Scientia Horticulturae 161 (2013) 340–349

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Influence of photo-selective netting on fruit quality parameters and bioactive compounds in selected tomato cultivars

Peter Phushdi Tinyane, Dharini Sivakumar*, Puffy Soundy

Department of Crop Sciences, Tshwane University of Technology, Pretoria 0001, South Africa

ARTICLE INFO

Article history:
Received 25 January 2013
Received in revised form 11 June 2013
Accepted 17 June 2013

Keywords:
Antioxidant activity
Flavonoids
Lycopene
Odour active volatile compounds
Photo-selective netting
Solanum lycopersicum

ABSTRACT

Tomato fruit quality for fresh consumption is determined by size, colour, firmness, flavour, aroma and nutritional properties. Choice of tomato cultivar is important in terms of fruit quality and bioactive compounds. The aim of this study is 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, fruit mass, CIE-Lab colour parameters (L^*, a^*, b^*] bioactive compounds (ascorbic acid, lycopene, β-carotene, total phenols) and total antioxidant activity in three tomato cultivars (AlfaV, Irit and SCX 248) at harvest. Principle component analysis illustrated cv. AlfaV fruits under black nets were lower in mass, less firm, higher in bioactive compounds and soluble soild concentration (SSC) but lower in titratable acidity (TA) and intense in red colour. However, under pearl nets cv. AlfaV showed higher fruit mass, firmness and moderately higher bioactive compounds. Cultivar 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 small, less firm, low 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. Cultivar AlfaV grown under the red net showed higher number of odour active aroma compounds in fruit while yellow nets significantly affected the synthesis of odour active aroma compounds. Pearl and red photo-selective nets improved the overall fruit quality; fruit mass, fruit firmness and bioactive components in cv. AlfaV and cv. SCX 248 respectively and can be further implemented within protected cultivation practices.

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 et al., 1977; Khachik et al., 2002; Vinson et al., 1998). 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 recommended intake (DRI) for vitamin A and C (Betancourt et al., 1977). In ripened tomatoes, rutin [quercetin 3-*O*-rutinoside; quercetin3-(6-rhamnosylglucoside)] has been reported to be the major flavonoid compound (Davies and Hobson, 1981; Slimestad and Verheul, 2009). Lycopene, carotenoids and flavonoids have been known to show protective effects against cancers and cardiovascular diseases (Rao and Agarwal, 2000; Levy and Sharoni, 2004; Andersen and Markham, 2006). Lycopene, carotenoids and flavonoids act as a strong antioxidant that protects cells from reactive oxygen species (Spencer et al., 2005).

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) and aroma volatiles. The odour active volatiles (3-methylbutanal, (Z)-3-hexenal, hexanal, 1-octen-3-one, methional, 1-penten-3-one, 3-methylbutanal, trans-2-heptenal, 6-methyl-5-hepten-2-one, 2-isobutylthiazole, phenyl acetaldehyde, methylsalicylate, 2-phenylethanol, geranyacetone, and β-ionone, furaneol, linaool, methional, citral, 2,4 decadienal) contribute to fresh tomato aroma (Tandon et al., 2001).

Antioxidants and minerals were shown to vary according to the cultivar and crop management practices (Dorais, 2007). The health promoting compounds in tomatoes are also influenced by the maturity stage at harvest (Helyes and Lugasi, 2006). Moreover, interaction effects were reported with respect to the bioactive

* Corresponding author. Tel.: +27 12 382 5303; fax: +27 12 382 5869.
E-mail addresses: dharinisivakumar@yahoo.co.uk, SivakumarD@tut.ac.za (D. Sivakumar).

0304-4238/$ – see front matter
http://dx.doi.org/10.1016/j.scienta.2013.06.024

compounds and cultivars, environmental factors (light and temperature) and crop management practices (Dorais, 2007). The use of shading nets for cultivation of agricultural crops is becoming a popular non-chemical approach and aims to provide physical protection from weather conditions (excessive solar radiation and temperature), or environmental hazards (wind and hail) or birds and insects transmitting viral diseases, together with promoting desired physiological responses linked to light quality. The photo-selective nettings contain spectral filters with differential light scattering properties and altered proportions of red/far-red waveband (R/FR) ratio (Fletcher et al., 2005). 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, 2008; Rajapakse and Shahak, 2007). Furthermore, it is also reported that the truss appearance and flowering rate are affected by temperature (Zoltán and Helyes, 2004).

Tomato production under photo selective shade net has shown to increase marketable yield and to protect the fruit from physiological disorders such as sunscald injury (El-Gizawy et al., 1992; El-Aidy and El-Afry, 1983), blossom end rot and cracked skin (Lorenzo et al., 2003). 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).

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). Brandt et al. (2003) 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° and 25 °C (Dumas et al., 2003; Lumpkin, 2005). Higher temperatures were reported to reduce the vitamin C content in fruit and vegetable crops (McKeon et al., 2006). Also, growing tomato without shading under slight water stress and strong light intensity predicated increased sugar content and antioxidant compounds. Bertin et al. (2000) reported higher sugar content in tomato fruit 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. Recently, the aroma volatiles in tomatoes such as (Z)-3-hexenal, 3-methylbutanol and 6-methyl-5-hepten-2-one were reported to increase in tomato fruits of shaded plants (Krumbein and Schwarz, 2012).

Effect of photo-selective netting on lycopene content was reported by Gomez et al. (2001) and Lopez et al. (2007). Ilić et al. (2012) 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).

However, little information is available on the influence of photo-selective shade netting on overall fruit quality parameters, bioactive compounds and odour active aroma 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 our study was to investigate the effect of different colour photo- selective netting in comparison to the commercially used black net on (1) overall quality parameters (SSC, TA, fruit mass and firmness), (2) bioactive compounds (ascorbic acid, total phenols, flavonoid, lycopene, β-carotene contents) and antioxidant scavenging activity at harvest in three commercial tomato cultivars grown in South Africa and (3) to determine the influence of photo-selective netting on odour active aroma compounds of tomato cv. AlfaV.

Table 1
Nutrient composition of fertilizer applied during tomato production.

Period	Composition (%, w/v)
Transplant to 1st flower truss	0.05 (1.39 kg hydroponics ® and, 1.11 kg $Ca(NO_3)_2$)
1st flower truss to 3rd flower truss	0.08 (2.4 kg hydroponics ® and, 1.6 kg $Ca(NO_3)_2$)
3rd flower truss to end	0.12 (3.125 kg hydroponics ® and, 2.095 kg $Ca(NO_3)_2$, 0.78 kg KNO_3)

2. Materials and methods

Tomato cvs. AlfaV, Irit and SCX 248 were grown during 2011 and 2012 seasons in a tunnel (5 m high), covered with photo-selective shade nets (pearl yellow and red) and a black (control) net. The study was conducted at Tshwane University of Technology, Experimental Farm, Bon-Accord, Pretoria North (latitude: 25°37′S, longitude: 28°12′E, altitude 1173 m). The colour-nets (ChromatiNet$^{(TM)}$) were manufactured by Polysack Plastic Industries in Israel, placed as permanent structures. A completely randomized block design was used, with three replicate nets assigned to each of the four treatments (red, pearl, yellow and black control net). Black net is used commercially in South Africa for production of fruits and vegetable. Each treatment and block consisted of eight rows of 36 plants. The three cultivars were replicated three times in a Latin square layout within each net.

2.1. Planting materials

Three indeterminate tomato cvs. AlfaV, Irit and SCX 248, were used in this study. The seedlings were obtained from Seedcor (Pty, Ltd) South Africa. The plants were grown following the technique usually implemented by the local producers. The seedlings were transplanted into 5 L black polyethylene bags using coir-sand as a growing medium (plant density was 2.88 plants m^{-2}). All plants were irrigated using drip irrigation. The nutrient solutions for irrigation were mixed in a 5000 L tank as presented in Table 1. The hygroponic® fertilizer was supplied by Hygrotech Pty. Ltd., Pretoria South Africa.

2.2. Coloured net characteristics

In order to test the effect of photo-selective nets (ChromatiNet$^{(TM)}$, Israel) four different shading nets were used: the photo-selective nets included 'coloured-ColorNets' (red, yellow) as well as 'neutral-ColourNets' (pearl) and the traditional black net that is used commercially for tomato production (used as a control 25%). The shading intensity of red, yellow and pearl nets were 40%. The nets are unique in that they both modify the non-visible spectrum and enhance light scattering. The photo-selective nets are based on the incorporation of various chromatic additives, light dispersive and reflective elements into the netting materials during manufacturing. The shading nets were mounted on a steel structure (12 m × 12 m) about 5 m in height over the plants and the dimension of the tunnels.

2.3. Light interception by nets and microclimate measurements

Photosynthetically active radiation (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 done at 12.00 h on clear days. The relative shading 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., 2006). Air temperature and relative humidity were also monitored and the data collected by Tinytag T/RH data loggers (Gemini data loggers Ltd., UK). Data loggers were placed above the tree canopy protected from direct solar radiation, rain or sprays.

2.4. Fruit quality analysis at harvest

Tomato fruits from the three cultivars were harvested at mature pink (45–53 h°) stage 26 weeks after planting from the Experimental Farm. Harvesting was carried out manually in the early morning. Total marketable yield was (kg m^{-2}) determined based on fruits that are free from diseases or disorders or injuries or deformation and uniform size and colour. Tomatoes (n = 85 per cultivar per replicate of photo-selective netting) were, weighed and the average fresh weight was expressed in g per cultivar per photo-selective net. Thereafter, the tomatoes, were transported to the Department of Crop Sciences laboratory Tshwane University of Technology, at 25 °C within 30 min for evaluation of fruit mass, fruit colour, firmness, soluble sold content, titratable acidity, ascorbic acid, lycopene, β-carotene, total phenol, flavonoid contents and antioxidant scavenging activity.

2.5. Fruit mass, colour, firmness, soluble soluble solids (SSC) content, titratable acidity (TA)

Marketable yield per 144 m^2 was determined and tomatoes were remained unmarketable when the fruits are infected with diseases or pest damage or physiological disorders. Fresh fruit mass (g) was determined after harvest. 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 homogenized 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 and Kubota, 2006). 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 and Majumder, 2003).

2.6. 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) using the following equations:

$$\text{Lycopene}(\mu\text{g g FW}^{-1}) = -0.0458A663 + 0.204A645 + 0.372A505 - 0.0806A453$$

$$\beta\text{-carotene}(\text{mg g FW}^{-1}) = 0.216A663 - 1.220A645 + 0.304A505 - 0.452A453$$

The A663, A645, A505 and A453 are the absorbance at 663, 645, 505 and 453 nm, respectively. According to Nagata and Yamashita these equations enable the simultaneous determination of lycopene and β-carotene in the presence of chlorophylls. The assays were carried out in triplicate.

2.7. Total phenol and flavonoid contents

Total phenolic content was determined using the modified Folin–Ciocalteau method (Singleton et al., 1999; Luthria et al., 2006). Tomato sample (0.2 g) was homogenized 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_2CO_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 homogenized 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) 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% $NaNO_2$ was added. After 5 min, 15 μL of 10% $AlCl_3$ 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.

2.8. 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 homogenized 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). About 210 μL aliquots of 0.04 nM 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

Table 2
Temperature, RH and Photosynthetic active radiation measurements under different photo-selective netting and the control net during cultivation.

Shade type	Air temperature (°C)			RH (%)			PAR (μmol m^{-2} s^{-1})		
	Mean	±SD	CV (%)	Mean	±SD	CV (%)	Mean	±SD	CV (%)
Pearl	42.18	1.78	4.23	25.41	4.86	19.14	827.56	69.89	8.45
Yellow	35.88	2.33	6.48	35.12	11.73	33.40	851.81	52.75	6.19
Red	35.43	2.25	6.34	40.00	12.14	30.35	744.13	69.05	9.28
Black (control)	30.27	1.52	5.02	60.78	16.22	26.68	1339.33	86.09	6.43
LSD (P < 0.05)	5.16			9.71			107.69		

(sample required to reduce the absorbance of the radical by 50%) in mg of gallic acid equivalent per gram of fruit.

2.9. Aroma volatile analysis

A set of twenty fruit per photo-selective net (red or pearl or yellow) or black net replicate were harvested at pink stage and tomato puree was obtained from individual fruit using a commercial hand blender with 10 mL saturated $CaCl_2$ solution for 30 s and held at 40 °C in a water bath. Thereafter, the samples were gently mixed and equilibrated for 5 min at 40 °C. Manual head-space solid-phase microextractions (HS-SPME) were carried out using a SPME fibre holder containing a PDMS/CAR fibre (Supelco Inc., Bellefonte, PA, USA). The SPME fibre was exposed to the sample headspace for 55 min at 40 °C. The volatile compounds were desorbed by inserting the fibre into the glass-lined splitless injector port GC for 5 min at 200° C and the volatiles were separated using a capillary column (BP5, 30 m × 0.25 mm i.d., 0.25 m film thickness) (J & W Scientific, Folscom, CA, USA). Helium was used as a carrier gas at a constant flow rate of 1 mL min^{-1}. The column temperature programme was carried out according to Marković et al. (2007) and initially set at 40 °C for 5 min, thereafter it was raised to 150 °C at a rate of 5 °C min^{-1}. This was followed by a further increase up to 280 °C at 10 °C min^{-1} where it was held for 3 min. Separation and identification of the aroma volatiles were carried out on an Agilent 6890 N gas chromatograph (GC) (Agilent) using N_2 as the carrier gas at a flow rate of 5 mL min^{-1}. A split/splitless injector was used (ratio 1:5) and maintained at 200 °C. The detector was kept at 250 °C. The GC oven was programmed from 40 °C (3 min hold) to 190 °C at a rate of 5 °C min^{-1}, where it was held for 7 min. The ionization of the samples was achieved at 70 eV using the scan mode. The mass range studied was m/z 30–250. Helium was used as the carrier gas at a flow rate of 5 mL min^{-1}. The identities of the volatiles were confirmed by comparing the collected mass spectra with those of authenticated chemical standards and to reference spectra in a mass spectral library (National Institute for Standard Technology, and Technology (NIST) mass spectral library, Version 2.0). Identification was also confirmed by comparing the mass spectra and retention time with standards [2,6-dimethyl-5-hepten-2-ol (Goren et al., 2010) and methyl salicylate, 2-isobutylthiazole E-2-hexenal was also obtained, Sigma Aldrich, Fluka Johannesburg, South Africa]. The relative peak areas of the total ion chromatogram were normalized with the peak area of the internal standard. The observations were reported as normalized amount of aroma volatiles (%) = peak area of an aroma volatile/Total peak area of aroma volatiles (Zhang et al., 2007).

2.10. 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 with four harvests. Means of significant source effects were compared using Fischer's least significant difference (LSD) procedures were applied at a 5% significance. Pearson's correlation coefficients were calculated to determine the strength of the linear relationships between the PAR or air temperature and the 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 forWindows, version 6.0 (Statsoft Inc., Tulsa, UK) was used.

3. Results and discussion

3.1. Photosynthetic radiation and microclimate under the shade nets

The PAR was higher (average 1564.356 μmol m^{-2} s^{-1}) in the open field and Table 2 shows the PAR under different photo-selective nets. The PAR was higher under the black nets (control), and lower under the red nets. The photo-selective nets were provided by the Polysac Plastics Industries (Pty. Ltd.), Israel to provide 40% shading PAR. However, the average shading effect throughout production period varied from 42 to 48%.

The shading effects of photo-selective nettings were higher than the black control net. The black plastic threads are opaque and the light entering through the holes of 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. (2006) when a major fraction of the sunlight actually passes through the plastic threads and, it is selectively filtered. It can be concluded that the shading effect in red net can be due to densely knitted pattern of the threads. The average air temperature and the RH during 2010–2011growing season were significantly higher and lower respectively under the photo-selective nettings than the black nets (control). This could be due to the more densely knitted pattern of the threads in the photo-selective netting which negatively affected the ventilation. Significant correlations were also observed between air temperature and RH (r = −0.787, P < 0.001) as well as PAR (r = 0.650, P < 0.001). On the other hand, pearl net provided the most stable microclimatic conditions throughout the study as it had the least coefficient of variation for air temperature and RH while yellow net was noted to have the least ability to stabilize the fluctuation of the environmental factors measured.

3.2. Fruit quality parameters and bioactive compounds

Table 3 shows the physicochemical properties and bioactive compounds of the tomato fruits grown under different photo-selective nets. The SSC ranged between 3.59 and 4.40%. Among the three cultivars, cv. AlvfaV resulted in the highest SSC followed by Irit and cv. SCX 248 resulted in the lowest SSC. These values are similar with those reported by Lumpkin (2005), Gupta et al. (2011)

Table 3
Effect photo-selective netting on the physicochemical properties and bioactive compounds of three tomato cultivars.

Type of nets	SSC[a] (%)	TA[b] (%)	Ascorbic acid (mg 100 g FW^{-1})	Total antioxidant activity (mg GAE g^{-1})	Total phenol content (mg GAE 100 g FW^{-1})	Lycopene (μg g FW^{-1})	β-Carotene (μg g FW^{-1})	Flavonoids (mg rutin 100 g FW^{-1})
Red	3.991a	0.46c	17.79c	0.107ab	46.80b	14.36b	0.1372b	88.6
Yellow	3.968a	0.51ab	18.12c	0.092b	35.91c	12.92bc	0.1198b	94.5
Pearl	3.928a	0.46c	19.84b	0.121a	46.90b	11.77c	0.1350b	85.1
Black (control)	4.333b	0.51a	21.98a	0.121a	54.53a	17.64a	0.1664a	77.4
P < *F*	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.132
LSD	0.135	0.029	1.14	0.016	6.15	1.86	0.017	14.50
Types of cultivars								
AlfaV	4.269a	0.4323b	18.82a	0.1216a	46.4	14.52b	0.1551a	101.24a
SCX 248	3.733b	0.4494b	16.99c	0.1026b	47.0	10.37c	0.1067b	94.32a
Irit	4.163a	0.5941a	22.50a	0.1062b	44.7	17.63a	0.1571a	63.62b
P < *F*	<.001	<.001	<.001	0.015	0.671	<.001	<.001	<.001
LSD	0.117	0.025	0.986	0.014	5.33	1.61	0.015	12.56
Cultivar × net								
AlfaV × Red	3.88cd	0.45de	15.06d	0.089de	51.56b	13.00def	0.14bc	91.29abcd
AlfaV × Yellow	4.5a	0.36g	16.97cd	0.102cde	32.97c	10.44fg	0.13bcd	114.36ab
AlfaV × Pearl	4.08bc	0.43ef	20.84b	0.146ab	45.52b	13.98cde	0.15bc	108.58abc
AlfaV × Black	4.60a	0.44def	22.40b	0.150a	55.53a	20.66b	0.20a	90.71bcd
SCX 248 × Red	3.89cd	0.36g	17.77c	0.122bc	44.64b	16.69c	0.14bc	91.62abcd
SCX 248 × Yellow	3.66de	0.57bc	16.59cd	0.080e	36.83c	11.39ef	0.10de	116.35a
SCX 248 × Pearl	3.59e	0.37g	16.38cd	0.106cde	53.32a	6.19h	0.10ab	85.20cde
SCX 248 × Black	3.80de	0.48d	17.20c	0.102cde	53.32a	7.23gh	0.08e	84.10cde
Irit × Red	4.2b	0.63a	20.54b	0.109cd	44.20b	13.40def	0.12cd	83.00de
Irir × Yellow	3.78de	0.55c	20.81b	0.093de	37.93c	16.93c	0.13bcd	52.72f
Irit × Pearl	4.11bc	0.58abc	22.30b	0.110cdc	41.88b	15.15cd	0.16b	61.51ef
Irit × Black	4.55a	0.61ab	26.34a	0.112cd	54.75a	25.05a	0.22a	57.25f
P < *F*	<.001	<.001	<.001	0.001	0.298	<.001	<.001	0.026
LSD	0.2338	0.05077	1.971	0.02716	10.66	3.226	0.03069	25.11

[a] Soluble soilds concentration.
[b] TA – Titratable acidity.

and Ilić et al. (2012). All three cultivars grown under black nets resulted in the highest SSC. The data shows a strong influence of higher light conditions (PAR) on SSC (r = 0.812, P < 0.001) and the SSC was reported to decrease during cooler days (Aldrich et al., 2010). However, cultivar × net interaction was noted and fruits of cvs. AlfaV under yellow (35.8 °C) and black nets (30.27 °C) to and cv. Irit under black nets (30.27 °C) resulted in significantly higher SSC values while cv. SCX 248 under pearl nets (42.1 °C) resulted in 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) was reported to the SSC (Walker and Ho, 1977). On the other hand, temperature increase (40 °C) could have caused sink competition as reported in cherry tomatoes, promoting fruit evapotranspiration and higher sugar levels. However the sugar concentration was reduced due to the sink competition caused by the increased respiration during higher temperatures (Gautier et al., 2005).

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). A moderate correlation was noted between temperature and TA (r = −0.52). Different observations were reported regarding the shading effect and titirable acidity in tomato fruit. According to El-Gizawy et al. (1992), increasing shading levels from 35% to 63% increased the titratable acidity in tomato fruit while Riga et al. (2008) 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 3. The TA was significantly higher in cv. Irit produced under red net whereas cv. AlfaV and cv. SCX 248 under yellow and red nets respectively showed significantly lower TA.

According to Davies and Hobson (1981) 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 (Rosales et al., 2006). 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 × 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 < 0.001). The total phenolic compounds in tomatoes were observed to decrease with increasing temperatures during the production period (r = −0.58, P < 0.001). Reduction of total phenolic compounds in tomatoes during cooler period was reported by Aldrich et al. (2010).

The lycopene content was significantly higher in tomatoes grown under the black nets whereas the tomatoes grown under pearl nets had lower lycopene content. The observed variation was due to air temperature and light quality with lycopene content in tomatoes affected by higher temperatures (r = −0.90, P < 0.001) and PAR (r = 0.66, P < 0.001). However, excessive sunlight was reported to inhibit the synthesis of lycopene (Brandt et al., 2006). According to Helyes et al. (2007), 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 AflaV and Irit tomatoes. On the other hand, tomatoes grown under red net showed higher lycopene content than tomatoes grown under the pearl net. Similar observations were reported by Lopez et al. (2007) and Ilić et al. (2012). The observed differences between the lycopene content in tomatoes under the red and pearl nets could be the 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) that lycopene synthesis is mediated by phytochrome. Among all the cultivars, Irit showed significantly higher lycopene content (Table 3). The lycopene contents of our tomatoes were lower than those reported for newly bred tomatoes reported by Gupta et al. (2011) and cv. Vedeta (Ilić et al., 2012); the values are however, higher than that reported for cherry (Rosales et al., 2011) and are within the range reported for *Savoura* tomatoes (Bui et al., 2010). Cultivar × net interaction was significant for cv. AlfaV and cv. Irit tomatoes produced under the black net and SCX 248 under the red nets had significantly higher lycopene content. It is interesting to note that the SCX 248 tomatoes produced under the black and pearl nets produced significantly lower lycopene content (Table 3). This confirms the influence of higher temperature (pearl net) and PAR (black net) on lycopene biosynthesis.

The β-carotene content in tomatoes grown under the black net was significantly higher than for the tomatoes obtained from the other nets. β-Cartotene biosynthesis in tomato is influenced by the temperature ($r = -0.71$, $P < 0.001$) and PAR ($r = 0.72$, $P < 0.001$). Temperatures over 30–35 °C and strong solar radiation was reported to inhibit lycopene biosynthesis and stimulate the oxidation of lycopene to β-carotene (Dumas et al., 2003). According to Gautier et al. (2005) β-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 β-carotene contents in the exocarp (Rosales et al., 2006). However, according to our investigations cvs. AlfaV and Irit had higher β-carotene content than cv. SCX 248. Significant cultivar × net interaction was found. Cultivars AlfaV and Irit under the black nets and cv. SCX 248 under red net produced tomatoes with significantly higher β-carotene content whereas cv. SCX 248 tomatoes grown under pearl, black and yellow nets had significantly lower β-carotene content (Table 3). However, significantly lower β-carotene content in cv. SCX 248 tomatoes under the black nets was due to its degradation. Based on the findings of this study, it can be concluded that the red nets improve the lycopene and β-carotene contents in tomato cultivars (genotypes) that are genetically designed to produce lower lycopene and β-carotene contents (e.g. cv. SCX 248).

Flavonoids are beneficial in many ways and act as antioxidants, antiproliferative or antibacterial agents (Harborne and Williams, 2000). Flavonoid content (mg of rutin equivalents 100 g^{-1} FW) was significantly higher in cv. AlfaV and lower in cv. Irit. The PAR was negatively correlated to the flavonoid content in our investigation ($r = -0.55$, $P < 0.001$) and according to the reports of Cen and Bornman (1990) the PAR could promote flavonoid synthesis. Significant cultivar × net interaction was observed in our study with respect to flavonoid content. Cultivars AlfaV and SCX 248 under yellow nets had significantly higher flavonoid content (Table 3). In cherry tomatoes a temperature increase from 27 to 32 °C was reported to increase the rutin and caffeic acid (Gautier et al., 2008). 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 μmol m^{-2} 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. However, red nets helped to improve the flavonoid content in cv. Irit which directly shows the influence of PAR (744.13 μmol m^{-2} s^{-1}) on flavonoid content. Cv. SCX 248 had relatively low flavonoid content under the black and pearl nets. 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 and Kader, 2000) 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 ($r = 0.808$, $P < 0.001$). Cultivars Irit and SCX 248 showed significantly higher and lower ascorbic content respectively (Table 3). Cultivar × net interaction was detected in our study. Cultivar Irit under black net produced significantly higher ascorbic acid content while cv. Irit under red net produced significantly lower ascorbic acid content.

Our investigation showed that total phenols, β-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. Among the cultivars the antioxidant property was higher in cv. AlfaV. Cultivar × net interaction was evident from our study. Cultivar AlfaV grown under black nets produced significantly higher antioxidant activity while SCX 248 under yellow net gave significantly lower antioxidant activity.

The fresh mass per fruit ranged from 88.9 to 114 g (Table 4) and the differences observed in fresh mass were more significantly due to genetical (cultivar) than environmental (shading) differences. Pearl net favoured the increase on fruit mass for all three cultivar, while fruits produced under the red nets weighed less and this could be due to influence of reduced PAR under the red nets. Total PAR received during the production stage from flowering to harvest was reported to correlate strongly with the fresh mass of fruits (Giniger et al., 1988; De Koning, 1989; Bertin et al., 2000). Shading reduces the export of photosythates from vegetative organs to the fruits (Corelli Grappadelli et al., 1990). Among the cultivars, AlfaV gave highest fruit mass while fruit mass was lower in cv. SCX 248 (Table 4). However, a significant cultivar x netting effect was obtained in this study and fruit mass was higher for cultivars AlfaV, Irit and SCX 248 under yellow, pearl and red nets respectively. Fruit mass was lower in cv. AlfaV and cv. SCX 248 produced under black nets and cv. Irit under red nets.

Table 4 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 and Gómez, 2004) and fruit remained yellow in colour as a result of inhibition of lycopene synthesis and the accumulation of yellow/orange carotenoids (Tijskens and Evelo, 1994). On the other hand, cvs. Irit and AlfaV showed reddish fruits than cv. SCX 248. Significant cultivar x net interaction was found with cv. Irit and cv. AlfaV cultivars under black net producing more reddish fruit whereas yellow net gave the highest redness in cv. 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). 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 was 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 β-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. Cultivars AlfaV and Irit tomatoes grown under black nets had higher a^* and lower b^* coordinate values and showed intense red colour.

Table 4
Effect photo-selective netting on colour, weight and yield of three tomato cultivars.

Type of nets	L^*	a^*	b^*	Fruit mass (g/fruit)
Red	40.62c	17.66b	22.49a	95.19b
Yellow	41.89b	19.25a	22.65a	99.67a
Pearl	44.33a	16.82b	19.70b	99.99a
Black (control)	42.26b	19.44a	22.34a	97.97b
P < *F*	<.001	<.001	<.001	0.041
LSD	0.5151	0.326	0.826	3.663
Types of cultivars				
AlfaV	42.24b	21.43a	22.87a	105.02a
SCX 248	43.75a	11.89b	22.71a	92.21c
Irit	40.84c	21.55a	19.80b	97.39b
P < *F*	<.001	<.001	<.001	<.001
LSD	0.4461	0.282	0.715	3.172
Cultivar × net				
AlfaV × Red	41.7 ± 2.5^{cd}	19.3 ± 4.7^{d}	22.6 ± 2.8^{de}	94.0 ± 21.7^{abc}
AlfaV × Yellow	41.6 ± 2.3^{c}	21.7 ± 3.1^{ef}	23.5 ± 3.3^{e}	113.7 ± 14.5^{h}
AlfaV × Pearl	43.0 ± 1.4^{ef}	21.3 ± 2.1^{ef}	22.1 ± 2.4^{cde}	108.8 ± 18.4^{gh}
AlfaV × Black	42.6 ± 1.5^{de}	23.4 ± 3.7^{gh}	23.3 ± 2.6^{e}	103.6 ± 11.7^{de}
SCX 248 × Red	38.7 ± 2.8^{a}	13.4 ± 3.1^{c}	27.7 ± 4.2^{h}	97.2 ± 15.9^{bcd}
SCX 248 × Yellow	43.6 ± 2.2^{f}	14.1 ± 5.5^{c}	23.7 ± 5.4^{g}	91.5 ± 7.9^{ab}
SCX 248 × Pearl	48.2 ± 1.9^{h}	9.0 ± 3.0^{a}	17.9 ± 2.4^{a}	91.2 ± 15.7^{ab}
SCX 248 × Black	44.5 ± 1.7^{g}	11.1 ± 4.8^{b}	21.6 ± 2.3^{cd}	88.9 ± 11.1^{a}
Irit × Red	41.5 ± 2.3^{c}	20.3 ± 2.6^{de}	17.1 ± 2.6^{a}	96.4 ± 20.4^{bcd}
Irir × Yellow	40.5 ± 2.6^{b}	22.0 ± 3.6^{fg}	20.8 ± 5.4^{c}	93.8 ± 13.5^{abc}
Irit × Pearl	41.8 ± 1.3^{cd}	20.2 ± 4.3^{de}	19.1 ± 2.4^{b}	100.0 ± 19.2^{cd}
Irit × Black	39.7 ± 2.8^{b}	23.8 ± 3.7^{h}	22.2 ± 3.7^{cde}	101.4 ± 13.3^{d}
P < *F*				<.001
LSD				6.344

It is evident that the cultivar differences greatly influenced all the parameters that were investigated in our experiment. The marketable yield was higher for cv. AlfaV under pearl net whereas cv. Irit and cv. SCX 248 showed higher marketable yield under red net. All three tomato cultivars showed lower production of marketable fruits under the commercially used black net (Fig. 1). These investigations will provide valuable information for farmers especially regarding the nutritional quality of the cultivar that they grow.

3.3. 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, β-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, β-carotein, lycopene and ascorbic acid. Relative humidity was positively correlated to SSC, TA, β-carotene, lycopene and negatively correlated to fruit firmness (Table 5).

3.4. PCA analysis

PCA was carried out to investigate the data stucture, in order to establish a cultivar and net classification based on the obtained data including the physico-chemical properties and bioactive compounds. With respect to eigen values > 1, two principal components were obtained with their factor loading shown in Fig. 2A. 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,

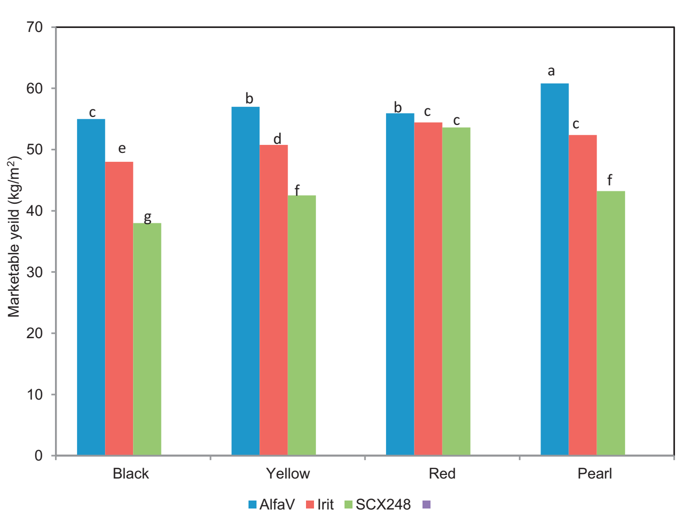

Fig. 1. Influence of photo selective shade netting on marketable yield of tomato cultivars. Means in each bar with the same type of letter are not significantly different, $P < 0.05$.

Table 5
Pearson's correlation coefficients between photosynthetically active radiation or microclimate conditions (air temperature or RH) and the fruit quality parameters or bioactive compounds.

Parameter	Air temperature	PAR	Air RH
a	0.63^{**}	0.645^{**}	0.49 ns
b	-0.69^{**}	0.234 ns	0.64^{**}
Soluble solids concentration	-0.835^{**}	0.812^{**}	0.730^{**}
Titratable acidity	-0.623^{**}	0.407 ns	0.589^{**}
Firmness	0.783^{**}	-0.726^{**}	-0.762^{**}
Fruit weight	0.152 ns	0.325 ns	−0.388 ns
β-Carotene	-0.73^{***}	0.727^{**}	0.53^{*}
Lycopene	-0.893^{***}	0.660^{**}	0.703^{**}
Total phenols	−0.42 ns	0.56^{**}	0.188 ns
Flavonoids	0.21 ns	-0.556^{**}	−0.38 ns
Ascorbic acid	-0.549^{*}	0.808^{***}	0.256 ns

Correlation results include means from three cultivars, grown under four different shade nettings (three photo-selective and commercial black net) during 2010 and 2011 seasons.
ns, not significant.
* Asterisks indicate significance at $P < 0.05$.
** Asterisks indicate significance at $P < 0.01$.
*** Asterisks indicate significance at $P < 0.0001$.

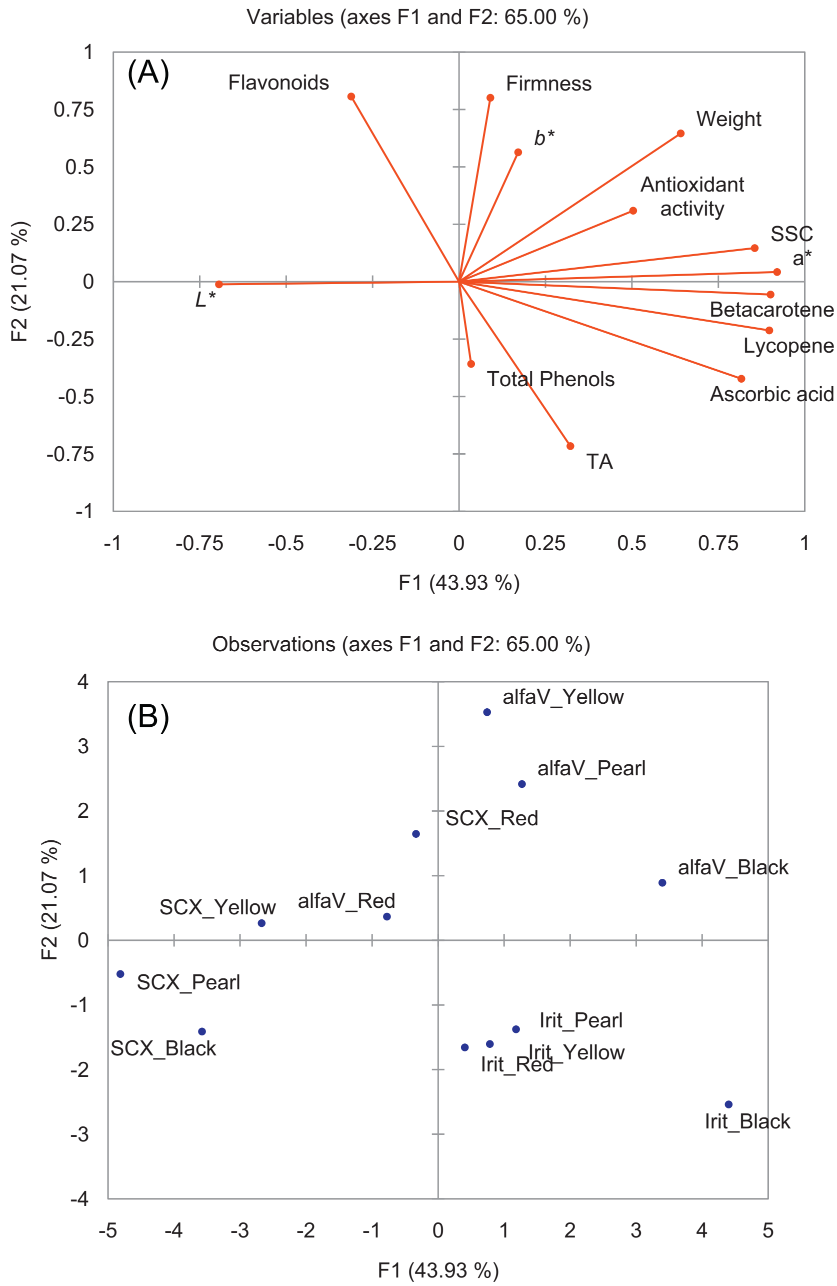

Fig. 2. Principal component analysis (PCA) showing (A) correlation loadings and (B) bioactive compounds and quality parameters and other properties in different tomato cultivars grown under different photo-selective nettings [Red, Yellow, Pearl and Black (control)]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

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 Fig. 2A.

Results of the PCA analysis are shown in Fig. 2. As illustrated in Fig. 2A, 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 Fig. 2B. 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. Cultivar 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 cv. AlfaV produced under pearl net. Marketable fruits assessments included fruits that were free from pest attack and diseases (data not presented).

3.5. Odour active aroma volatiles of AlfaV tomatoes grown under photo-selective nettings

Among the three tomato cultivars the cv. AlfaV was shown to have good quality fruits at harvest. Therefore, the aroma

Table 6
Changes in odour active aroma volatiles of cv. AlfaV tomato fruit grown under different photo-selective nettings at harvest.

Compound	RT (min)	Pre-harvest treatment (Net types)				Aroma descriptors
		Photo-selective red netting [NAAV (%)]	Photo-selective yellow netting [NAAV (%)]	Photo-selective pearl netting [NAAV (%)]	Photo-selective black netting [NAAV (%)]	
Aliphatic ketones						
6-Methy1-5-hepten-Z-one	26.23	0.264 ± 0.003	0.3408 ± 0.12	0.2512 ± 0.004	0.821 ± 0.091	Sweet or floral
Geranylacetone	2.09	0. 211 ± 0.012	0.035 ± 0.32	0.192 ± 0.056	0.0163 ± 0.064	Sweet/citrus/ester
1-Penten-3-one	1.602	0.78 ± 0.010	nd	0.151 ± 0.076	nd	Grassy/herbal
Aliphatic aldehydes						
(E)-2-heptenal	5.497	0.387 ± 0.114	nd	0.299 ± 0.16	nd	Dried fruit
(E)-2-octenal	8.800	0.125 ± 0.02	0.1245 ± 0.013	0.15 ± 0.003	0.089 ± 0.018	
Nonanal	10.588	0.1770 ± .056	nd	0.19 ± 0.082	nd	
(E)-2-hexenal	2.377	0. 56 ± 021	nd	nd	nd	Stale/grassy/green
Citral	17.479	0. 90 ± 007	nd	0.31 ± 0.051		Lemon
2,4-Decadienal	18.435	0.264 ± 0.136	nd	0.11 ± 0.045	0.0196 ± 0.071	Medicinal or chalky
Terpenoids						
2,2,6-Trimethylcyclohexanone	13.276	0.218 ± 0.002	0.0197 ± 0.08	0.127 ± 0.087	0.1864 ± 0.012	
Aromatic compounds						
Methyl salicylate	14.130	0.658 ± 0.130	0.14168 ± 0.007	0.289 ± 0.083	0.1993 ± 0.052	Plastic/pesticide
Sulfur compounds						
2-Isobutylthiazole	7.843	0.1055 ± 0.050	0.0398 ± 0.01	0.0945 ± 0.034	0.1199 ± 0.008	Fermented/pungent

NAAV: normalized amount of aroma volatiles (%) = peak area of an aroma volatile/Total peak area of aroma volatiles. RT: retention time; identification of target compounds confirmed by reference standards.

volatile analysis was carried out only for cv. AlfaV fruit. GC–MS analysis of the volatile fraction isolated by HP-SPME method from the fruit at harvest showed that cv. AlfaV produced under the red nets had higher number (12) of odour active volatile compounds that contributed to tomato aroma (Tandon et al., 2001) in comparison to the other nets (Table 6). The aroma synthesis under different nets was as follows: red net > pearl net > black net > yellow net. The increased synthesis of odour active volatile compounds under the red net could be linked to the light quality. The compounds were identified as three aliphatic ketones [6-methy1-5-hepten-Z-one, geranylacetone, 1-penten-3-one], six aliphatic aldehydes [(E)-2-heptenal, (E)-2-octenal, nonanal, (E)-2-hexenal, citral, 2,4–Decadienal], one terpenoid [2,2,6-trimethylcyclohexanone], one aromatic compound [methyl salicylate] and one sulfur compound [2-isobutylthiazole]. The 6-methy1-5-hepten-Z-one is responsible for the sweet or floral note in tomato aroma and geranylacetone relates to the sweet/citrus/ester aroma in tomato. The 2,4-decadienal is responsible for the medicinal or chalky odour. The odour active volatiles found in cv. AlfaV and their aroma descriptors are given in Table 6. The 6-methy1-5-hepten-Z-one and geranylacetone are known as lycopene degradation products (Caris-Veyrat et al., 2003). Under yellow nets cv. AlfaV tomato showed significantly higher levels ($P < 0.05$) of 6-methy1-5-hepten-Z-one and geranylacetone and this could be due to the light quality observed under the yellow net. Under the yellow net cv. AlfaV tomatoes showed lower lycopene content and this could explain the increase in lycopene degradation products. Moreover, the levels of odour active volatile compounds in cv. AlfaV under the red nets were significantly higher than levels that were noted under the yellow net although the shading effect was more or less similar. The untrained taste panel data showed higher scores for 'very much like' for cv. AlfaV tomato grown under red nets (data not shown). However, the sensory evaluation with the trained panel for the descriptive aroma components needs to be conducted observation of untrained panellists.

4. Conclusions

The results of our study provide useful information on environmental variation related to colour shade nets on bioactive compounds and quality parameters. Cultivar differences were shown to affect the bioactive compounds, antioxidant activity and fruit quality of tomatoes. Selection of cultivars that are superior in nutrition can benefit growers and retailers who cater tomatoes to the health conscious consumers. Fruit size (mass), firmness, colour and aroma are the important parameters that attract consumers. Based on our study cultivar AlfaV was the best cultivar followed by cv. Irit with respect to fruit quality and bioactive compounds. Although the red nets influenced the biosynthesis volatiles in tomato cv. AlfaV, the photo-selective pearl net can be recommended to improve the overall fruit quality, fruit mass, firmness, aroma and bioactive components. On the other hand, photo-selective red net can be recommended for cv. Irit and can be further implemented within protected cultivation practices.

Acknowledgements

The financial support by the NRF (Competitive Funding for Rated Researchers programme) is greatly acknowledged and the authors wish to thank Hygrotech (Pty) and Seedcore (Pty) South Africa for providing fertilizers and seedlings for this trials. The postgraduate bursary award from the NRF to Mr. Peter Phushdi Tinyane is greatly acknowledged. The authors sincerely thank Mr. Martin Maboko from the Agricultural Research Council (Vegetable and Ornamental Plant Institute) for advising us on planting and establishing the hydroponic system at the Tshwane University of Technology Experimental Farm. Authors also thank Dr. Shahak for providing access to their web reference Shahak, 2012.

References

Andersen, Ø.M., Markham, K.R., 2006. Flavonoids: Chemistry, Biochemistry and Applications. CRC, Boca Raton, FL, USA.
Aldrich, H.T., Salandanan, K., Kendall, P., Bunning, M., Stonaker, F., Oktay, K., Stushnoff, C., 2010. Cultivar choice provides options for local production of organic and conventionally produced tomatoes with higher quality and antioxidant content. J. Sci. Food Agric. 90, 2548–2555.
AOAC, 2000. International, Official Methods of Analysis, 16th ed. AOAC International, Gaithersburg, MD.
Bertin, N., Guichard, S., Leonard, C., Longuenesse, J.J., Langlois, D., Navez, B., 2000. Seasonal evolution of the quality of fresh glasshouse tomatoes under Mediterranean conditions, as affected by air vapour pressure deficit and plant fruit load. Ann. Bot. 85, 741–750.

Betancourt, L.A., Stevens, M.A., Kader, A.A., 1977. Accumulation and loss of sugars and reduced ascorbic in attached and detached tomato fruits. J. Amer. Soc. Hortic. Sci. 102, 721–723.

Brandt, S., Lugasi, A., Barna, É, Hóvári, J., Pék, Z., Helyes, L., 2003. Effects of the growing methods and conditions on the lycopene content of tomato fruits. Acta Aliment Hung 32, 269–278.

Brandt, S., Pek, Z., Barna, E., Lugasi, A., Helyes, L., 2006. Lycopene content and colour of ripening tomatoes as affected by environmental conditions. J. Sci. Food Agric. 86, 568–572.

Bui, H.T., Makhlouf, J., Ratti, C., 2010. Postharvest ripening characterization of greenhouse tomatoes. Int. J. Food Prop. 13, 830–846.

Bucheli, P., Voirol, E., Delatorre, R., Lopez, J., Rytz, A., Tanksley, S.D., Petiard, V., 1999. Definition of nonvolatile markers for flavor of tomato (*Lycopersicon esculentum* Mill.) as tools in selection and breeding. J. Agric. Food Chem. 47, 659–664.

Caris-Veyrat, C., Schmid, A., Carail, M., Bohm, V., 2003. Cleavage products of lycopene produced by *in vitro* oxidations: characterization and mechanisms of formation. J. Agric. Food Chem. 51, 7318–7325.

Cen, Y.P., Bornman, J.F., 1990. The response of bean plants to UV-B radiation under different irradiance of background visible light. J. Exp. Bot. 41, 1489–1495.

Corelli Grappadelli, L., Sansavini, S., Ravaglia, G.F., 1990. Effects of shade and sorbitol on fruit growth and abscission in apple. In: Sym. Proceed XXIIIth International Horticultural Congress, Florence, Italy, p. 620.

Davies, J.N., Hobson, G.E., 1981. The constituents of tomato fruit: the influence of environment, nutrition and genotype. CRC Crit. Rev. Food Sci. Nutr. 15, 205–280.

De Koning, A.N.M., 1989. Development and growth of a commercially grown tomato crop. Acta Hortic. 260, 267–273.

Dorais, M., 2007. Effect of cultural management on tomato fruit health qualities. Acta Hortic. 744, 200–205.

Dumas, Y., Dadomo, M., Di Lucca, G., Grolier, P., 2003. Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. J. Sci. Food Agric. 83, 369–382.

Du Toit, R., Volsteedt, Y., Apostolides, Z., 2001. Comparison of the antioxidant content of fruits, vegetables and teas measured as vitamin C equivalents. Toxicology, 166 63–16669.

Elad, Y., Brand, M., David, D.R., Sztejnberg, A., 2007. Effect of colored shade nets on pepper powdery mildew (*Leveillula taurica*). Phytoparasitica 35, 285–299.

El-Aidy, F., El-Afry, M., 1983. Influence of shade on growth and yield of tomatoes cultivated during the summer season in Egypt. Plasticulture 47, 2–6.

El-Gizawy, A.M., Abdallah, M.M.F., Gomaa, H.M., Mohamed, S.S., 1992. Effect of different shading levels on tomato plants 2. Yield and fruit quality. Acta Hortic. 323, 349–354.

Fletcher, J.M., Tatsiopoulou, A., Mpezamihigo, M., Carew, J.G., Henbest, R.G.C., Battey, P., 2005. Far-red light filtering by plastic film, greenhouse-cladding materials: effects on growth and flowering in petunia and impatiens. J. Hortic. Sci. Biotechnol. 80, 303–306.

Gautier, H., Diakou-Verdin, V., B'enard, C., Reich, M., Buret, M., Bourgaud, F., 2008. How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance? J. Agric. Food Chem. 56, 1241–1250.

Gautier, H., Rocci, A., Buret, M., Grasselly, D., Causse, M., 2005. Fruit load or fruit position alters response to temperature and subsequently cherry tomato quality. J. Sci. Food Agric. 85, 1009–1016.

Goren, A., Alkalai-Tuvia, S., Perzalan, Y., Aharon, Z., Ilic, Z., Fallik, E., 2010. Harvested tomato quality and nutritional levels as affected by high temperatures in Mediterranean wholesale markets, and home or refrigerated temperatures. Adv. Hortic. Sci. 24, 200–206.

Giniger, R.T.M.S., McAvoy, R.T., Giacomelli, G.A., Janes, H.W., 1988. Computer simulation of a single truss tomato cropping system. Trans. ASAE 31, 1176–1179.

Gomez, R., Costa, J., Amo, M., Alvarruiz, A., Picazo, M., Pardo, J.E., 2001. Physicochemical and colorimetric evaluation of local varieties of tomato grown in SE Spain. J. Sci. Food Agric. 81, 1101–1105.

Gupta, A., Kawatra, A., Sehgal, S., 2011. Physical-chemical properties and nutritional evaluation of newly developed tomato genotypes. Afr. J. Food Sci. Technol. 2, 167–172.

Harborne, J.B., Williams, C.A., 2000. Advances in flavonoid research since 1992. Phytochemistry 55, 481–504.

Helyes, L., Lugasi, A., 2006. Formation of certain compounds having technological and nutritional importance in tomato fruits during maturation. Acta Aliment Hung 35, 183–193.

Helyes, L., Lugasi, A., Pék, Z., 2007. Effect of natural light on surface temperature and lycopene content of vine ripened tomato fruit. Can. J. Plant Sci. 87, 927–929.

Ilić, Z.S., Milenković, L., Stanojević, L., Cvetković, D., Fallik, E., 2012. Effects of the modification of light intensity by color shade nets on yield and quality of tomato fruits. Sci. Hortic. 139, 90–95.

Javanmardia, J., Kubota, C., 2006. Variation of lycopene, antioxidant activity, total soluble solids and weight loss of tomato during postharvest storage. Postharvest. Biol. Technol. 41, 151–155.

Khachik, F., Carvalho, L., Bernstein, P.S., Muir, G.J., Zhao, D.Y., Katz, N.B., 2002. Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health. Exp. Biol. Med. 227, 845–851.

Krumbein, A., Schwarz, D., 2012. Grafting: a possibility to enhance health-promoting and flavour compounds in tomato fruits of shaded plants? Sci. Hortic. 127, 167–171.

Lee, S.K., Kader, A.A., 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest. Biol. Technol. 20, 207–220.

Levy, J., Sharoni, Y., 2004. The functions of tomato lycopene and its role in human health. HerbalGram 62, 49–56.

Lopez, D., Carazo, N., Rodrigo, M.C., Garcia, J., 2007. Coloured shade nets effects on tomato crops quality. Acta Hortic. 747, 121–124.

López Camelo, A.F., Gómez, P.A., 2004. Comparison of color indexes for tomato ripening, Horticultura Brasileira. Brasília 22, 534–537.

Lorenzo, P., Sanchez-Guerrero, M.C., Medrano, E., Garcia, M.L., Caparros, I., Giminez, M., 2003. Effect on microclimate, water use efficiency, and yield of a tomato crop grown under different salinity levels of the nutrient solution. Acta Hortic. 609, 181–186.

Lumpkin, H.A., 2005. Comparison of lycopene and other phytochemicals in tomatoes grown under conventional and organic management systems. In: Technical Bulletin No. 34. AVRDC 05-623, Taiwan, p. 48.

Luthria, D.L., Mukhopadhyay, S., Krizek, D.T., 2006. Content of total phenolics and phenolic acids in tomato (*Lycopersicon esculentum* Mill.) fruits as influenced by cultivar and solar UV radiation. J. Food Compost. Anal. 19, 771–777.

Marković, K., Vahčić, K., Kovačević, G., Banović, M., 2007. Aroma volatiles of tomatoes and tomato products evaluated by solid-phase micro extraction. Flavour Frag. J. 22, 395–400.

Mazumdar, B.C., Majumder, K., 2003. Methods on Physico-chemical Analysis of Fruits. Daya Publication House, Delhi, India.

McKeon, A.W., Warland, J., McDonald, M.R., 2006. Long-term climate and weather patterns in reation to crop yield: a minireview. Can. J. Bot. 84, 1031–1036.

Messina, V., Domínguez, P.G., Sancho, A.M., de Reca, N.W., Carrari, F., Grigioni, G., 2012. Tomato quality during short-term storage assessed by colour and electronic nose. Int. J. Electrochem. 687429, 1–7, http://dx.doi.org/10.1155/2012/687429, Article ID.

Nagata, M., Yamashita, I., 1992. Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. Nippon Shokuhin Kogyo Gakkaish 39, 925–928.

Oren-shamir, M., Gussakovsky, E.E., Shpiegel, E., Nissim-Levi, A., Ratner, K., Ovadia, R., Raffo, A., La Malfa, G., Fogliano, V., Maiani, G., Quaglia, G., 2006. Seasonal variations in antioxidant components of cherry tomatoes (*Lycopersicon esculentum* cv. Naomi F1). J. Food Compos. Anal. 19, 11–19.

Rajapakse, N.C., Shahak, Y., 2007. Light quality manipulation by horticulture industry. In: Whitelam, G., Halliday, K. (Eds.), Light and Plant Development. Blackwell Publishing, UK, pp. 290–312.

Rao, A.V., Agarwal, S., 2000. Role of antioxidant lycopene in cancer and heart disease. J. Am. Coll. Nutr. 19, 563–569.

Riga, P., Anza, M., Garbisu, C., 2008. Tomato quality is more dependent on temperature than on photosynthetically active radiation. J. Sci. Food Agric. 88, 158–166.

Rosales, M.A., Ruiz, J.M., Hern'andez, J., Soriano, T., Castilla, N., Romero, L., 2006. Antioxidant content and ascorbate metabolism in cherry tomato exocarp in relation to temperature and solar radiation. J. Sci. Food Agric. 86, 1545–1551.

Rosales, M., Cervilla, L.M., Sánchez-Rodríguez, E., Rubio-Wihelmi, M., Blasco, B., Ríos, J.J., Soriano, T., Castilla, N., Romero, L., Ruiz, J., 2011. The effect of environmental conditions on nutritional quality of cherry tomato fruits: evaluation of two experimental Mediterranean greenhoses. J. Sci. Food. Agric. 91, 152–162.

Shahak, 2012. Coloured shade nets a new agro-technology. Curr. Res. Ornamental, www.polysack.com/files/cf8ed7312fe796d76fb634a6fb0899ed.pdf (Accessed 20.07.12).

Shahak, Y., Gal, E., Offir, Y., Ben-Yakir, D., 2008. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. Acta Hortic. 797, 75–80.

Shahak, Y., Gussakovsky, E.E., Gal, E., Ganelevin, R., 2004. ColorNets: crop protection and light-quality manipulation in one technology. Acta Hortic. 659, 143–151.

Singleton, V.L., Orthofer, R., Lamuela-Raventos, R.M., 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteu reagent. Meth. Enzymol. 299, 152–178.

Slimestad, R., Verheul, M., 2009. Review of flavonoids and other phenolics from fruits of different tomato (*Lycopersicon esculentum* Mill.) cultivars. J. Sci. Food Agric. 89, 1255–1270.

Spencer, J.P.E., Kuhnle, G.G.C., Hajirezaei, M., Mock, H.P., Sonnewald, U., Rice-Evans, C., 2005. The fenotypic variation of the antioxidant potential of different tomato varieties. Free Radic. Res. 39, 1005–1016.

Stamps, R.H., 2009. Use of colored shade netting in horticulture. HortScience 44, 239–241.

Tandon, K., Jodán, M., Goodner, K.L., Baldwin, E.A., 2001. Characterization of fresh tomato aroma volatiles using GC-Olfactometry. In: Sym. Proceed. Florida State Horticultural Society, vol. 114, pp. 142–144.

Tijskens, L.M.M., Evelo, R.G., 1994. Modeling colour of tomatoes during postharvest storage. Postharvest. Biol. Technol. 4, 85–98.

Vinson, J.A., Hao, Y., Su, X., Zubik, L., Hao, Y., Su, X.H., 1998. Phenol antioxidant quantity and quality in foods: vegetables. J. Agric. Food Chem. 46, 3630–3634.

Walker, A.J., Ho, L.C., 1977. Carbon translocation in tomato—effects of fruit temperature on carbon metabolism and rate of translocation. Ann. Bot. 41, 825–832.

Zhang, Z.M., Zeng, D.D., Gong-Ke., L., 2007. The study of the aroma profile characteristics of durian pulp during storage by the combination sampling method coupled with GC–MS. Flavour Fragr. J. 22, 71–77.

Zhishen, J., Mengcheng, T., Jianming, W., 1999. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chem. 64, 555–559.

Zoltán., P., Helyes, L., 2004. The effect of daily temperature on truss flowering rate of tomatoe. J. Sci. Food Agric. 84, 1671–1674.