition. The authors postulate that the increased TF content with increasing shade could be associated with significantly higher leaf chlorophyll and carotenoid contents under lower light levels. A light intensity of 790 µmol m\(^{-2}\) s\(^{-1}\) yielded a higher TP content in ginger crops (*Z. officinale*) planted in the glasshouse shade (Ghasemzadeh et al., 2010:3888). Similar results were reported by Maršić et al. (2011:190) in tomato fruit grown inside tunnels. Phenols and flavonoids are major contributors of antioxidant activity in fruit and vegetables, thus it is suggested that increased phenols and flavonoid components in shaded plants are related to lower temperatures under such conditions (Ghasemzadeh et al., 2010:3887). However, Wilkens, Spoerke and Stamp (1996:247) reported high soluble phenol contents in plants grown under high light rather than in low light conditions.

### 2.4 CONCLUSION

This literature review addressed information on the production of tomatoes – comparing open field and in-house production methods, disease occurrence and pest infestation, marketable fruit yields and fruit quality at harvest, and lastly, health promoting compounds. The production of high economic value crops such as tomatoes and lettuce is occasionally limited to greenhouse structures or normal
netting materials, with no additives. However, crop production under greenhouse conditions carries high input costs, which amongst others include electricity; whereas under normal netting materials crop yields are lower due to the microclimatic conditions, high disease and pest infestation, resulting in poor quality produce (unmarketable fruits). Environmental conditions play a major role in crop production and determine the types of microorganisms and diseases that are likely to affect crops. As a result, farmers are constantly seeking alternative methods for improving yields and the quality of produce, with lower input costs and minimal application of pesticides. Consumers are also more aware of what they eat, thus demanding high quality crops with greater health promoting compounds. The application of photo-selective netting is gaining popularity around the world; it is a technology that can be used as an alternative to improve crop yields and quality, reduce the application of pesticides, lengthen the shelf life of produce and ensure sustainable crop production even in areas where agriculture is not practised due to adverse environmental conditions.
CHAPTER THREE

EFFECT OF PHOTO-SELECTIVE NETS ON TOMATO PLANT GROWTH AND YIELD

3 SUMMARY

This experiment was conducted to determine the effect of three photo-selective nets (40% shading – red, pearl and yellow) on the growth parameters and yield of the tomato (*Solanum lycopersicum*). The commercial black net (25% shading) was included for the sake of comparison (control). The variables measured were plant height, leaf area, stem diameter, flowering, fruit trusses, number of fruits, fruit mass, leaf chlorophyll content, incidence of bacterial and fungal diseases, pest infestation and microclimatic assessment [air temperature (AT), relative humidity (RH) and photosynthetic active radiation (PAR)]. Plant height and leaf area measurements were significantly high for plants produced under the red and yellow nets, while stem diameter measurements were greater for plants produced under the red nets. The flowering intensity was high for plants grown under the red, yellow and pearl nets, while the number of fruits per plant was higher under the pearl and yellow nets. Photo-selective nets exhibited higher AT and lower RH compared with the black (control) nets, whereas the PAR was higher under the black (control) nets with 25% shading. Of the three cultivars (cv.), cv. SCX 248 showed a significantly higher plant height and number of fruits, whereas cv. AlfaV revealed a larger fruit mass and leaf
area and cv. Irit exhibited a significantly thicker stem diameter. The marketable yield was higher in cv. AlfaV under the pearl nets, while cv. SCX 248 and Irit showed a higher marketable yield under the red nets. No significant differences were observed in the leaf chlorophyll content; either in the three cultivars or between the different shade nets. Furthermore, the shade nets exerted no significant effect on disease and pest incidences as was noted in cv. SCX 248 which was highly affected by white flies. Bacterial leaf speck and spot was also more prevalent on cvs SCX 248 and Irit. Incidences of early blight were observed to be low during this study in all three cultivars; however, cvs AlfaV and SCX 248 indicated a higher incidence of early blight. All three cultivars grown under the black (control) nets exhibited less plant height, less fruit mass, and a lower fruit marketable yield. This experiment demonstrated that pearl and yellow nets are best suited to produce a substantial number of tomatoes with a greater mass. Cultivar versus net interaction was clearly observed in this study. Cultivar AlfaV under the red nets revealed a higher plant height, fruit trusses and number of fruits.

3.1 INTRODUCTION

Good agricultural practices in combination with conducive environmental conditions are vital for sustainable crop productions. Tomato yields and quality are adversely affected by varying climatic conditions which include high solar radiation and temperature, followed by pests which cause direct feeding damage and often transmit viruses (Ben-Yakir et al., 2013:249, Higashide, 2009:1878, De Koning, 1989:329). The optimum temperature for tomato production ranges from 21 ºC to 25
°C with an average monthly minimum temperature greater than 18 °C and a monthly maximum temperature of 27 °C (Haque et al., 1999; Araki et al., 2000). Fruit setting is optimal between 18 °C and 20 °C (De Koning, 1994).

Temperatures that fall below 16 °C can cause flower abscission, whereas temperatures above 30 °C can induce fruit cracking and blotchy ripening. Elevating temperatures can also increase the rate of fruit growth, consequently hastening maturity and leading to a reduction in the mean weight of the tomato fruits (Hurd & Graves, 1985:359; Sawhney & Polowick, 1985:1031). However, Marcelis and Baan Hofman-Eijer (1993:321), demonstrated that the effect of temperature on the growth of cucumbers was dependent on the availability of photosynthetic assimilate. It is well known that netting can provide sustainable crop production under severe environmental conditions because of its ability to (a) provide protection from environmental hazards (e.g., excessive solar radiation, wind, hail, flying pests); (b) improve plant microclimates (thus reducing heat or chill, drought stresses, etc.); (c) moderate rapid climatic stresses; and (d) be cheaper and less energy consuming than greenhouses. According to Polysack Plastic Industries, Ltd (Nir-Yitzhak, Sufa, Israel), photo-selective nets (ChromatiNet™) are developed to modify the spectrum of filtered light, enhance the content of scattered light, and affect the thermal components of light in the infrared region, thereby enhancing desirable physiological responses such as yield, quality and maturation rates, and plant compactness and its morphology (Shahak et al., 2004a:143).
According to Shahak et al. (2004b:610), nets offer varying mixes of natural, unmodified light and spectrally modified, diffused light depending on the chromatic additives of the plastic and the density of the knitting design. McMahon and Kelly (1990:209) reported that plants grown under grey ChromatiNet™ exhibit an increase in their number of shoots and buds as well as a noticeable increase in their branching. Red ChromatiNet™ reduces the spectrum of blue, green, and yellow light and increases the R and FR light spectrum (Shahak et al., 2004a:145). McElhannon (2007:44) reported that the effect of red ChromatiNet™ on the light spectrum yields plants with a larger surface area, healthier darker green foliage, and longer and thicker stems. Furthermore, Polysack claims that red ChromatiNet™ produces earlier flowering plants without decreasing their flower quality (Oren-Shamir et al., 2001:353). According to Shahak et al. (2004a:145), pearl ChromatiNet™ has the ability to scatter incoming light, thus allowing the light to better penetrate the plant canopy, resulting in an increased photosynthetic efficiency. The latter accelerates plant growth, increases the number of secondary branches and improves the overall plant quality (Oren-Shamir et al., 2001:353). Therefore, the objective of this investigation was to compare different coloured photo-selective nets (red, pearl and yellow) and the commercially used black net on three indeterminate tomato cultivars (AlfaV, Irit and SCX 248) planted during the 2011 to 2012 growing season. The comparison was based on plant growth parameters (plant height, leaf area, stem diameter, leaf chlorophyll, fresh fruit weight and total fruit marketable yield, flowering and fruit trusses) and incidences of pests and diseases.
3.2 MATERIALS AND METHODS

3.2.1 Location

The study was carried out in a net tunnel (length 12 m & height 5 m) at the Experimental farm of Tshwane University of Technology, Bon-Accord, Pretoria North (25° 37’ S and 28° 12’ E latitude and longitude respectively, at an altitude of 1173 m above sea level) during the 2011 to 2012 growing season. The tunnels were covered with red, pearl and yellow photo-selective nets (ChromatiNet™) and a black control net, which is used by most commercial farmers in the country.

3.2.2 Treatments and experimental design

Three coloured photo-selective nets (pearl, red, and yellow) with 40% shading each and a black (25% shading) traditional net, which is used commercially in South Africa for the production of fruit and vegetables, provided the required shading materials and were installed as permanent structures. The photo-selective nets (ChromatiNet™) were manufactured by Polysack Plasctics Industries in Israel. They are unique in that they modify the non-visible spectrum and enhance light scattering. The experiment was laid out in a completely randomised design, with three replicate nets assigned to each of the four treatments (red, pearl, yellow and black net).
Figure 3.1: Photographs illustrating yellow photo-selective nets and black control nets

Figure 3.2: Photograph illustrating red and pearl photo-selective nets
3.2.3 Planting materials

Three indeterminate tomato cultivars, namely, AlfaV, Irit and SCX 248 were transplanted at six weeks old during the 2011 to 2012 growing season. The seedlings were obtained from SeedCor (Pty, Ltd) South Africa. They were transplanted into 5 L black plastic bags using coir-sand as a growing medium (the planting density was 2.88 plants m$^{-2}$). The physical properties of the coir medium were moisture (13.30%), pH (0.059), bulk density (0.0619 g ml$^{-1}$), water holding capacity (71.7%) and air porosity (6.93%). Irrigation was applied through drippers; one dripper per plant which was controlled by a computerised irrigation system and had a discharge rate of 33.3 ml min$^{-1}$ at four hour intervals, four times a day.

A set of 72 plants per cultivar were planted under each replicate net. Each treatment and block consisted of eight double rows of 36 plants each. The spacing between the plants within a double row was 50 cm x 50 cm while the spacing between the rows was 1 m. To minimise the effect of position within the nets, each cultivar was replicated three times in a Latin square layout. The nutrient solution for irrigation was mixed in a 5 000 L tank as indicated in Table 3.1; the pH of the solution was maintained within a range of 5.6 to 6.0 (nitric acid was used to adjust the pH). The hydroponic® fertiliser was supplied by Hygrotech (Pty, Ltd) Pretoria, South Africa. The nutritional composition of the hydroponic® fertiliser was [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 1254 g kg$^{-1}$, Mn 299 g kg$^{-1}$, Zn 149 g kg$^{-1}$, Cu 22 g kg$^{-1}$, B 373 g kg$^{-1}$, Mo 37 g kg$^{-1}$] and SOLU-CAL Ca (NO$_3$)$_2$ [N 117 g kg$^{-1}$, Ca 166 g kg$^{-1}$].
Table 3.1: Nutrient composition of the fertiliser applied during tomato production

<table>
<thead>
<tr>
<th>Period</th>
<th>Composition (% w/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transplant to 1st flower truss</td>
<td>0.05 [1.39 kg hydroponics® and, 1.11 kg Ca(NO₃)₂]</td>
</tr>
<tr>
<td>1st flower truss to 3rd flower truss</td>
<td>0.08 [(2.4 kg hydroponics® and, 1.6 kg Ca(NO₃)₂]</td>
</tr>
<tr>
<td>3rd flower truss to end</td>
<td>0.12 [3.125 kg hydroponics® and, 2.095 kg Ca(NO₃)₂, 0.78 kg KNO₃]</td>
</tr>
</tbody>
</table>

Hygrotech Sustainable Solutions (Pty) Ltd

3.2.4 Cultural practices

Foliar feed comprising of nitrospray plus, calmabon liquid, hygroboost flo, hyper feed, millerplex, asco-gro, sporekill and nu-film P was occasionally applied to all the treatments to alleviate nutrient deficiencies. The foliar feed recipe was dissolved in a 16 L spraying tank of water and mixed thoroughly before application. The nutrient composition of the fertilisers used in the foliar feeding programme is presented in Table 3.2.
Table 3.2: Nutrient composition of the fertilisers used in the foliar feeding programme

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Active ingredients</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calmabon liquid</td>
<td>Nitrogen</td>
<td>88 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Calcium</td>
<td>89 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>17 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Boron</td>
<td>1526 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Molybdenum</td>
<td>1517 mg kg$^{-1}$</td>
</tr>
<tr>
<td>Asco-gro</td>
<td>Nitrogen</td>
<td>2 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Phosphate</td>
<td>2 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Potash</td>
<td>3 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Chelated iron</td>
<td>1340 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Chelated calcium</td>
<td>1160 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Chelated manganese</td>
<td>110 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Molybdenum</td>
<td>30 mg kg$^{-1}$</td>
</tr>
<tr>
<td>Hyperfeed</td>
<td>Nitrogen</td>
<td>164 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
<td>274 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>1.0 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Zinc</td>
<td>0.5 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Boron</td>
<td>1.2 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Phosphate</td>
<td>55 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>0.9 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>0.5 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Molybdenum</td>
<td>0.075 g kg$^{-1}$</td>
</tr>
<tr>
<td>Nitrospray plus</td>
<td>Nitrogen</td>
<td>165 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Phosphorus</td>
<td>68 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
<td>23 g kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>756 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Manganese</td>
<td>383 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Zinc</td>
<td>383 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>383 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Boron</td>
<td>196 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Molybdenum</td>
<td>6.3 mg kg$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>Cytokinins</td>
<td>0.75 mg kg$^{-1}$</td>
</tr>
<tr>
<td>Sporekill</td>
<td>Didecyldimethylammonium chloride</td>
<td>120 g L$^{-1}$</td>
</tr>
<tr>
<td>Nu-film</td>
<td>Poly-1-p-Methane</td>
<td>875 g L$^{-1}$</td>
</tr>
</tbody>
</table>

According to the product labels as manufactured by Hygrotech Sustainable Solutions (PTY) LTD

The application of foliar feed was guided by the development of the plants from the transplanting stage up to the harvest period, as well as when the plants showed signs of nutrient deficiency. Insect pests and diseases were controlled chemically.
Furthermore, the tomato plants were supported by twisting trellis twine around the main stem and fixing it to a stay wire. Pruning was also done regularly; lateral branches, suckers and auxiliary branches were cut and pinched off in order to retain a single stem.

3.2.5 Light interception by nets and microclimatic measurements

PAR (400±700 nm) outside and under the nets was measured weekly using a Ceptometer AccuPAR model LP-80 (Decagon Devices Ltd, USA). All measurements were carried out at 12.00 h on clear days. The relative shading provided by each net for the PAR ranges, was determined as $S_{PAR} = 100 \times (1 - PAR/PARo)$ where "o" corresponds to the solar radiation measured outside the net house. Light intensities, in PAR, were obtained by integration over the respective wavelength ranges of the solar radiation spectra (Oren-shamir et al., 2001:353). Air temperature and relative humidity were also monitored and the data were collected by Tinytag T/RH data loggers (Gemini data loggers Ltd, UK). These data loggers were placed above the tree canopy and protected from direct solar radiation, rain or sprays.

3.2.6 Plant measurements

Growth parameters such as plant height, stem diameter, number of fruit trusses, flowering intensity, leaf area, leaf chlorophyll and incidences of pests and diseases were recorded on a weekly basis for five weeks. Plant growth measurements were
taken from 15 plants per cultivar in each shade net replicate. Plant heights were measured in centimeters (cm), leaf areas were measured in millimeters squared (mm$^2$) and stem diameters were recorded in millimeters (mm) using a measuring tape. The number of fruits and flower sets were counted from 15 selected plants per cultivar from each shade net replicate. Incidences of pests and diseases were recorded from the affected leaves of 15 selected plants per cultivar in each shade net replicate. Leaf chlorophyll was measured non-destructively using a SPAD 502 chlorophyll meter (SPAD units) (Konica Minolta, Japan). Individual fruit masses from selected plants were also recorded.

3.2.7 Harvesting and fruit sampling

Tomato fruits produced from the three cultivars on the Experimental Farm were harvested at the mature pink (45-53 h $^9$) stage, 26 weeks after planting. Harvesting was carried out manually in the early morning. The total marketable yield was (kg m$^{-2}$) determined by fruits that were free from diseases, disorders, injuries or deformation and uniform in size and colour. These tomatoes (n=85 per cultivar per replicate of photo-selective nets) were then weighed and the average fresh weight was expressed in g per cultivar per photo-selective net. The fresh fruit mass (g) was thus determined after harvesting.
3.2.8 Statistical analysis

The experiment was analysed as a (4) nets versus (3) cultivar factorial design in a completely randomised design. All data were analysed with the aid of the Genstat program, and the least significant difference (LSD) was calculated at the 5% level of significance.

3.3 RESULTS AND DISCUSSION

3.3.1 PAR and microclimate under the shade nets

The PAR was higher (average 1564.356 μmol m\(^{-2}\) s\(^{-1}\)) in the open field than under the different photo-selective nets as indicated in Table 3.3 below. The PAR was higher under the black nets (control), and lower under the red nets. The photo-selective nets, supplied by Polysack Plastics Industries (Pty, Ltd), Israel, provided 40% shading from PAR. However, the average shading effect throughout the production period varied from ~42% to 48% and is illustrated in Figure 3.3.
Table 3.3: Air temperature (AT), relative humidity (RH) and photosynthetic active radiation (PAR) measurements under different photo-selective nets and the control net during cultivation.

<table>
<thead>
<tr>
<th>Shade Type</th>
<th>Air Temperature °C</th>
<th>Relative Humidity (%)</th>
<th>Photosynthetic Active Radiation (μmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearl</td>
<td>42.18±1.78a</td>
<td>25.41±4.86c</td>
<td>827.56±69.89b</td>
</tr>
<tr>
<td>Yellow</td>
<td>35.88±2.33b</td>
<td>35.12±11.73b</td>
<td>851.81±52.75b</td>
</tr>
<tr>
<td>Red</td>
<td>35.43±2.25b</td>
<td>40.00±12.14b</td>
<td>744.13±69.05b</td>
</tr>
<tr>
<td>Black (control)</td>
<td>30.27±1.52c</td>
<td>60.78±16.22a</td>
<td>1339.33±86.09a</td>
</tr>
</tbody>
</table>

LSD (p≤0.05) 5.16 9.71 107.69

Means followed by the same letter within the column are significantly different at 5% level of probability.

Figure 3.3: Shading effects of different shade nets

Means in each bar with the same type of letter are not significantly different at 5% level of probability.

The shading effects of the photo-selective nets were significantly (p≤0.05) higher than that of the black control nets (Figure 3.3). The black plastic threads are opaque; thus, the light entering through the holes in the nets is transmitted. However, the photo-selective shade nets are knitted more densely to achieve the shading effect, and according to Oren-Shamir et al. (2001:353), a major fraction of sunlight actually
passes through the plastic threads and is then selectively filtered. It can therefore be
collected that the shading effect under red nets may be due to the densely knitted
pattern of the threads. The average air temperature and the RH during the 2011 to
2012 growing season were significantly higher and lower respectively under the
photo-selective nets than under the black nets (control). This could be due to the
more densely knitted pattern of the threads in the photo-selective nets which
negatively affected the ventilation. Significant correlations were also observed
between air temperature and RH ($r=0.787$, $p<0.001$) and PAR ($r=0.650$, $p<0.001$).
On the other hand, the pearl nets provided the most stable microclimatic conditions
throughout the study as they had the least coefficient of variation for AT and RH,
while the yellow nets were noted to have the least ability to stabilise the fluctuation of
the environmental factors measured.

### 3.3.2 Plant height

There were significant differences ($p \leq 0.05$) in the plant height of the three cultivars
planted under the different shade nets (Figure 3.4). A greater plant height was
attained by cv. SCX 248 compared with cvs. AlfaV and Irit (Figure 3.4). The height of
plants under the black control net was significantly ($p \leq 0.05$) lower whereas the plant
height was higher under the yellow and red photo-selective nets (Figure 3.5). The
greater plant height under the photo-selective nets might have been brought about
by a lower light intensity inside these nets which caused the plants to grow taller
(shade avoidance) in order to increase their light interception and to facilitate the
photosynthetic processes (Kasperbauer, 1987:353). The interaction of cv. versus
shade net was clearly observed in this study; cv. AlfaV and cv. SCX 248 produced under the red and the yellow nets respectively, exhibited a significantly (p≤0.05) higher plant height as indicated in Table 3.4.

Figure 3.4: Variations in the plant height of the three tomato cultivars

Means in each bar with the same type of letter are not significantly different at 5% level of probability
Figure 3.5: Effect of photo-selective nets on the plant height of the three tomato cultivars

Means in each bar with the same type of letter are not significantly different at 5% level of probability

3.3.3 Stem diameter

Cultivar Irit had a significantly (p≤0.05) thicker stem diameter than the other two cultivars, SCX 248 and AlfaV (Figure 3.6). However, the stem diameter measurements were significantly (p≤0.05) lower for plants produced under the pearl nets and higher for those produced under the red nets (Figure 3.7). Cultivar SCX 248 grown under the pearl nets exhibited a lower measurement in stem diameter, while cv. Irit grown under the red nets showed significantly (p≤0.05) higher stem diameter measurements (Table 3.4). However, according to Costa et al. (2010:352), no significant difference was observed in the stem diameters and petiole lengths of Ocimum selloi grown under red or blue shade (ChromatiNet™ 50%) in comparison with the full sunlight treatments. The reason for the observed lower measurements in
stem diameter for plants grown under photo-selective nets in this study can be explained by the shade avoidance and photoreceptor, phytochrome, which is located in the meristematic tissue of the shoot tip (Solomakhin & Blanke, 2008:217). Under shading, plants redirect photo-assimilates for shoot elongation and away from structures dedicated to resource acquisition and to storage, at the expense of leaf development (Brutnell, 2006:417).

Figure 3.6: Variations in the stem diameter of the three tomato cultivars

Means in each bar with the same type of letter are not significantly different at 5% level of probability
It is evident from this study that, amongst the three cultivars, cv. AlfaV showed a significantly \((p \leq 0.05)\) higher measurement in leaf area than cv. Irit or SCX 248 (Figure 3.8). Plants produced under the black and pearl nets exhibited a significantly \((p \leq 0.05)\) lower measurement in leaf area as illustrated in Figure 3.9. However, plants grown under the yellow nets had significantly \((p \leq 0.05)\) higher leaf areas (Figure 3.9). A significant interaction between cv. and shade net on leaf area was observed. The leaf area of cv. SCX 248 was significantly larger \((p \leq 0.05)\) under the red nets (Figure 3.10), whereas, cv. AlfaV indicated a significantly \((p \leq 0.05)\) larger leaf area under the pearl, yellow and black nets as illustrated in Figure 3.10. On the other hand, cv. Irit grown under yellow nets showed a significantly \((p \leq 0.05)\) larger leaf area (Figure
Leaves grown in strong light conditions are generally smaller and thicker and contain less chlorophyll per unit leaf mass (Gratani, Covone & Larcher, 2006:549). On the other hand, plants grown in the shade tend to have a larger leaf area (as observed in the photo-selective nets, Figure 3.9), because cells expand more under low light intensities in order to receive light for photosynthesis (Boardman, 1977:355).

**Figure 3.8:** Variations in the leaf area of the three tomato cultivars

Means in each bar with the same type of letter are not significantly different at 5% level of probability.
Figure 3.9: Effect of photo-selective nets on the leaf area of the three cultivars

Means in each bar with the same type of letter are not significantly different at 5% level of probability.

Figure 3.10: The effect of cultivar versus shade net on the leaf area

Means in each bar with the same type of letter are not significantly different at 5% level of probability.
3.3.5 Leaf chlorophyll

No significant differences were observed in the leaf chlorophyll content; either in the three cultivars or between the different shade nets (Table 3.4). Leaf chlorophyll synthesis depends on the genotype and the light transmitted by the shade nets during leaf growth (Solomakhin & Blanke, 2008:217). The results of this study contradict the findings of Solomakhin and Blanke (2008:217). According to Solomakhin and Blanke (2008:217), the leaf chlorophyll content was higher in apple cvs Fuji and Pinova produced under coloured hail nets with a light transmission spectra ranging from 300 to 800 nm.

![Figure 3.11](image.png)

**Figure 3.11:** Photograph illustrating plants grown under the black (control) net
Figure 3.12: Photograph illustrating plants grown under the red net

Figure 3.13: Photograph illustrating plants grown under yellow photo-selective nets
3.3.6 Flowering and fruit trusses

At four weeks, after transplanting the plants, the flowering intensity was higher under the red, pearl and yellow photo-selective nets compared with the black control net (Figure 3.15). Interaction of cv. versus shade net and cultivar effect failed to show any significant effect on flowering. Of the three cultivars, SCX 248 indicated a significantly ($p \leq 0.05$) high number of fruit trusses (Figure 3.16) under the black, yellow and pearl nets (Table 3.4). Cultivar Irit exhibited a smaller number of fruit trusses per plant under the red nets as opposed to the other shade nets (Table 3.4). The photo-selective nets revealed no significant effect on the number of fruit trusses. This appears to contradict Shahak et al. (2008:66), who demonstrated that fruit
setting is one of the photo-selective responses resulting from the high flowering intensity induced by an optimum microclimate under the nets. Zoltán and Helyes (2004:1671) reported that truss appearance and flowering rates are affected by temperature. The interaction of cv. versus shade net on fruit trusses was evident in cv. AlfaV grown under the red nets (Table 3.4), where high numbers of fruit trusses were obtained.

**Figure 3.15:** Effect of shading on flowering intensity at four weeks after transplanting

Means in each bar with the same type of letter are not significantly different at 5% level of probability.
Means in each bar with the same type of letter are not significantly different at 5% level of probability

### 3.3.7 Number of fruits

Cultivar SCX 248 produced a significantly \((p\leq0.05)\) higher number of fruits per plant under the pearl, yellow, and black (control) nets (Table 3.4). The high number of fruits produced by cultivar SCX 248 (Figure 3.17) might be due to its greater plant height (Figure 3.4) and smaller trunk diameter (Figure 3.7), because tall plants are more likely to produce more flowers and fruit trusses (Susko & Lovet-Doust, 2000:1398). A significantly \((p\leq0.05)\) higher number of fruits per plant was recorded under the pearl and yellow nets (Figure 3.18). The higher number of fruits produced under the photo-selective nets (pearl and yellow) might be due to the modification of the light quality by the photo-selective nets which promote fruit setting and fruitlet survival (Shahak et al., 2008:66). According to Shahak et al. (2008:77), this might have resulted from either the higher content of scattered or diffuse light under the
photo-selective nets or from the modified spectral composition of the light or both. A lower number of fruits per plant was produced under the red and the black control nets (Figure 3.18). The interaction of cv. versus shade net was shown by cultivar AlfaV produced under the red nets, where a significantly ($p \leq 0.05$) higher number of fruit trusses and fruits per plant were produced (Table 3.4).

Figure 3.17: Effect of photo-selective nets on the number of fruits per plant

Means in each bar with the same type of letter are not significantly different at 5% level of probability
Figure 3.18: Number of fruits per plant or net type

Means in each bar with the same type of letter are not significantly different at 5% level of probability.
Table 3.4: Cultivar versus shade net interaction on plant height, stem diameter, leaf chlorophyll, fruit trusses per plant, and number of fruits per plant

<table>
<thead>
<tr>
<th>Cultivar (cv)</th>
<th>Shade type</th>
<th>Plant height (cm)</th>
<th>Stem diameter (mm)</th>
<th>Leaf chlorophyll (SPAD units)</th>
<th>Fruit trusses/plant</th>
<th>Number of fruits/plant</th>
<th>Fruit mass (g/fruit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlfaV x</td>
<td>Pearl</td>
<td>122.2±22ef</td>
<td>33.99±2cdef</td>
<td>52.83±3.3</td>
<td>2.1±0.7cd</td>
<td>9.6±3cde</td>
<td>108.8±18.4gh</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td>133.3±17bc</td>
<td>33.93±3def</td>
<td>52.18±2.7</td>
<td>2.0±0.8cd</td>
<td>9.3±4de</td>
<td>113.7±14.5h</td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td>138.4±23a</td>
<td>33.78±2ef</td>
<td>51.83±3.3</td>
<td>2.4±0.9b</td>
<td>11.2±4.b</td>
<td>94.0±21.7abc</td>
</tr>
<tr>
<td>Black (control)</td>
<td></td>
<td>114.6±19h</td>
<td>35.04±3bc</td>
<td>53.83±1.6</td>
<td>1.9±0.9cd</td>
<td>8.9±4de</td>
<td>103.6±11.7de</td>
</tr>
<tr>
<td>Irit x</td>
<td>Pearl</td>
<td>124.2±22e</td>
<td>35.03±1bcd</td>
<td>53.28±3.1</td>
<td>2.1±0.9cd</td>
<td>9.8±4cd</td>
<td>100.0±19.2cd</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td>130.4±22cd</td>
<td>35.62±3b</td>
<td>51.76±2.3</td>
<td>2.1±0.9c</td>
<td>10.4±5bc</td>
<td>93.8±13.5abc</td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td>132.6±26bc</td>
<td>37.37±3a</td>
<td>51.50±3.2</td>
<td>1.9±1.1d</td>
<td>8.7±5e</td>
<td>96.4±20.4bcd</td>
</tr>
<tr>
<td>Black (control)</td>
<td></td>
<td>118.5±19g</td>
<td>35.78±3b</td>
<td>52.30±1.5</td>
<td>2.0±0.8cd</td>
<td>9.0±3de</td>
<td>101.4±13.3d</td>
</tr>
<tr>
<td>SCX 248 x</td>
<td>Pearl</td>
<td>127.8±21d</td>
<td>31.49±2g</td>
<td>52.78±4.9</td>
<td>2.5±0.7ab</td>
<td>13.1±4a</td>
<td>91.2±15.7ab</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td>137.5±18a</td>
<td>34.46±3cde</td>
<td>52.87±2.7</td>
<td>2.4±0.9ab</td>
<td>13.1±4a</td>
<td>91.5±7.9ab</td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td>127.8±21b</td>
<td>34.84±2bcde</td>
<td>51.86±3.7</td>
<td>2.0±0.9cd</td>
<td>9.4±4de</td>
<td>97.2±15.9bcd</td>
</tr>
<tr>
<td>Black (control)</td>
<td></td>
<td>119.7±17fg</td>
<td>33.02±2f</td>
<td>53.71±1.4</td>
<td>2.6±0.9a</td>
<td>12.3±4a</td>
<td>88.9±11.1a</td>
</tr>
</tbody>
</table>

LSD (p≤0.05) 3.337  1.1067  1.325  0.1926  0.9850  11.68

Means followed by the same letter within the column are not significantly different at 5% level of probability.
3.3.8 Fruit mass

The fresh mass per fruit ranged from 88.9 g to 114 g (Table 3.4) and the differences observed in the fresh mass were more significant (p≤0.05) due to their genotype (cultivar) rather than their environmental (shading) differences. Cultivar AlfaV exhibited a significantly (p≤0.05) higher fruit mass under shading than did cv. SCX 248 or Irit (Figure 3.19). Average fruit mass was not significantly affected by any of the shade nets (data not shown). There were however, cultivar differences in fruit mass. For instance, a high fruit mass was recorded for cultivar AlfaV grown under the pearl and the yellow nets (Table 3.4). The higher fruit mass obtained by AlfaV produced under the photo-selective pearl and yellow nets might also be due to the suitable microclimate provided by the nets which induced a change in the microclimate around the fruit surface (decrease of 5-6 °C) and an increase in RH, leading to a reduction in transpiration during fruit growth (Tombesi, Antagnozzi & Palliotti, 1993:88). Shahak et al. (2004b:612) also suggest that the larger fruit size obtained from plants grown under the photo-selective nets might be due to reduced water stress in the nets as well as the ability of the nets to limit environmental stresses which may constrain canopy assimilation metabolism. On the other hand, the fruit mass of cv. SCX 248 improved under the red nets and cv. Irit also exhibited a higher fruit mass under the pearl and the black nets (Table 3.4).
3.3.9 Marketable yield

Tomato production under photo-selective shade nets has been shown to increase the marketable yield and to protect the fruit from physiological disorders such as sunscald injury (El-Gizawy et al., 1992:349; El-Aidy & El-Afry, 1983:2), blossom end rot and cracked skin (Lorenzo et al., 2003:181). In the present study, the marketable yield was higher for cv. AlfaV under the pearl nets, whereas cv. Irit and SCX 248 showed a higher marketable yield under the red nets. All three tomato cultivars showed a lower production of marketable fruits under the commercially used black nets (Figure 3.20).
Figure 3.20: Marketable yield of the three cultivars planted under different shade nets

Means in each bar with the same type of letter are not significantly different at 5% level of probability

3.3.10 Disease and pest infestation

The use of shade netting had no significant effect on disease and pest infestation (data not shown). Furthermore, there was no cultivar versus net interaction observed in terms of diseases and pests. Of the three cultivars, cv. SCX 248 was highly affected by white flies, while cvs. SCX 248 and Irit revealed higher incidences of bacterial speck and spot on the leaves. Although the incidences of early blight were low during this study in all three cultivars, cvs. AlfaV and SCX 248 were observed to show higher early blight incidences as illustrated in Figure 3.21. Elad et al. (2007:285) reported that bacterial and fungal diseases tend to spread more rapidly in
shade environments than in full sunlight, and the condition could be accelerated in moist areas.

**Figure 3.21**: Cultivar effect on incidences of pests and diseases

Means in each bar with the same type of letter are not significantly different at 5% level of probability.
CHAPTER FOUR

INFLUENCE OF PHOTO-SELECTIVE NETTINGS ON PHYSICO-CHEMICAL PROPERTIES AND BIOACTIVE COMPOUNDS IN TOMATO CULTIVARS

4 SUMMARY

The aim of this study was to verify the influence of photo-selective nettings on fruit quality and nutritional properties of tomato cultivars. Three types of photo-selective nets (red, yellow and pearl with 40% shading) were compared with commercial black net (25% shading) for fruit quality parameters [firmness, soluble solids concentration, titratable acidity, CIE-Lab colour parameters ($L^*, a^*, b^*$)] bioactive compounds (ascorbic acid, lycopene, β-carotene, total phenols and flavonoids) and total antioxidant activity in three tomato cultivars (AlfaV, Irit and SCX 248) at harvest maturity stage (pink). Principle component analysis illustrated cv. AlfaV fruits under black nets were lower in mass, less firm, higher in bioactive compounds but lower in TA and intense in red colour. However, under pearl nets cv. AlfaV showed higher fruit mass, firmness and moderately higher bioactive compounds. SCX 248 fruits under red nets were moderate in size, firmness, and bioactive compounds in comparison to the other nets. Cv. Irit fruit under all net types were lower in mass, less firm, lower in SSC, higher in TA while the black nets increased their bioactive compounds. Significant correlations were observed between bioactive compounds and the air temperature and photosynthetic active radiation. Pearl and red photo-selective nets improved the overall fruit quality; fruit mass, fruit firmness and
bioactive components in AlfaV and SCX 248 respectively and can be further implemented within protected cultivation practices.

4.1 INTRODUCTION

Tomatoes (Solanum lycopersicum) are a rich source of carotenoids (especially lycopene, β-carotene - a precursor of vitamin A), phenolics (flavonoids), vitamin C and trace amounts of vitamin E (Betancourt, Stevenson & Kader, 1977:721; Khachik et al., 2002:845; Vinson et al., 1998:3630). Lycopene is responsible for the red colour in tomatoes. A 100 g tomato was reported to provide 20-40% of the U.S recommended daily intake (DRI) for vitamin A and C (Betancourt, Stevens & Kader, 1977:721). In ripened tomatoes, rutin [quercetin 3-O-rutinoside; quercetin3-(6-rhamnosylglucoside)] has been reported to be a major flavonoid compound (Davies & Hobson, 1981:205; Slimestad & Verheul, 2009:1255). Lycopene, carotenoids and flavonoids have been known to show protective effects against cancers and cardiovascular diseases (Rao & Agarwal, 2000:563; Levy & Sharoni, 2004:49; Andersen & Markham, 2006). Lycopene, carotenoids and flavonoids act as strong antioxidants that protect cells from reactive oxygen species (Spencer et al., 2005:1005).

Tomato fruit quality for fresh consumption is determined by size, colour, firmness, flavour, aroma and nutritional properties. The reducing sugars (glucose and fructose) and organic acids (citric and malic acids) are responsible for the sweet-sour taste of tomatoes. Tomato flavour is also linked to the ratio of reducing sugars to organic acids (Bucheli et al., 1999:659) and aroma volatiles. Antioxidants and minerals were
shown to vary according to the cultivar and crop management practices (Dorais, 2007:200). The health promoting compounds in tomatoes are also influenced by the maturity stage at harvest (Helyes & Lugasi, 2006:183). Moreover, interaction effects were reported with respect to the bioactive compounds and cultivars, environmental factors (light and temperature) and crop management practices (Dorais, 2007:200). Photo-selective nets contain spectral filters with differential light scattering properties and altered proportions of red/far-red waveband (R/FR) ratio (Fletcher et al., 2005:303; Shahak et al., 2008:75). The actual functions of colour shade net depend on chromatic additives to the plastic and the knitting design (Shahak, 2012). The physiological responses linked to light quality include fruit-set, size, weight, colour, and harvest time (Shahak et al., 2004:143; Rajapakse & Shahak, 2007:290).

Use of photo selective shade netting decreases the light quantity and also alters light quality to a varying extent, and causing a change in thermal climate (Elad et al., 2007:285; Shahak et al., 2008:75). The biosynthesis of lycopene is affected by air temperature and sunlight. Exposure of fruits to excessive sunlight was reported to inhibit the synthesis of lycopene (Brandt et al., 2006:568). Brandt et al. (2003:269), stated that the growing methods such as water supply, open field or greenhouse conditions affected the lycopene content in tomatoes and the lycopene content varied between cultivar types (Daniela, cherry tomato and Delfine F1).

The optimum temperature for lycopene synthesis is between 22 °C and 25 °C (Dumas et al., 2003:369; Lumpkin, 2005). Higher temperatures were reported to reduce the vitamin C content in fruit and vegetable crops (McKeon et al., 2006:1031). Also, growing tomato without shading under slight water stress and
strong light intensity predicated increased sugar content and antioxidant compounds. Bertin et al. (2000:741) reported higher sugar content in tomato fruits grown during summer with increased sweetness in tomatoes. On the other hand, antioxidants in fruit and vegetable crops can also be altered by exposure to high temperatures during the growing season. Effect of photo-selective netting on lycopene content was reported by Gomez et al. (2001:1101) and Lopez et al. (2007:121). Ilić et al. (2012:90) reported the effect of photo-selective netting on lycopene and β-carotene contents in tomato cv. Vedeta. With the consumer and grower’s concern about fresh produce quality, the quality and quantity values of radiation and microclimate parameters under the photo-selective netting technology should be correlated with crop performance and produce quality (Stamps, 2009:239).

However, little information is available on the influence of photo-selective shade netting on overall fruit quality parameters and bioactive compounds at harvest in different tomato cultivars. On the other hand, the use of shading in horticulture production is becoming popular due to the increase in temperature during summer. Therefore, the objective of our study was to investigate the effect of different colour photo-selective netting in comparison to the commercially used black net on (a). overall quality parameters [colour, soluble solids content, titratable acidity and firmness] (b). bioactive compounds [ascorbic acid, total phenols, flavonoids, lycopene, β-carotene contents] and antioxidant scavenging activity at harvest in three commercial tomato cultivars grown in South Africa.
4.2 MATERIALS AND METHODS

The physico-chemical parameters and the bioactive compounds were determined from the freshly harvested tomatoes mentioned in chapter 3 that were used to determine the fresh weight. After harvesting, tomatoes were transported to the Department of Crop Sciences Postharvest laboratory Tshwane University of Technology, at 25 °C within 30 min for evaluation of fruit mass, fruit colour, firmness, soluble solids content, titratable acidity, ascorbic acid, lycopene, β-carotene, total phenol, flavonoid contents and antioxidant scavenging activity.

4.2.1. Analysis of physico-chemical properties of tomato cultivars at harvest maturity stage (pink)

4.2.1.1 Colour, firmness, soluble solids content (SSC), and titratable acidity (TA)

Fruit colour was objectively measured with a Minolta CR-400 chromameter (Minolta, Osaka, Japan) at four equatorial points on tomato fruit surface. The chromameter was calibrated with a standard white tile. In the CIE colour system, positive $a^*$ values describe the intensity of red colour, positive $b^*$ values describe the intensity of yellow colour and the $L^*$ value describes lightness (black=0, white=100). A destructive deformation test was used to evaluate fruit firmness by loading the tomatoes on a penetrometer (T.R. Turoni Srl. Italy). For firmness measurement, fruit sample was
placed stationary on a penetrometer stand and the compressive force (kg) required for 5 mm deformation of the fruit was recorded. Each fruit was cut in to pieces and homogenised in a conventional blender (Braun, Safeway, UK) in order to obtain the fruit juice. Thereafter, the fruit juice was filtered using a Whatman No 4 filter paper and the filtrate was used to determine the SSC and TA. The SSC content of the fruit was determined by using a pocket refractometer (Atago Co., Tokyo, Japan) and expressed as % (Javanmardia & Kubota, 2006:153). The TA was determined by titrating 10 ml of juice with 0.1 N NaOH, using phenolphthalein as an indicator and expressed as citric acid % (Mazumdar & Majumder, 2003).

4.2.2 Analysis of bioactive compounds of tomato cultivars at harvest maturity stage (pink)

4.2.2.1 Ascorbic acid, Lycopene and β-carotene contents

The ascorbic acid content was determined according to AOAC (2000) and expressed as mg per 100 g. Lycopene and β-carotene from tomato cultivars were extracted in a mixture of acetone:n-hexane (4:6) and centrifuged at 3000 × g for 5 min at 4 °C. Thereafter, optical density of the supernatant was determined at 663 nm, 645 nm, 505 nm and 453 nm using a Microplate Reader (Zenyth 200rt UK-Biochrom Ltd). The acetone:n-hexane (4:6) mixture was used as blank. The lycopene and β-carotene contents were determined according to Nagata and Yamashita (1992:925) using the following equations:
Lycopene (μg g FW$^{-1}$) = $-0.0458A_{663} + 0.204A_{645} + 0.372A_{505} - 0.0806A_{453}$

$\beta$-carotene (μg g FW$^{-1}$) = $0.216A_{663} - 1.220A_{645} + 0.304A_{505} - 0.452A_{453}$

The $A_{663}$, $A_{645}$, $A_{505}$ and $A_{453}$ are the absorbance at 663, 645, 505 and 453 nm, respectively. According to Nagata and Yamashita (1992:925), these equations enable the simultaneous determination of lycopene and $\beta$-carotene in the presence of chlorophylls. The assays were carried out in triplicate.

4.2.2.2 Total phenol and flavonoid contents

Total phenolic content was determined using the modified Folin-Ciocalteau method (Singleton et al., 1999:152; Luthria, Mukhopadhyay & Krizek et al., 2006:774). Tomato sample (0.2 g) was homogenised with 2 mL acetone: water (1:1 v/v) for 1 h at 25 °C. A 9 µL aliquot of tomato extract was mixed with 109 µL of Folin-Ciocalteau reagent. After 3 min of equilibrium time at 25 °C, 180 µL of (7.5% w/v) Na$_2$CO$_3$ solution was added to the extract. The solutions were mixed and allowed to stand for 5 min at 50 °C and after cooling to 25 °C the absorbance was measured at 760 nm (Zenyth 200rt Microplate Reader UK-Biochrom Ltd). Total phenolic compounds were calculated using a standard curve of gallic acid and expressed as mg of gallic acid equivalents (GAE) 100 g$^{-1}$ FW.

In order to determine the flavonoid content, tomato sample (0.3 g) was homogenised with 2 mL of methanol. The tomato extract (1.7 mL) was incubated for 30 min at 25
°C, shaking occasionally, and subsequently the extract was centrifuged at 6000 × g rpm for 10 min and the supernatants were taken for analysis. The flavonoid content was determined as described by Zhishen et al. (1999:556) on triplicate aliquots of the homogenous juice. The assay was carried out by pipetting 112.5 µL of distilled water into a well of microplate followed by the addition of 12.5 µL of methanolic extract, and 7.5 µL of 5% NaNO₂ was added. After 5 min, 15 µL of 10% AlCl₃ was added and finally 50 µL of 1 M NaOH was added after 6 min. The absorbance was read at 510 nm using a Microplate Reader (Zenyth 200rt Microplate Reader UK-Biochrom Ltd). Flavonoid content was calculated using a standard curve of rutin and expressed as mg of rutin equivalents 100 g⁻¹ FW.

4.2.2.3 Antioxidant scavenging activity

The 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method was used to determine the free-radical scavenging activity. For DPPH, tomato fruits were homogenised in methanol: water (60:40), and centrifuged at 6000 × g for 10 min. After centrifugation, the extracts were diluted with extraction solvent in order to obtain solutions of 40, 60, 80 and 100 mg ml⁻¹. Solution (0.01 mg ml⁻¹) of gallic acid was prepared immediately before the analysis and was used as a positive control. The capacity to scavenge the “stable” free radical DPPH was monitored according to du Toit et al. (2001:65). About 210 µL aliquots of 0.04 mM 1, 1-Diphenyl-2-picrylhydrazyl prepared in methanol was mixed with 23 µL of the test sample in a 96 well microplate. The control samples contained all the reagents except the extract or positive control antioxidant. The reaction mixture was left at 25 °C for 60 min. The absorbance (Abs) was measured spectrophotometrically at 515 nm (Zenyth 200rt Microplate Reader,
UK-Biochrom Ltd). The results were expressed as EC 50 (sample required to reduce the absorbance of the radical by 50%) in mg of gallic acid equivalent per gram of fruit.

4.2.3 Statistical analysis

Experimental data were subjected to two-way analysis of variance to determine the effect of cultivar and photo-selective netting on tomato fruit quality parameters and bioactive compounds in three tomato cultivars. The experiments were repeated over time, with four harvests. To compare the effect of different photo-selective netting on the different attributes of the three cultivars, Fischer’s least significant difference (LSD) procedures were applied at a significant level of 5%.

Pearson’s correlation coefficients were calculated to determine the strength of the linear relationships between the PAR or air temperature and fruit quality parameters (SSC, TA, firmness, fruit mass) or bioactive compounds (total phenols, flavonoids, ascorbic acid content, lycopene, β-carotene) or antioxidant scavenging activity for all three cultivars. Principal component analysis (PCA) was used to reduce the number of variables in the data matrix and to select the most discriminating parameters. On the other hand, principal components can show interrelationships between the variables (loading plot) and detect sample patterns, groupings, similarities or differences (score plot). The statistical package STSG Statistica for Windows, version 6.0 (Stat soft Inc., Tulsa, UK) was used.
4.3 RESULTS AND DISCUSSION

4.3.1 Fruit quality parameters and bioactive compounds

Table 4.1 A and B shows the physicochemical properties and bioactive compounds of the tomato fruits grown under different photo-selective nets. The soluble solids concentration (SSC) ranged between 3.59 and 4.40%. Among the three cultivars, AlfaV resulted in the highest SSC followed by Irit and SCX 248 resulted in the lowest SSC. These values are similar to those reported by Lumpkins (2005), Gupta et al. (2011:167) and Ilić et al. (2012:90). All the three cultivars grown under black nets had the highest SSC. The data (Table 4.3) shows a strong influence of higher light conditions (PAR) on SSC \( (r=0.812, \ p<0.01) \). SSC has been was reported to decrease during cooler days (Aldrich et al., 2010:2548).
Table 4.1 A: Effect of photo-selective netting on the physicochemical properties and bioactive compounds of three tomato cultivars

<table>
<thead>
<tr>
<th>Cultivar type</th>
<th>AlfaV</th>
<th>SCX 248</th>
<th>Irit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC (%)</td>
<td>4.269a</td>
<td>3.733b</td>
<td>4.163a</td>
</tr>
<tr>
<td>TA (%)</td>
<td>0.4323b</td>
<td>0.4494b</td>
<td>0.5941a</td>
</tr>
<tr>
<td>Ascorbic acid (mg 100 g FW⁻¹)</td>
<td>18.82a</td>
<td>16.99c</td>
<td>22.50a</td>
</tr>
<tr>
<td>Total antioxidant activity (mg GAE 100 g FW⁻¹)</td>
<td>0.1216a</td>
<td>0.1026b</td>
<td>0.1062b</td>
</tr>
<tr>
<td>Lycopene (µg g FW⁻¹)</td>
<td>46.4</td>
<td>47.0</td>
<td>44.7</td>
</tr>
<tr>
<td>β-carotene (µg g FW⁻¹)</td>
<td>14.52b</td>
<td>10.37c</td>
<td>17.63a</td>
</tr>
<tr>
<td>Flavonoids (mg rutin 100 g FW⁻¹)</td>
<td>0.1551a</td>
<td>0.1067b</td>
<td>0.1571a</td>
</tr>
<tr>
<td>p&lt;F</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>LSD</td>
<td>0.117</td>
<td>0.025</td>
<td>0.986</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the column are not significantly different at 0.001 level of probability
Table 4.1 B: Effect of photo-selective netting on the physicochemical properties and bioactive compounds of three tomato cultivars

<table>
<thead>
<tr>
<th>Net type</th>
<th>SSC (%)</th>
<th>TA (%)</th>
<th>Ascorbic acid (mg 100 g FW⁻¹)</th>
<th>Total antioxidant activity (mg GAE g⁻¹)</th>
<th>Total phenol content (mg GAE 100 g FW⁻¹)</th>
<th>Lycopene (µg g FW⁻¹)</th>
<th>β-carotene (µg g FW⁻¹)</th>
<th>Flavonoids (mg rutin 100 g FW⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cv x net</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AlfaV x Red</td>
<td>3.88cd</td>
<td>0.45de</td>
<td>15.06d</td>
<td>0.089de</td>
<td>51.56b</td>
<td>13.00def</td>
<td>0.14bc</td>
<td>91.29abcd</td>
</tr>
<tr>
<td>AlfaV x Yellow</td>
<td>4.5a</td>
<td>0.36g</td>
<td>16.97cd</td>
<td>0.102cde</td>
<td>32.97c</td>
<td>10.44fg</td>
<td>0.13bcd</td>
<td>114.36ab</td>
</tr>
<tr>
<td>AlfaV x Pearl</td>
<td>4.08bc</td>
<td>0.43ef</td>
<td>20.84b</td>
<td>0.146ab</td>
<td>45.52b</td>
<td>13.98cde</td>
<td>0.15bc</td>
<td>108.58abc</td>
</tr>
<tr>
<td>AlfaV x Black</td>
<td>4.60a</td>
<td>0.44def</td>
<td>22.40b</td>
<td>0.150a</td>
<td>55.53a</td>
<td>20.66b</td>
<td>0.20a</td>
<td>90.71bcd</td>
</tr>
<tr>
<td>SCX 248 x Red</td>
<td>3.89cd</td>
<td>0.36g</td>
<td>17.77c</td>
<td>0.122bc</td>
<td>44.64b</td>
<td>16.69c</td>
<td>0.14bc</td>
<td>91.62abcd</td>
</tr>
<tr>
<td>SCX 248 x</td>
<td>3.66de</td>
<td>0.57bc</td>
<td>16.59cd</td>
<td>0.080e</td>
<td>36.83c</td>
<td>11.39ef</td>
<td>0.10de</td>
<td>116.35a</td>
</tr>
<tr>
<td>SCX 248 x Pearl</td>
<td>3.59e</td>
<td>0.37g</td>
<td>16.38cd</td>
<td>0.106cde</td>
<td>53.32a</td>
<td>6.19h</td>
<td>0.10ab</td>
<td>85.20cde</td>
</tr>
<tr>
<td>SCX 248 x Black</td>
<td>3.80de</td>
<td>0.48d</td>
<td>17.20c</td>
<td>0.102cde</td>
<td>53.32a</td>
<td>7.23gh</td>
<td>0.08e</td>
<td>84.10cde</td>
</tr>
<tr>
<td>Irit x Red</td>
<td>4.2b</td>
<td>0.63a</td>
<td>20.54b</td>
<td>0.109cd</td>
<td>44.2b</td>
<td>13.4def</td>
<td>0.12cd</td>
<td>83.0de</td>
</tr>
<tr>
<td>Irit x Yellow</td>
<td>3.78de</td>
<td>0.55c</td>
<td>20.81b</td>
<td>0.093de</td>
<td>37.93c</td>
<td>16.93c</td>
<td>0.13bcd</td>
<td>52.72f</td>
</tr>
<tr>
<td>Irit x Pearl</td>
<td>4.11bc</td>
<td>0.58abc</td>
<td>22.3b</td>
<td>0.11cdc</td>
<td>41.88b</td>
<td>15.15cd</td>
<td>0.16b</td>
<td>61.51ef</td>
</tr>
<tr>
<td>Irit x Black</td>
<td>4.55a</td>
<td>0.61ab</td>
<td>26.34a</td>
<td>0.112cd</td>
<td>54.75a</td>
<td>25.05a</td>
<td>0.22a</td>
<td>57.25f</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the column are not significantly different at 0.001 level of probability.
A cultivar x net interaction was observed whereby, fruits of cvs. AlfaV under yellow (35.8 °C) and black nets (30.27 °C) and Irit under black nets (30.27 °C) had significantly higher SSC values while SCX 248 under pearl nets (42.1 °C) had significantly lower SSC. It has been shown that some cultivars have the genetic background to have high SSC and that solar radiation and temperature can affect SSC levels. Temperature (~30 °C) has previously been shown to influence SSC content of the fruits (Walker & Ho, 1977:825). High temperatures (40 °C) could lead to sink competition as reported in cherry tomatoes, promoting fruit evapotranspiration and higher sugar levels. However the sugar concentration is frequently reduced due to the sink competition caused by the increased respiration during higher temperatures (Gautier et al., 2005:1241).

Among the cultivars, cv. Irit showed significantly higher TA than the other two cultivars and the black nets gave higher TA in all fruits, which shows that the cooler temperatures (under black nets) favoured the accumulation of acids than the higher temperatures (yellow nets) (Aldrich et al., 2010:2548). A moderate correlation was noted between temperature and TA ($r=-0.62$). Different observations were reported regarding the shading effect and titratable acidity in tomato fruit. According to El-Gizaway et al. (1992:349), increasing shading levels from 35% to 63% increased the titratable acidity in tomato fruit while Riga et al. (2008:158) reported that shading tomato plants by 50% did not affect the concentration of titratable acidity. However, significant cultivar x net interaction was observed as shown in Table 4.1 B. The TA was significantly higher in cv. Irit produced under red net whereas AlfaV and SCX 248 under yellow and red nets respectively showed significantly lower TA.
According to Davis and Hobson (1981:205) the SSC can be considered as the easiest, cheapest and quickest measure linked to the sugar content especially during commercial marketing and the authors suggested that it could be used as the primary criteria for ranking the fruit quality of commercial varieties.

The bioactive compounds; total phenols, ascorbic acid, lycopene, β-carotene and flavonoids responsible for the antioxidant properties need to be evaluated in order to determine the tomato fruit quality (Raffo et al., 2006:11; Rosales et al., 2006:1545). In our study the total phenolic compounds were significantly higher in fruits harvested under the black nets. The cultivar difference was not significant and cultivar x net interaction was not observed with respect to total phenolic compounds. The accumulation of total phenolic compounds in tomato fruits was moderately correlated to the PAR \( r=0.56, p<0.01 \) (Table 4.3). The total phenolic compounds in tomatoes were observed to decrease with increasing temperatures during the production period. Reduction of total phenolic compounds in tomatoes during cooler period was reported by Aldrich et al. (2010:2548).

The lycopene content was significantly higher in tomatoes grown under the black nets whereas the tomatoes grown under photo-selective nets had lower lycopene content (Table 4.1 A). The observed variation was due to air temperature and light quality with lycopene content in tomatoes affected by higher temperatures \( r= -0.90, p<0.0001 \) and PAR \( r=0.66, p<0.01 \) (Table 4.3). However, excessive sunlight was reported to inhibit
the synthesis of lycopene (Brandt et al., 2006:568). According to Helyes et al. (2007:927), fruit surface temperature was a more accurate predictor of fruit lycopene content than air temperature. In our study the pearl net had higher air temperature within the net with lower PAR while the black nets had lower air temperature and higher PAR, due to the knitting patterns of the nets and could have increased the surface fruit temperature within the pearl net and affected the lycopene content in SCX 248 tomatoes (Table 4.1 B). On the other hand tomatoes grown under red net showed higher lycopene contents than tomatoes grown under the pearl net (Table 4.1 A). Similar observations were reported by Lopez et al. (2007:121) and Ilić et al. (2012:90). The observed differences between the lycopene content in tomatoes under the red and pearl nets could be due to the stimulation of lycopene accumulation in tomatoes under the red net due to the slight variation in red light as explained by Ilić et al. (2012:90) that lycopene synthesis is mediated by phytochromes. Among all the cultivars, Irit showed significantly higher lycopene content (Table 4.1 A). The lycopene contents of our tomatoes were lower than those reported for newly bred tomatoes reported by Gupta et al. (2011:167) and cv. Vedeta (Ilić et al., 2012:90); the values are however, higher than that reported for cherry (Rosale et al., 2006:1545) and are within the range reported for Savoura tomatoes (Bui et al., 2010:830). Cultivar x net interaction was significant (p<0.001) for AlfaV and Irit tomatoes produced under the black net and SCX 248 under the red net which had significantly (p<0.001) higher lycopene content (Table 4.1 B). It is interesting to note that the SCX 248 tomatoes produced under the black and pearl nets produced significantly (p<0.001) lower lycopene content (Table 4.1 B). This confirms the
influence of higher temperature (pearl net) and PAR (black net) on lycopene biosynthesis.

The $\beta$-carotene content in tomatoes grown under the black net was significantly (p<0.001) higher than for the tomatoes obtained from the other nets (Table 4.1 A). $\beta$-carotene biosynthesis in tomato is influenced by the temperature ($r = -0.73$, p<0.0001) and PAR ($r = 0.72$, p<0.01). Temperatures over 30-35 °C and strong solar radiation was reported to inhibit lycopene biosynthesis and stimulate the oxidation of lycopene to $\beta$-carotene (Dumas et al., 2003:369). According to Gautier et al. (2005:1241), $\beta$-carotene degradation increases from 35 to 40 °C. In cherry tomatoes high solar radiation and temperature (36 °C) was shown to reduce the lycopene and $\beta$-carotene contents in the exocarp (Rosales et al., 2006:1545). However, according to our investigations; cvs. AlfaV and Irit had higher $\beta$-carotene content than cv. SCX 248 (Table 4.1 A). Significant cultivar versus net interaction was found. Cultivars AlfaV and Irit under the black nets and SCX 248 under red net produced tomatoes with significantly (p<0.001) higher $\beta$-carotene content whereas cv. SCX 248 tomatoes grown under pearl, black and yellow nets had significantly lower $\beta$-carotene content (Table 4.1 A). However, significantly lower $\beta$-carotene content in SCX 248 tomatoes under the black nets might have been due to faster degradation. Based on these observations, it appears that the red nets can improve lycopene and $\beta$-carotene contents in tomato cultivars (genotypes) that are genetically predisposed to produce lower lycopene and $\beta$-carotene contents (e.g. SCX 248).
Flavonoids are beneficial in many ways and act as antioxidants, antiproliferative or antibacterial agents (Harborne & Williams, 2000:481). Flavonoid content (mg of rutin equivalents 100 g\(^{-1}\) FW) was significantly \(p<0.001\) higher in cv. AlfaV and lower in Irit (Table 4.1 A). The PAR was negatively correlated to the flavonoid content in our investigation \(r=-0.55, p<0.01\) (Table 4.3) and according to the reports of Cen and Bornman (1990:1481) the PAR could promote flavonoid synthesis. Significant cultivar x net interaction was observed in our study with respect to flavonoid content. Cultivars AlfaV and SCX 248 under yellow nets had significantly \(p<0.001\) higher flavonoid content (Table 4.1 B). In cherry tomatoes a temperature increase from 27 to 32 °C was reported to increase the rutin and caffeic acid (Gautier \textit{et al.}, 2008:1241). According to our results during the fruit production period the average temperature and PAR under the yellow and red nets were around 35 °C and 851.81 \(\mu\text{mol m}^{-2}\text{s}^{-1}\) respectively and could have stimulated the biosynthesis of flavonoids. On the other hand, cv. Irit under black and yellow nets had lower flavonoid content (Table 4.1 B). However, the red net helped to improve flavonoid content in cv. Irit which directly shows the influence of PAR \(744.13 \mu\text{mol m}^{-2}\text{s}^{-1}\) on flavonoid content (Table 4.1 B). SCX 248 had relatively low flavonoid content under the black and pearl nets (Table 4.1 B). Our findings with respect to different cultivars and shade nets show that the influence of PAR and light quality influences flavonoid content.

Ascorbic acid content was shown to increase in the presence of higher light intensity during the production period in fresh produce (Lee & Kader, 2000:207) and this explains the higher ascorbic acid content obtained in tomatoes produced under the black nets.
Also, a strong correlation was detected between the ascorbic content and PAR during our study \((r=0.808, \ p<0.0001)\) (Table 4.3). Cultivars Irit and SCX 248 showed significantly \((p<0.001)\) higher and lower ascorbic content respectively (Table 4.1 A). Cultivar versus net interaction was detected in our study. Cultivar Irit under black net produced significantly \((p<0.001)\) higher ascorbic acid content while cv. Irit under red net produced significantly \((p<0.001)\) lower ascorbic acid content (Table 4.1 A).

Our investigation showed that total phenols, \(\beta\)-carotene and ascorbic acid acted as antioxidants and moderately correlated to the antioxidant scavenging activity. Antioxidant scavenging activity was higher in tomatoes produced under the black and pearl nets (Table 4.1 A). Among the cultivars the antioxidant property was higher in AlfaV. Cultivar versus net interaction was evident from our study. AlfaV grown under black nets produced significantly \((p<0.001)\) higher antioxidant activity while SCX 248 under yellow net gave significantly \((p<0.001)\) lower antioxidant activity (Table 4.1 B).

Table 4.2 shows the mean values of CIE-Lab colour parameters of tomato fruits. Black and yellow nets favoured the increase of colour coordinate \(a^*\) indicating more reddish fruits whereas pearl and red nets had significantly lower colour coordinate \(a^*\) and slightly less reddish in colour. The \(a^*\) value showed a moderate correlation with the PAR \((r=0.54, \ p<0.001)\). Higher temperature was reported to affect colour development in tomatoes \((r=0.56, \ p<0.001)\) (López Camelo & Gómez, 2004:534) and fruit remained yellow in colour as a result of inhibition of lycopene synthesis and the accumulation of
yellow/orange carotenoids (Tijskens & Evelo, 1994:85). On the other hand cvs. Irit and AlfaV showed reddish fruits than cv. SCX 248. Significant cultivar x net interaction was found with Irit and AlfaV cultivars under black net producing more reddish fruit whereas yellow net gave the highest redness in SCX 248 tomato fruit. When red colour was tended to increase, a decrease in $L^*$ value was obtained in tomatoes by Messina et al. (2012:1). On this basis tomatoes grown under black, yellow and red nets showed higher $L^*$ values and were low in $a^*$ indicating less intense red colour ($r= -0.45$, $p<0.1$), although, fruits were harvested at pink stage. The intensity of red colour pigment in tomato is determined by relative composition of lycopene and chlorophyll while yellowness depends on the $\beta$-carotene content. The intensity of the yellow colour was shown by higher $b^*$. There was a highly significant correlation between $a^*$ and lycopene content ($r=0.72$, $p<0.01$). These findings suggest that light quality and temperature influence colour pigment synthesis in tomato. AlfaV and Irit tomatoes grown under black nets had higher $a^*$ and lower $b^*$ coordinate values and showed intense red colour (Table 4.2).
**Table 4.2:** Effect of cultivar and shade net on physical properties (colour) of tomato fruits

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Shading Color</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlfaV</td>
<td>Red</td>
<td>41.7 ± 2.5cd</td>
<td>19.3 ± 4.7d</td>
<td>22.6 ± 2.8de</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>42.6 ± 1.5de</td>
<td>23.4 ± 3.7gh</td>
<td>23.3 ± 2.6e</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>41.6 ± 2.3c</td>
<td>21.7 ± 3.1ef</td>
<td>23.5 ± 3.3e</td>
</tr>
<tr>
<td></td>
<td>Pearl</td>
<td>43.0 ± 1.4ef</td>
<td>21.3 ± 2.1ef</td>
<td>22.1 ± 2.4cde</td>
</tr>
<tr>
<td>Irit</td>
<td>Red</td>
<td>41.5 ± 2.3c</td>
<td>20.3 ± 2.6de</td>
<td>17.1 ± 2.6a</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>39.7 ± 2.8b</td>
<td>23.8 ± 3.7h</td>
<td>22.2 ± 3.7cde</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>40.5 ± 2.6b</td>
<td>22.0 ± 3.6fg</td>
<td>20.8 ± 5.4c</td>
</tr>
<tr>
<td></td>
<td>Pearl</td>
<td>41.8 ± 1.3cd</td>
<td>20.2 ± 4.3de</td>
<td>19.1 ± 2.4b</td>
</tr>
<tr>
<td>SCX 248</td>
<td>Red</td>
<td>38.7 ± 2.8a</td>
<td>13.4 ± 3.1c</td>
<td>27.7 ± 4.2h</td>
</tr>
<tr>
<td></td>
<td>Black</td>
<td>44.5 ± 1.7g</td>
<td>11.1 ± 4.8b</td>
<td>21.6 ± 2.3cd</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>43.6 ± 2.2f</td>
<td>14.1 ± 5.5c</td>
<td>23.7 ± 5.4g</td>
</tr>
<tr>
<td></td>
<td>Pearl</td>
<td>48.2 ± 1.9h</td>
<td>9.0 ± 3.0a</td>
<td>17.9 ± 2.4a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the column are not significantly different at 5% level of probability

### 4.4 CORRELATION ANALYSIS

When all three cultivars were considered over the 2011 and 2012 seasons and growing conditions (photo-selective nets and control black net). The SSC, colour coordinate $a^*$, lycopene content, $\beta$-carotene and ascorbic acid were positively correlated with the PAR while the PAR was negatively correlated to the firmness at harvest. Air temperature had a negative correlation with SSC, TA, $\beta$-carotene, lycopene and ascorbic acid. Relative humidity was positively correlated to SSC, TA, $\beta$-carotene, lycopene and negatively correlated to fruit firmness (Table 4.3).
Table 4.3: Pearson’s correlation coefficients between PAR or microclimate conditions (AT or RH) and the fruit quality parameters or bioactive compounds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Air Temperature</th>
<th>PAR</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.63**</td>
<td>0.645**</td>
<td>0.49 ns</td>
</tr>
<tr>
<td>b</td>
<td>-0.69**</td>
<td>0.234 ns</td>
<td>0.64**</td>
</tr>
<tr>
<td>Soluble solids</td>
<td>-0.835**</td>
<td>0.812**</td>
<td>0.730**</td>
</tr>
<tr>
<td>Titratable acidity</td>
<td>-0.623**</td>
<td>0.407 ns</td>
<td>0.589**</td>
</tr>
<tr>
<td>Firmness</td>
<td>0.783**</td>
<td>-0.726**</td>
<td>-0.762**</td>
</tr>
<tr>
<td>Fruit weight</td>
<td>0.152 ns</td>
<td>0.325 ns</td>
<td>-0.388 ns</td>
</tr>
<tr>
<td>β-Carotene</td>
<td>-0.73***</td>
<td>0.727**</td>
<td>0.53*</td>
</tr>
<tr>
<td>Lycopene</td>
<td>-0.893***</td>
<td>0.660**</td>
<td>0.703**</td>
</tr>
<tr>
<td>Total phenols</td>
<td>-0.42 ns</td>
<td>0.56**</td>
<td>0.188 ns</td>
</tr>
<tr>
<td>Flavonoids</td>
<td>0.21 ns</td>
<td>-0.556**</td>
<td>-0.38 ns</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>-0.549*</td>
<td>0.808***</td>
<td>0.256 ns</td>
</tr>
</tbody>
</table>

Correlation results include means from three cultivars, grown under four different shade nettings during 2011 and 2012 growing season. n.s, not significant; asterisks indicate significance at *p<0.05; **p<0.01; ***p<0.0001

4.5 PCA ANALYSIS

PCA was carried out to investigate the data structure, in order to establish a cultivar and net classification based on the obtained data including the physicochemical properties and bioactive compounds. With respect to Eigen values >1, two principal components were obtained with their factor loading shown in Figure 4.1. Eighty seven percent of the original variance in the data set of fruit properties (PC1 21.07% and PC2 43.93%) was explained by the first two principal components. The two PCs explained 65% of the x-variables selecting thirteen parameters, including total phenols, flavonoids, β-carotene, lycopene, ascorbic acid, antioxidant activity, L*, a*, b*, fruit mass, firmness, SSC and TA. Total phenols, β-carotene, lycopene, ascorbic acid, antioxidant activity L*, a* were
mainly accounted for with PC1 while fruit mass, firmness, $b^*$ and flavonoids were mainly accounted for with PC2 as shown in Figure 4.1.

**Figure 4.1**: Principal Component Analysis (PCA) for physicochemical properties and bioactive compounds.
Results of the PCA analysis are shown in Figure 4.1 and 4.2. As illustrated in Figure 4.1, bioactive compounds such as β-carotene ($r=0.91$), lycopene ($r=0.90$), ascorbic acid content ($r=0.82$) antioxidant activity ($r=0.54$) and quality parameters: $a^*$ ($r=0.92$), $L^*$, SSC ($r=0.86$), on PC1 and the quality parameters: firmness ($r=0.80$) and fruit mass ($r=0.65$), $b^*$, TA ($r=-0.72$) and bioactive compounds: flavonoids ($r=0.81$) and total phenols ($r=-0.36$), on PC2 helped to classify the cultivars and nets in Figure 4.2. Based on this analysis it is evident that cv. AlfaV fruits produced under black nets were lower in mass and less firm with higher concentration of bioactive compounds, higher in SSC,
less acidic, intense in red colour. However, cv. AlfaV fruits under pearl nets showed
greater fruit mass, firmness and were moderately rich in bioactive compounds. SCX 248
fruits under red nets were moderate in size, firmness, and bioactive compounds in
comparison to the other nets. Cultivar Irit under all net types was small, less firm, had
low SSC and more acidic while black nets enabled to increase bioactive compounds.
Overall, the total yield related to marketable fruits was higher in AlfaV produced under
pearl net. Marketable fruits assessments included fruits that were free from pest attack
and diseases.
CHAPTER FIVE

5 GENERAL CONCLUSIONS

The selection of a tomato variety that can yield a high number of fruits with better quality as well as a colour net that can provide conducive growing conditions can both benefit growers that are currently experiencing lower yields under protected cultivation and in open fields. Pearl net shading can be recommended to improve marketable fruit yields of cv. AlfaV, while red net shading can be recommended for cvs SCX 248 and Irit. Photo-selective netting in general, however, did not show any influence on the incidences of disease or pest infestation during the growing season. However, plant morphological parameters, fruit trusses, and numbers of fruit per plant were influenced by cultivar versus photo-selective net interactions. Flowering, fruit set and fruit production were also enhanced in cvs AlfaV and SCX 248 produced under red nets. Cultivar AlfaV exhibited a greater fruit mass when produced under shade nets, which offers great potential for satisfying consumer demand.

The data presented and discussed in chapter four provide useful information on the environmental changes related to colour shade nets on fruit quality parameters and bioactive compounds in tomatoes. Cultivar differences were shown to affect bioactive compounds, antioxidant activity and fruit quality in tomatoes. Thus, the proper selection of tomato cultivars that are nutritionally superior can benefit growers and retailers who cater to health conscious consumers who in turn value fruit size (mass), firmness,
colour, as well as health benefits being the most important parameters. Based on the current study, cv. AlfaV was the best cultivar with respect to fruit quality and bioactive compounds, followed by cv. Irit. Photo-selective pearl nets can be recommended to improve the overall fruit quality, fruit mass, firmness and bioactive components in cv. AlfaV. On the other hand, photo-selective red nets can be recommended for cv. Irit with respect to quality and bioactive compounds and can furthermore be implemented in protected cultivation.
REFERENCES


Mediterranean conditions, as affected by air vapour pressure deficit and plant fruit load. *Annals of Botany*, 85:741-750.


