Postharvest Biology and Technology 73 (2012) 22–27

Contents lists available at SciVerse ScienceDirect

Postharvest Biology and Technology

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

Low temperature-induced lycopene degradation in red ripe tomato evaluated by remittance spectroscopy

Brian Farneti[a,*], Rob E. Schouten[a], Ernst J. Woltering[a,b]

[a] Horticultural Supply Chains Group, Wageningen University, Droevendaalsesteeg 1, 6708 PD Wageningen, The Netherlands
[b] Food & Biobased Research, Wageningen University and Research Centre, P.O. Box 17, 6700 AA Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 20 March 2012
Accepted 20 May 2012

Keywords:
Chilling injury
Heat shock
Colour
HPLC

ABSTRACT

Tomatoes are mostly harvested at the orange and red-ripe stages. A survey among consumers indicated that tomatoes are most often stored in the refrigerator well below 10 °C, a temperature considered harmful for chilling sensitive products such as tomato. Also during distribution, tomatoes may be exposed to chilling temperatures. The effects of storage at chilling temperatures on quality aspects of tomatoes were investigated. The colour and lycopene content of red ripe tomatoes of two cultivars (cocktail and round type) was evaluated during 20 days of storage at 4, 8, 12 and 16 °C. Colour was repeatedly measured over time by tristimulus colour measurements, RGB image analysis and colour intensity was scored by eye using a consumer panel. Lycopene content was repeatedly assessed by following the NAI index over time. This index, obtained from remittance VIS spectroscopy, was found to relate closely to the lycopene level as measured by HPLC measurements of pericarp tissue. Temperatures below 12 °C resulted in lycopene loss in ripe-red tomatoes and substantial colour loss well assessed by visual evaluation. Colour measurement using tristimulus colour measurements and RGB image analysis did not correlate well with lycopene content. Prior hot water treatment did not prevent lycopene loss. Results show that storage of red ripe tomatoes at chilling temperatures reduces the nutritional and presumed health promoting value and affects fruit visual quality.

1. Introduction

Storage of tomatoes and other tropical or subtropical products between 0 and 12 °C induces chilling injury (King and Ludford, 1983). The major chilling injury symptoms in tomatoes appear in mature-green and breaker fruit. These symptoms include a failure to ripen normally, surface pitting and increased fungal decay (Jackman et al., 1992; Lurie et al., 1997; Saltveit, 2002). Chilling injury symptoms in non-ripe tomatoes can be alleviated by short term exposure to high temperature (Whitaker, 1994; Lurie et al., 1997; Saltveit, 2001, 2005; Lu et al., 2010; Luengwilai et al., 2012). Currently, tomatoes are mostly harvested at the orange and red stages and often stored in the consumer's refrigerator before consumption. Due to the sensitivity to chilling temperatures tomato storage in the refrigerator is not recommended (Parnell et al., 2004), but in practice it is common. In a survey among over 1800 respondents, more than 60% stated that they store tomatoes in the refrigerator (Table 1 supplementary material).

Next to ascorbic acid and β-carotene, lycopene is one of the main antioxidants in ripe tomatoes (Clinton, 1998; Sies and Stahl, 1998; Ilahy et al., 2011). Lycopene is an acyclic carotenoid with eleven conjugated double bonds. The long chromophore in the polyene chain accounts for the red colour and for its antioxidant activity (Rice-Evans et al., 1997). Epidemiology studies have revealed an inverse correlation between consumption of lycopene rich diets and the incidence of several cancers and coronary heart diseases (Barnley, 2000; Hu et al., 2008; Karppi et al., 2009). Low temperature induced production of reactive oxygen species (ROS) (Suzuki and Mittler, 2006) might affect the lycopene content of red ripe tomatoes when stored in the refrigerator. Lycopene loss was found in fresh-cut watermelon stored at low temperatures preceding the appearance of pitting and lesion development (Perkins-Veazie and Collins, 2004; Perkins-Veazie, 2007).

High performance liquid chromatography (HPLC) is currently used for lycopene content assessment. Although HPLC offers high sensitivity, it is also an elaborate, costly and destructive technique thus prohibiting the repeated assessment of lycopene of the same tomatoes. Lycopene accounts for the majority of the tomato's red colour (Gray et al., 1994). As most lycopene in the tomato is found in the pericarp, efforts have been undertaken to link colour measurements with lycopene content. Arias et al. (2000) reports a number of well-established correlations between lycopene content and chromaticity values (a^*, a^*/b^* and $(a^*/b^*)^2$), although only one cultivar was tested. The relation between lycopene content and

* Corresponding author.
E-mail address: Brian.farneti@gmail.com (B. Farneti).

0925-5214/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.postharvbio.2012.05.008

a^*/b^* was found to be noisy and cultivar dependent (D'Souza et al., 1992) or, for fourteen cultivars, relatively weak (López et al., 2001). Based on the results of Pflanz and Zude (2008) we used remittance VIS spectroscopy as a technique to non-destructively assess lycopene content in the tomato pericarp tissue. This technique has been successfully applied to assess the chlorophyll content in apple (Zude-Sasse et al., 2002; Kuckenberg et al., 2008) and banana (Zude-Sasse, 2003) and for determination of carotenoids in carrot (Zude-Sasse et al., 2007).

The aim of this research was to investigate the influence of low temperature storage on the lycopene content of red ripe tomato of two types (round truss and cocktail truss) and to investigate whether remittance VIS spectroscopy can provide accurate estimates of the lycopene content. The normalized anthocyanin index (NAI) derived from the remittance VIS spectroscopic method is tested as an indicator for the lycopene content as measured by HPLC and compared with chromaticity, RGB image analysis and visual judgement.

2. Materials and methods

2.1. Plant material

Tomatoes (*Solanum lycopersicum* L.) of the cvs. Cappricia RZ (round truss) and Amoroso RZ (cocktail truss) from the breeding company RijkZwaan BV, The Netherlands, were obtained from a greenhouse in the south east of The Netherlands in June 2010. Both cultivars were grown under similar, commercial, growing conditions.

2.2. Lycopene measurements

Lycopene content of pericarp samples was determined according the method described by Lana et al. (2005). The lipophilic fraction of 20 mg of freeze-dried tomato pericarp was extracted in a 5 mL solution of tetrahydrofuran and methanol (1:3) The lycopene and β-carotene concentration was measured by HPLC with an Alltima C18, 3 μm, 100 mm × 4.6 mm column (Alltech, Illinois, USA) at 25 °C. The mobile phase used 75% methanol + 0.05 M ammonium acetate + 0.05% TEA and 25% ethyl acetate + 0.05% TEA. The flow rate was 1 mL min^{-1} and detection of lycopene was at 470 nm.

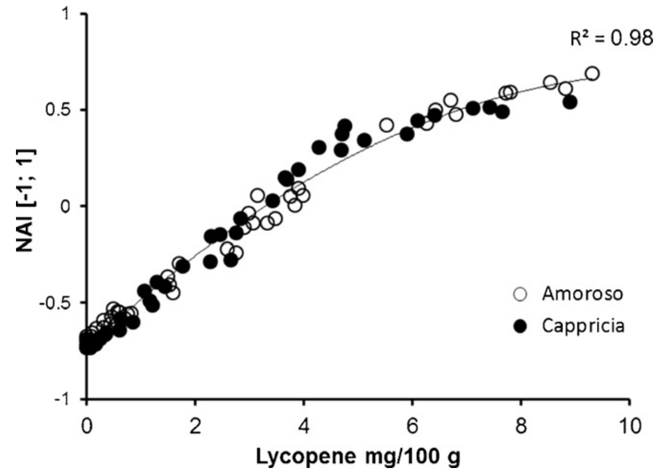

Fig. 1. Correlation between NAI values and lycopene content measured by HPLC in the pericarp of tomatoes cvs. Cappricia and Amoroso.

2.3. Remittance VIS spectroscopy and colour measurements

Remittance and chromaticity measurements were performed on three positions of the equatorial region of each tomato. A hand-held photodiode array spectrophotometer (Pigment Analyzer PA1101, CP, Germany) was applied for recording remittance spectra

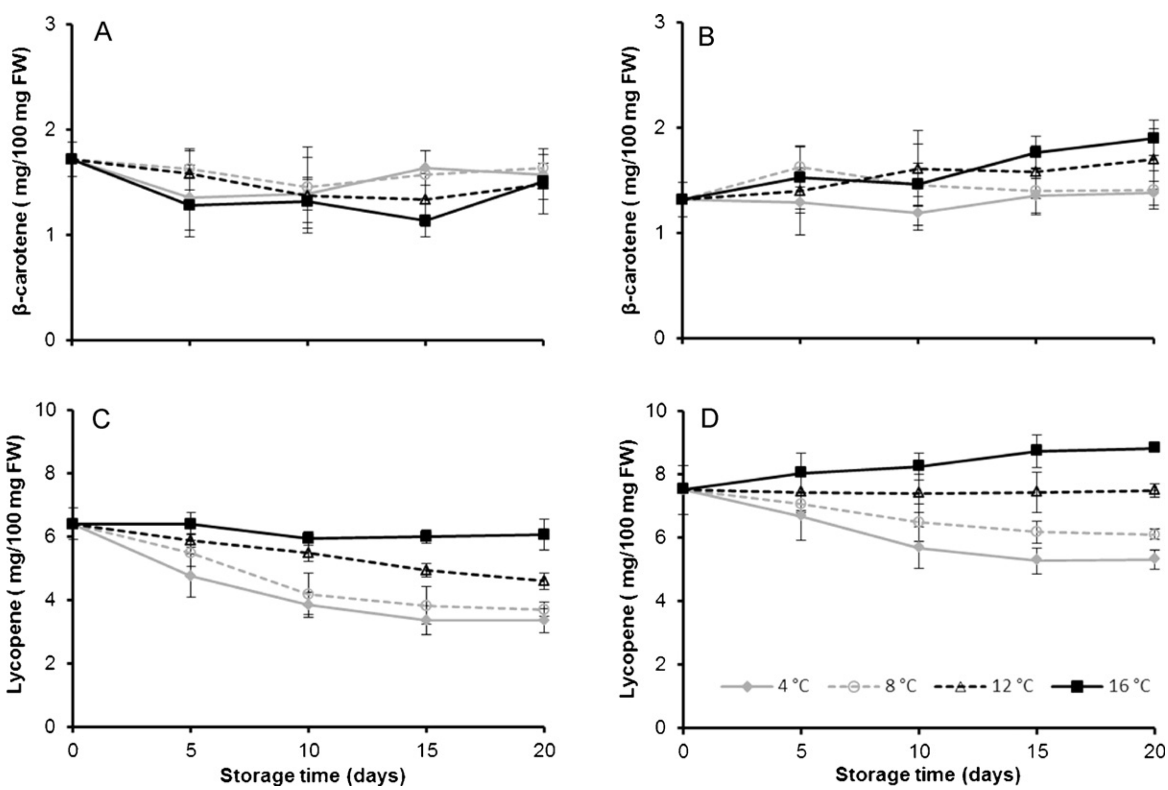

Fig. 2. Effect of storage temperature on carotenoid (lycopene and β-carotene) content of red ripe tomatoes cvs. Cappricia (panels A and C) and Amoroso (panels B and D) measured by HPLC. Values are mean with standard deviation of 15 tomatoes.

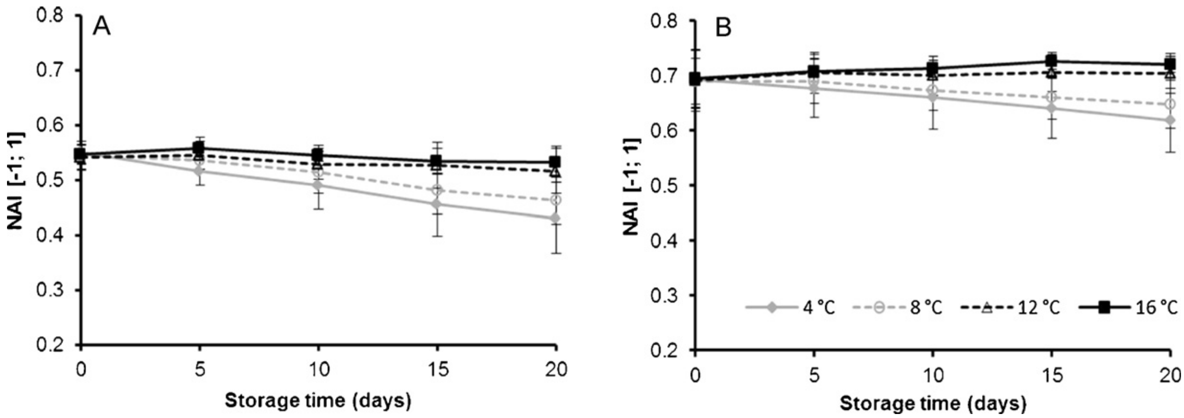

Fig. 3. Effect of storage temperature on NAI values for red-ripe tomatoes of cvs. Cappricia (panel A) and Amoroso (panel B). Values are mean with standard deviation of 30 tomatoes.

of tomato fruit between 350 and 1100 nm. Remittance was assessed at 570 ($R570$) and 780 ($R780$) nm by calculating the NAI index which is a normalized value between −1 and 1.

$$NAI = \frac{R780 - R570}{R780 + R570}$$

L^*, a^*, b^* system chromaticity values were measured using a tristimulus chromameter (CR-400, Minolta, Japan). Tomato colour was expressed as either a^* or a^*/b^* (Arias et al., 2000; Gómez et al., 2001). Tomato colour, expressed as RGB values from image analysis measurements, was measured on individual tomatoes using a colour video camera (JVC KY-F30 3CCD) in a controlled light environment and expressed as 1000/R (Schouten et al., 2007).

2.4. NAI-lycopene correlation

To determine the relationship between the lycopene content and the NAI index, 45 tomatoes per cultivar were collected varying in colour from dark green to dark red. Prior to the destructive lycopene assessment the remittance was measured three times on the equator of each fruit.

2.5. Storage experiment

A batch consisting of 110 red ripe (NAI > 0.4) tomatoes per storage temperature (4, 8, 12, 16 °C) and per cultivar were stored for 20 days. Remittance and colour were measured repeatedly on 30 tomatoes. On day 0, 5, 10, 15 and 20, 15 randomly taken fruit per batch were used for lycopene assessment by HPLC.

2.6. Visual colour evaluation

An attribute rating test on the evaluation of the red colour intensity was conducted on red ripe tomatoes at harvest and after 10 and 20 days of storage at 4, 8, 12, 16 °C. A 30 person consumer panel evaluated the tomato colour using a 10 cm unstructured scale, anchored at the two extremes with colour descriptors (0 cm – light red, 10 cm – dark red). Samples were randomly presented in an open area laboratory setting illuminated with cool white florescent lights. Each person evaluated four fruit per cultivar, one for each storage treatment. The significant differences in sensory attribute between the storage treatments were determined by the non-parametric statistical Kruskal–Wallis test with a significant level of 0.05 using SPSS 19.

2.7. Hot water treatment

Twenty red ripe tomatoes per cultivar were held in hot water at either 40, 45 or 50 °C for either 2, 5 or 10 min (Lurie et al., 1997; Saltveit, 2005) prior to 20 days of storage at 4 °C. Remittance was assessed on day 0, 5, 10, 15 and 20 during storage and compared with non-heat-treated tomatoes.

3. Results and discussion

3.1. Non-destructive lycopene assessment

HPLC measurements of lycopene content of individual tomato fruit, showed a clear relation with the averaged NAI values per tomato, for both cultivars (Fig. 1). Apparently, the NAI index, that corresponds to the absorption at 570 nm, is an excellent non-destructive indicator of the pericarp lycopene content, as was previously found by Pflanz and Zude (2008).

3.2. Effect of low temperature storage on lycopene

A decreasing lycopene content as measured by HPLC was observed over time at low storage temperatures (Fig. 2). This trend was also reflected in the NAI values (Fig. 3). In cv. Cappricia lycopene

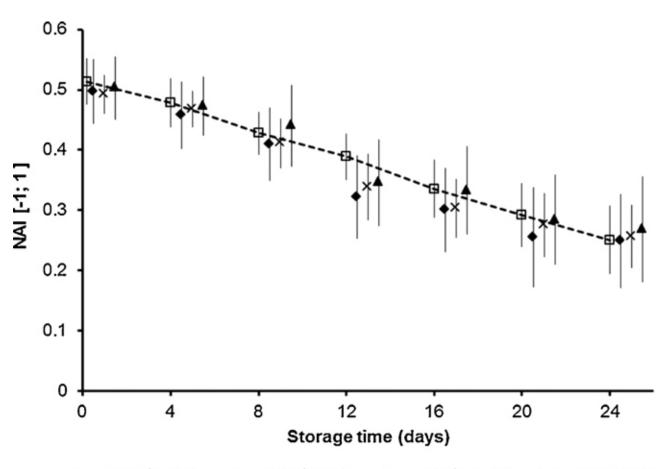

Fig. 4. Effect of pre storage hot water treatment at 45 °C on NAI values over time during cold storage (4 °C) for red ripe tomatoes of cv. Cappricia. To improve the graphical representation data points have been slightly shifted over the time axis; actual measurements were carried out simultaneously every four days. Each data point is the mean with standard deviation of 20 tomatoes.

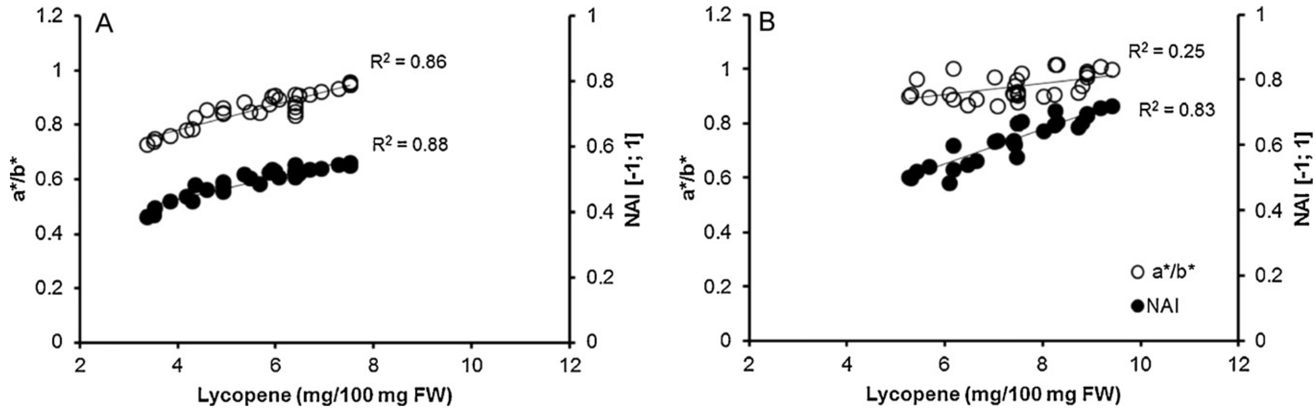

Fig. 5. Correlation between lycopene content, measured by HPLC, and colour index NAI and a^*/b^*(measured by Pigment Analyzer and Minolta chromameter respectively). Colour readings and lycopene content are taken from red ripe tomatoes of cv. Cappricia (panel A) and cv. Amoroso (panel B) stored for 20 days at four temperatures (4, 8, 12, 16 °C).

loss was already detected for tomatoes stored at 12 °C whereas for cv. Amoroso tomatoe, lycopene loss was not visible at this temperature. This indicates that cv. Cappricia is more chilling sensitive than cv. Amoroso. Tomatoes of cv. Amoroso stored at 16 °C showed an increase in lycopene content over time, presumably due to continued ripening. Temperature did not clearly affect the β-carotene content during storage (Fig. 3). The decrease of the lycopene content induced by low temperature storage may be caused by lycopene fragmentation. Lycopene quenches highly reactive singlet oxygen ($O_2^{\bullet -}$) and traps peroxyl radicals ($ROO^\bullet$) that results in break down products like acetone, methyl-heptanone, leavulinic aldehyde and glyoxal (Conn et al., 1991; Palozza, 1998). This presumed degradation of lycopene during storage not only reduces the nutritional and presumed health promotional value of the product but also affects visual quality, since colour is one of the main consumer quality attributes.

Heat shock treatments at 45 °C prior to storage at 4 °C did not stop lycopene degradation (Fig. 4). The other hot water temperature

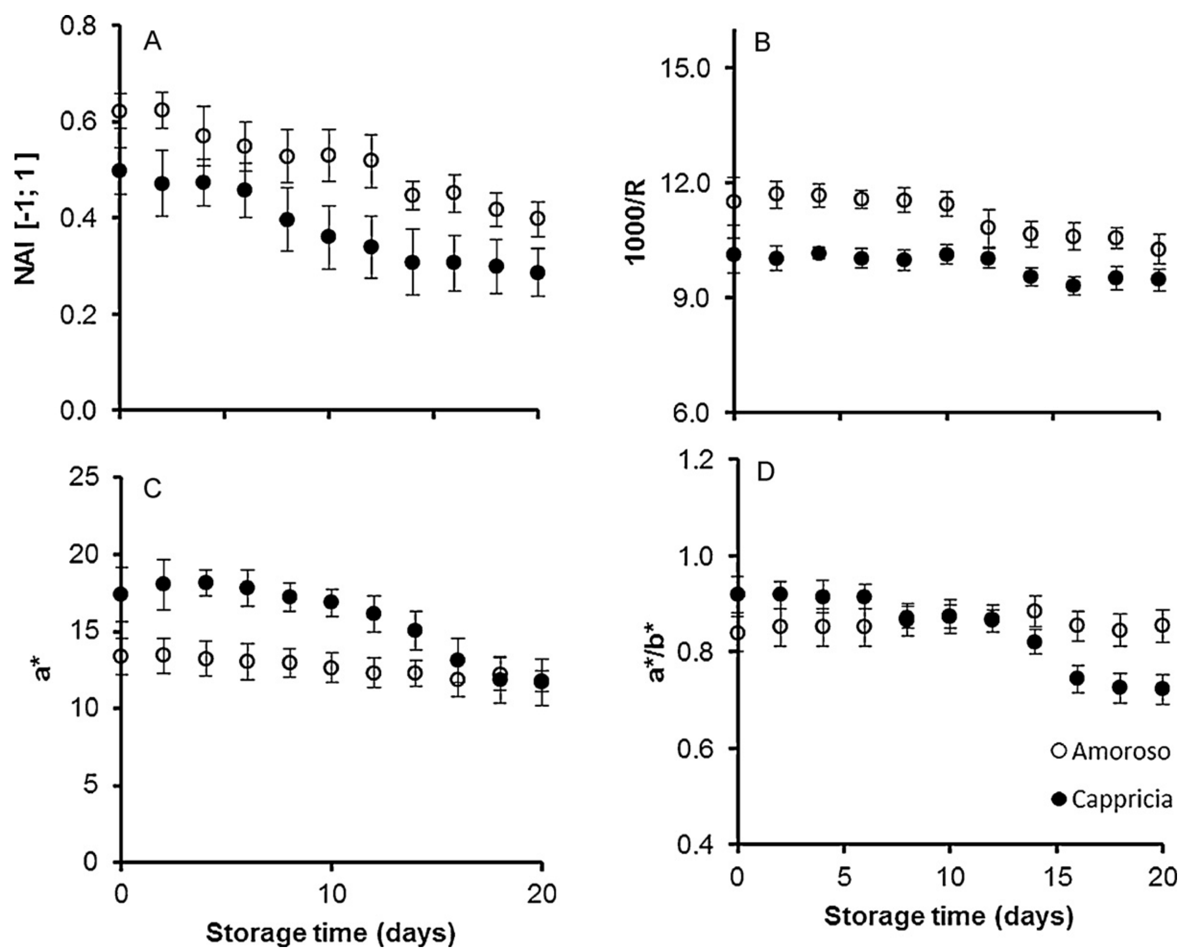

Fig. 6. Evaluation of low temperature (4 °C) storage of red ripe tomatoes of cvs. Cappricia and Amoroso on NAI values (panel A), colour measurements expressed as 1000/R (panel B), a^* (panel C) or a^*/b^* (panel D). Values are mean with standard deviation of 10 fruit.

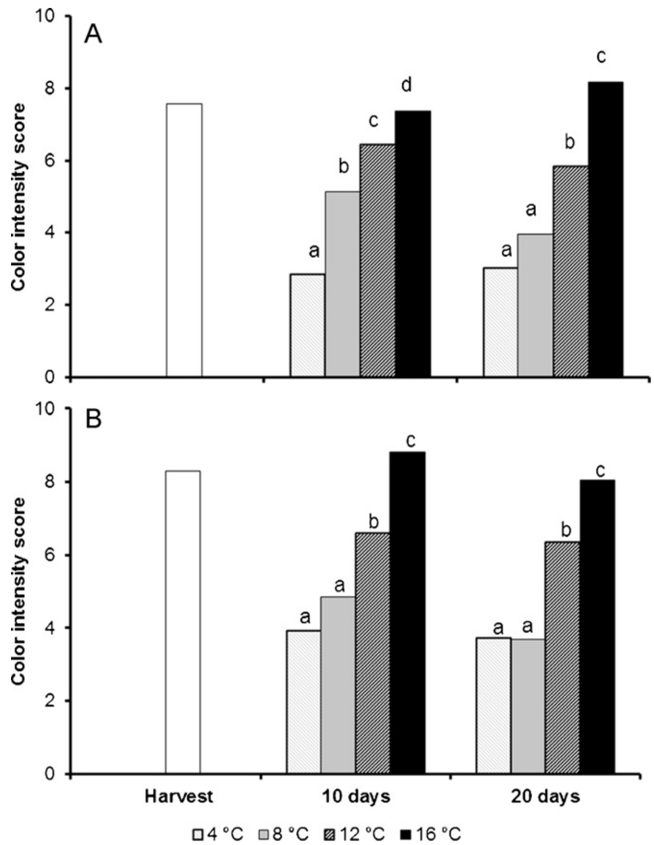

Fig. 7. Consumer panel evaluation scores of the colour intensity of red ripe tomatoes of cvs. Cappricia (panel A) and Amoroso (panel B) at harvest and following 10 and 20 days storage at different temperatures. Values are the mean of 30 evaluations with indicated statistical differences (significance level 0.05).

treatments (at 40 and 50 °C) had very similar results (data not shown). Although symptoms of chilling injury can be alleviated in tomatoes in earlier ripening stages (Luengwilai et al., 2012), heat shock apparently does not prevent lycopene degradation in red ripe tomatoes. Heat shock treatments induce the expression of heat shock proteins that may act as antioxidants under oxidative stress conditions (Levine et al., 1996). The expression of various tomato heat shock proteins is mainly induced in tomato fruit at the breaker stage when chloroplasts are transformed in chromoplasts (Neta-Sharir et al., 2005). Heat treatments in red ripe tomatoes might not therefore be accompanied by the induction of sufficient heat shock proteins or the lycopene decay at chilling temperature is not caused by oxidative stress.

3.3. *Effect of low temperature storage on colour*

The analytical measurements of lycopene during storage with HPLC and with the Pigment Analyzer were linearly correlated with a high correlation coefficient for both cv. Cappricia ($R^2 = 0.88$) and cv. Amoroso ($R^2 = 0.83$) (Fig. 5).

Colorimetric analysis with Minolta Lab was not always useful for detecting these colour differences since the chromaticity indexes (L^*, a^*, b^*, C^*, h^*) were not suitable to monitor the colour change during the cold storage (data not shown). Even the combination of these indexes (Arias et al., 2000), such as the a^*/b^* ratio, did not give useful results for both cultivars (Fig. 5). The correlation between lycopene content and a^*/b^* for the cv. Cappricia was similar to the one obtained with the Pigment Analyzer ($R^2 = 0.86$), while for the cv. Amoroso there was no correlation ($R^2 = 0.25$).

Fig. 6 shows chromaticity, RGB and NAI values graphically expressed in ranges that can be expected for orange to red tomatoes (Arias et al., 2000; Schouten et al., 2007). Chromaticity a^* values measured over time for cv. Cappricia were consistently higher than those of cv. Amoroso which is not in accordance with the lower lycopene levels in cv. Cappricia compared to cv. Amoroso. The a^*/b^* values over time for cv. Amoroso were unaffected by the cold treatment, again not in accordance with the decrease in lycopene content. Colour expressed as 1000/R was rather constant over time for both cultivars and not a useful indicator of lycopene content. The nature of remittance spectroscopy likely allows for probing the pericarp for a significant part in the radial direction. In the case of reflectance-based measurements such as chromaticity and RGB data are much more likely to be influenced by cuticle thickness or surface structure that varies per cultivar (Allende et al., 2004; Hetzroni et al., 2011). In addition, possible differences between lycopene levels in peel and pericarp (Sharma and Le Maguer, 1996; Marković et al., 2010) may cause different results when using different methods to assess colour. This might explain why the link between chromaticity values and lycopene level is sometimes strong (Arias et al., 2000) and sometimes weak (López et al., 2001).

For tomatoes of both cultivars stored at low temperatures a loss of red colour over time was visible by eye as evaluated by the consumer panel (Fig. 7). A good correlation was found between the scores by visual judgement of colour and the lycopene content. It seems from these experiments that the human eye is better able to assess colour/lycopene in tomato than tristumulus and RGB measurements. Only the NAI values showed a pattern very similar to the change in lycopene content.

4. Conclusions

Storage of tomatoes at temperatures below 12 °C, a common practice for consumers, induces lycopene degradation and, consequently, a reduction of the presumed health promoting value and external visual quality. Lycopene content of pericarp tissue can be assessed accurately and non-destructively by visible remittance spectroscopy. Comparison with tristimulus and RGB image analysis measurements turned out favourable for remittance spectroscopy likely due the deeper penetration depth into the pericarp tissue.

Acknowledgements

Authors wish to acknowledge the financial support of The Greenery BV and Rijk Zwaan BV. We also thank the tomato grower Harry Augustijn for delivery of fruit and the students Alberto Algarra Alarcon, Dube Praxedis, Tigist Nardos Tadesse and Xiao Cui for their help with the measurements.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.postharvbio.2012.05.008.

References

Allende, A., Desmet, M., Vanstreels, E., Verlinden, B.E., Nicolai, B.M., 2004. Micromechanical and geometrical properties of tomato skin related to differences inpuncture injury susceptibility. Postharvest Biology and Technology 34, 131–141.

Arias, R., Lee, T., Logendra, L., Janes, H., 2000. Correlation of lycopene measured by HPLC with the L^*, a^*, b^* colour readings of a hydroponic tomato and the relationship of maturity with colour and lycopene content. Journal of Agricultural and Food Chemistry 48, 1697–1702.

Barnley, P.M., 2000. Is lycopene beneficial to human health? Phytochemistry 54, 233–236.

Clinton, S.K., 1998. Lycopene; chemistry, biology and implications for human health and diseases. Nutrition Reviews 56, 35–51.
Conn, P.F., Schalch, W., Truscott, T.G., 1991. The singlet oxygen and carotenoid interaction. Journal of Photochemistry and Photobiology B: Biology 11, 41–47.
D'Souza, M.C., Singha, S., Ingle, M., 1992. Lycopene concentration of tomato fruit can be estimated from chromaticity values. HortScience 27, 465–466.
Gómez, 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. Journal of the Science of Food and Agriculture 81, 1101–1105.
Gray, J.E., Picton, S., Giovannoni, J.J., Grierson, D., 1994. The use of transgenic and naturally occurring mutants to understand and manipulate tomato fruit ripening. Plant, Cell and Environment 17, 557–571.
Hetzroni, A., Vana, A., Mizrach, A., 2011. Biomechanical characteristics of tomato fruit peels. Postharvest Biology and Technology 59, 80–84.
Hu, M.Y., Li, Y.L., Jiang, C.H., Liu, Z.Q., Qu, S.L., Huang, Y.M., 2008. Comparison of lycopene and fluvastatin effects on atherosclerosis induced by a high-fat diet in rabbits. Nutrition 24, 1030–1038.
Ilahy, R., Hdider, C., Lenucci, M.S., Tlili, I., Dalessandro, G., 2011. Phytochemical composition and antioxidant activity of high-lycopene tomato (*Solanum lycopersicum* L.) cultivars grown in Southern Italy. Scientia Horticulturae 127, 255–261.
Jackman, R.L., Gibson, H.J., Stanley, D.W., 1992. Effects of chilling on tomato fruit texture. Physiologia Plantarum 86, 600–608.
Karppi, J., Kurl, S., Nurmi, T., Rissanen, T.H., Pukkala, E., Nyyssönen, K., 2009. Serum lycopene and the risk of cancer: the kuopio ischaemic heart disease risk factor (KIHD) study. Annals of Epidemiology 19, 512–518.
King, M.M., Ludford, P.M., 1983. Chilling injury and electrolyte leakage in fruit of different tomato cultivars. Journal of American Society of Horticultural Science 108, 74–77.
Kuckenberg, J., Tartachnyk, I., Noga, G., 2008. Evaluation of fluorescence and remission techniques for monitoring changes in peel chlorophyll and internal fruit characteristics in sunlit and shaded sides of apple fruit during shelf-life. Postharvest Biology and Technology 48, 231–241.
Lana, M.M., Dekker, M., Linssen, R.F.A., van Kooten, O., 2005. Effects of cutting and maturity on lycopene concentration of fresh-cut tomatoes during storage at different temperatures. Acta Horticulturae 682, 1871–1877.
Levine, R.L., Mosoni, L., Berlett, B.S., Stadtman, E.R., 1996. Methionine residues as endogenous antioxidants in proteins. Proceedings of National Academy of Sciences of the United States of America 93, 15036–15040.
López, J., Ruiz, R.M., Ballesteros, R., Ciruelos, A., Ortiz, R., 2001. Colour and lycopene study of several commercial tomato varieties at different harvesting dates. Acta Horticulturae 542, 243–247.
Lu, J., Charles, M.T., Vigneault, C., Goyette, B., Raghavan, G.S.V., 2010. Effect of heat treatment uniformity on tomato ripening and chilling injury. Postharvest Biology and Technology 56, 155–162.
Luengwilai, K., Beckles, D.M., Saltveit, M.E., 2012. Chilling-injury of harvested tomato (*Solanum lycopersicum* L.) cv. micro-Tom fruit is reduced by temperature pre treatments. Postharvest Biology and Technology 63, 123–128.
Lurie, S., Laamim, M., Lapsker, Z., Fallik, E., 1997. Heat treatments to decrease chilling injury in tomato fruit: effects on lipids, pericarp lesions and fungal growth. Physiologia Plantarum 100, 297–302.
Marković, K., Panjkota-Krbavčić, I., Krpan, M., Bicanic, D., Vahčić, N., 2010. The lycopene content in pulp and peel of five fresh tomato cultivars. Acta Alimentaria 39, 90–98.
Neta-Sharir, I., Isaacson, T., Lurie, S., Weiss, D., 2005. Dual role for tomato heat shock protein 21: protecting photosystem II from oxidative stress and promoting colour changes during fruit maturation. Plant Cell 17, 1829–1838.
Palozza, P., 1998. Prooxidant actions of carotenoids in biologic systems. Nutrition Reviews 56, 257–265.
Parnell, T.L., Suslow, T.V., Harris, L.J., 2004. Tomatoes: safe methods to store, preserve, and enjoy, ANR publication 8116.
Perkins-Veazie, P., Collins, J.K., 2004. Flesh quality and lycopene stability of fresh-cut watermelon. Postharvest Biology and Technology 31, 159–166.
Perkins-Veazie, P., 2007. Carotenoids in watermelon and mango. Acta Horticulturica 746, 259–264.
Pflanz, M., Zude, M., 2008. Spectrophotometric analyses of chlorophyll and single carotenoids during fruit development of tomato (*Solanum lycopersicum* L.) by means of iterative multiple linear regression analysis. Applied Optics 47, 5961–5970.
Rice-Evans, C.A., Sampson, J., Bramley, P.M., Holloway, D.E., 1997. Why do we expect carotenoids to be antioxidants in vivo? Free Radical Research 26, 381–398.
Saltveit, M.E., 2001. Chilling injury is reduced in cucumber and rice seedlings and in tomato pericarp discs by heat-shocks applied after chilling. Postharvest Biology and Technology 21, 169–177.
Saltveit, M.E., 2002. The rate of ion leakage from chilling-sensitive tissue does not immediately increase upon exposure to chilling temperatures. Postharvest Biology and Technology 26, 295–304.
Saltveit, M.E., 2005. Influence of heat shocks on the kinetics of chilling-induced ion leakage from tomato pericarp discs. Postharvest Biology and Technology 36, 87–92.
Schouten, R.E., Huijben, T.P.M., Tijskens, L.M.M., van Kooten, O., 2007. Modelling quality attributes of truss tomatoes: linking colour and firmness maturity. Postharvest Biology and Technology 45, 298–306.
Sharma, S.K., Le Maguer, M., 1996. Lycopene in tomatoes and tomato pulp fractions. Italian Journal of Food Science 8, 107–113.
Sies, H., Stahl, W., 1998. Lycopene: antioxidant and biological effects and its bioavailability in the human. Proceedings of the Society for Experimental Biology and Medicine 218, 121–124.
Suzuki, N., Mittler, R., 2006. Reactive oxygen species and temperature stresses: a delicate balance between signalling and destruction. Physiologia Plantarum 126, 45–51.
Whitaker, B.D., 1994. A reassessment of heat treatment as a means of reducing chilling injury in tomato fruit. Postharvest Biology and Technology 4, 75–83.
Zude-Sasse, M., Truppel, I., Herold, B., 2002. An approach to non-invasive apple chlorophyll determination. Postharvest Biology and Technology 25, 123–133.
Zude-Sasse, M., 2003. Non-invasive prediction of banana fruit quality using VIS/NIR spectroscopy. Fruits 58, 1–8.
Zude-Sasse, M., Birlouez-Aragon, I., Paschold, P., Rutledge, D.N., 2007. Non-invasive spectrophotometric sensing of carrot quality from harvest to consumption. Postharvest Biology and Technology 45, 30–37.