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Kinetics of changes in the physical quality parameters of fresh tomato fruits (*Solanum lycopersicum*, cv. 'Zinac') during storage

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ABSTRACT

The effects of storage at different temperatures (2, 5, 10, 15, and 20 °C) conditions on whole tomato (*Solanum lycopersicum*, cv. 'Zinac', fruits harvested at mature-green stage) quality parameters, such as colour, chilling injury, firmness, weight loss and total phenolic content, were investigated during a month period.

Storage at all temperatures had significant impact on the quality parameters analysed. Significant alterations in tomato green colour, firmness and weight loss were observed. The results also revealed a slight increase in the total phenolic content, and that refrigeration storage at 2 and 5 °C induced chilling injuries.

A fractional conversion model fitted well the experimental data on colour parameters (a^* and °h value), firmness and weight loss. The storage temperature effect was successfully described by the Arrhenius law. These results represent a good predictive tool for tomato quality estimation along the food chain.

1. Introduction

Fresh tomato (*Solanum lycopersicum*) is consumed in large quantities mainly due to its nutritional and functional properties. Tomato is rich in bioactive compounds, such as carotenoids (lycopene, β-carotene precursor to vitamin A in the human body), ascorbic acid (vitamin C), tocopherols (vitamin E) and phenolic compounds (namely flavonoids and phenolic acids) (Soto-Zamora et al., 2005). Recent epidemiological studies have also shown a high correlation between lycopene consumption from tomato and protective effects against various forms of cancer, especially prostate cancer and cardiovascular diseases (Stahl and Sies, 2005; Basu and Imrhan, 2006).

Ripening is a complex process of fruit development, which can be described as a result of biochemical and physiological changes leading to a ripe stage that culminates in dramatic changes in colour, texture, and flavour (Javanmardi and Kubota, 2006). Tomato is a climacteric and a very perishable fruit that requires the use of preservation technologies, to slow the ripening process that occurs after harvest, to maintain its quality and consequently extend produce postharvest life.

The quality of fresh tomatoes is mainly determined by appearance (colour, visual aspects, size, and shape), firmness, flavour and nutritive value. Tomato colour is the first external characteristic which determines the degree of consumer acceptance. Important colour changes occur at various stages of tomato development in terms of chlorophyll (green colour), β-carotene (orange colour) and lycopene (red colour) contents. The most visible changes are associated with chlorophyll loss (green colour) and gradual accumulation of lycopene (red colour), where plastids such as chloroplasts present in the mature-green fruit are transformed into chromoplasts. Transformation of chloroplasts to chromoplasts normally occurs simultaneously with other ripening changes such as cell wall softening (Bathgate et al., 1985).

Firmness is another important quality-related attribute in tomato and may be considered as a final quality index by which the consumer decides to purchase fresh tomato, assessing it by a "finger test" at the time of selection (Batu, 1998). The major problem concerning tomato firmness is related to tissue softening which usually involves one of two mechanisms: weight loss with turgor loss, or a result of enzymatic activity. Weight loss is a non physiological process associated with postharvest dehydration resulting in turgor loss. Fruit weight loss is affected by several pre and postharvest factors, such as harvest date and storage temperature (Alia-Tejacal et al., 2007). This parameter could be used to define tomato quality, due to its impact on the tissue which becomes dull and very soft when weight loss is high. Changes in firmness related to enzymatic activity are due to pectinmethylesterase (PME, E.C.3.2.1.11) and polygalacturonase (PG, E.C. 3.2.1.15)

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Nomenclature

a^*	CIE colour space coordinate: degree of greenness/redness
b^*	CIE colour space coordinate: degree of blueness/yellowness
C	Numerical value of quality parameter at time t (colour parameter, firmness, weight loss)
E_a	Activation energy (kJ mol^{-1})
k	Reaction rate (day^1)
L^*	CIE colour space coordinate: degree of luminosity
R	Universal gas constant (8.314 J mol^{-1} K^{-1})
t	Storage time (days)
T	Absolute temperature (K)
$°h$	Hue angle colour
RH	Relative humidity (%)
Subscripts	
0	Initial value of quality parameter at time 0 (colour parameter, firmness, weight loss)
eq	Equilibrium value
ref	Reference value

activity. Enzymatic pectin degradation by PME and PG occurs in two phases: firstly, pectin is partially demethylated by PME resulting in methanol production and in a lower degree of methylation pectin and polygalacturonic acid, and secondly, the latter is depolymerised by PG. This results in short demethylated pectin chains and consequently in drastic texture changes, namely softening (Vu et al., 2004).

A technological approach to control these quality changes is to apply postharvest technologies to extend the shelf life of fruits and vegetables, being low temperature storage widely used to fulfil these objectives (Kalt et al., 1999). Shin et al. (2008) reported that fruits stored at higher temperatures show higher respirations rates and shorter storage period, contributing to faster fruit quality decay. Soto-Zamora et al. (2005) and Polenta et al. (2006) stated that storage temperatures below 13 °C may cause a physiological disorder – chilling injury, particularly in mature green stage. Chilling injury is characterised by the increase of membrane permeability, vigour reduction and development of disease susceptibility, such as dark spots on the skin, being an important factor in assessing the tomato quality to marketing purposes. Fruits physiological disorders occur when adequate storage conditions are not met and symptoms severity depend on temperature and time of exposure. Recommend storage temperature for tomato quality maintenance depends on maturity stage (Passam et al., 2007; Sargent and Moretti, 2009; Suslow and Cantwell, 2009), cultivar (Martins et al., 2003), and storage conditions (Almeida et al., 2005).

The improvement on tomato refrigeration storage conditions is required to enhance product́s quality and ensure long shelf life. From a technological point of view, controlling food quality means controlling chemical, physical and microbiological changes during food processing and storage. However, to be able to do that, the reactions of interest need to be studied in a quantitative way. Kinetic parameters describing such changes are thus needed. Limited published data on modeling quality parameters changes of stored tomato was found. In general, these studies evaluate only one or two quality parameters (texture and weight loss, (Van Djik et al, 2006a); pectin degrading enzymes, (Van Djik et al., 2006b); colour, (Schouten et al., 2007); colour and antioxidant content, (Pék and Helyes, 2010); metabolic profile, (Oms-Oliu et al., 2011) in different tomato varieties, without performing a global quality approach, and only one or a few storage conditions (except for Lana et al., 2005).

Therefore, the main objectives of this research are: (1) to evaluate the impact of storage conditions on whole fresh tomatoes quality, namely colour, firmness, weight loss, and phenolic content; and (2) to investigate the kinetics of the quality parameters alterations of stored tomato (cv. 'Zinac') at five different temperatures. This work provides useful information about the effects of different storage temperature conditions on important quality parameters that directly affect consumer acceptance (colour, texture, weigh loss; and/or nutritional value, phenolic content), on whole tomato, cv. 'Zinac', an important cultivar in the Portuguese fresh market. Moreover, the main novelty of this work is to have the breadth of vision to understand the degradation mechanisms involved and to predict the influence of storage conditions on critical quality parameters. Thus, the data obtained were modelled and the kinetics parameters, namely reaction order, rate constant and activation energy, were obtained as helpful tools to define optimal storage conditions for maximum quality of tomato (cv. 'Zinac').

2. Material and methods

2.1. Plant material and storage conditions

Tomato (*S. lycopersicum*, cv. 'Zinac') was obtained from a commercial greenhouse Carmo & Silvério in centre west of Portugal. Fruits were harvested at mature-green stage and their classification was performed through external colour according to USDA standard tomato colour classification (USDA, 1991). Tomatoes were selected with uniform colour and size, and without bruises or signs of infection. Upon arrival to the laboratory, fruits were gently washed under running tap water, paper dried and divided into five groups of 120 fruits each (~22 kg), and stored at 2, 5, 10, 15 and 20 °C (±0.5 °C) and 90 ± 1.0% RH (FITOCLIMA S 600 Pharma, Lisboa, Portugal). Temperature and humidity were monitored with a HygroLog data logger (Rotronic AG, Bassersdorf, Switzerland). Table 1 summarizes the tomato initial quality attribute values.

2.2. Colour evaluation and chilling injury index

The colour of tomato samples was evaluated using a tristimulus colorimeter (Minolta chroma Meter, CR-300, Osaka, Japan). The instrument was calibrated using a white standard tile (L^* = 97.10, a^* = 0.19, b^* = 1.95), using the illuminate C (10th observer). A CIE

Table 1
Tomato fruits initial quality attributes (average ± standard deviation).

Quality attributes	
Colour parameters	
L^*	52.2 ± 2.4
a^*	−13.5 ± 1.1
b^*	22.6 ± 1.5
$°h$	120.7 ± 1.4
Firmness (maximum force, N)	12.8 ± 0.3
Total phenolic content (mGAE.100 g^{-1})	25.4 ± 1.6
pH	4.22 ± 0.02
Soluble solids content (°Brix)	4.43 ± 0.05