Modelización del cambio de color y firmeza de tomates (*Lycopersicum esculentum* L.) a diferentes condiciones del almacenamiento

Modelling colour and firmness changes of stored tomatoes (*Lycopersicum esculentum* L.) at different conditions

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Resumen: El efecto de temperatura y tiempo del almacenamiento en color (a* y *ºh*) y firmeza (máximo de fuerza) de tomates (*Lycopersicum esculentum* L.) se analizó a 2º, 5º, 10º, 15º y 20 ºC. El desarrollo de éstos atributos de calidad siguieron a un modelo de cinética fraccionario. El coeficiente de correlación (R^2) para los modelos eran altos, 0.94 para los parámetros del color (a* y *ºh*) y 0.84 para la firmeza. Un aumento y disminución significativa ($p<0.05$) para a* y la fuerza del máximo, respectivamente, fue observada durante el almacenamiento. Este estudio puede contribuir por lo entendimiento del efecto real de temperatura y tiempo de almacenamiento en los mais importantes atributos de calidad de tomates, color y firmeza.

Abstract: The effect of temperature and storage time on tomatoes (*Lycopersicum esculentum* L.) colour (a* and *ºh*) and firmness (maximum force) were analysed at 2º, 5º, 10º, 15º and 20 ºC. The development of these quality attributes followed a fractional kinetic model. The regression coefficient (R^2) for the generated models were high, 0.94 for both colour parameters (a* and *ºh*) and 0.84 for firmness. A significant ($p<0.05$) increase and decrease for a* and maximum force, respectively, were observed during storage. This study can contribute for the understanding of the real effect of temperature and storage time on two important quality attributes of tomatoes, such as colour and firmness.

Introduction: Tomato (*Lycopersicum esculentum* L.) is a perennial and annual fruits, belonging to Solanaceae family and is originally from Southern North Central and South America, from Mexico to Argentina. Tomato can be consumed as fresh (salads) or as processed product (juice, soup or ketchup). Tomatoes are an important contributor of carotenoids (lycopene, β-carotene), ascorbic acid (vitamin C), tocopherols (vitamin E) and phenolic compounds. (Leonardi et al., 2000). Fresh and processed tomatoes are consumed in large quantities due to its richness in such compounds believed to provide protection from or reduce the risk of chronic degenerative diseases (Soto-Zamora et al, 2005). 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 texture, colour and flavour (Javanmardi and Kubota, 2006). Tomato ripening has been widely studied aiming at the extension of tomato shelf life. It has been shown that ripening processes and storage temperature can severely affect the final quality (colour and texture) and nutrient composition of fruit (Madhavi and Salunkhe, 1998). Tomatoes colour is the first external characteristic which determines the degree of consumer acceptance. Important colour changes occurs at various stages of tomatoes development in terms of chlorophyll (green), lycopene (red) and β-carotene (orange) contents (Gómez et al., 1998). Firmness is another important tomato quality and may be the final index by which the consumer decides to purchase tomatoes, using the "finger to test" tomato firmness at the time of selection (Batu, 1998). During post-harvest it is extremely necessary to apply treatments that promote ripening control to extend fruits shelf-life (Kalt et al., 1999) and refrigerated storage is the most widely used.
The aim of this work was to evaluate the development of tomatoes colour and firmness, stored at different temperatures (2º, 5º, 10º, 15º and 20 ºC) and to determine the kinetic parameters of such quality attributes changes for a better understanding of temperature and storage time effects.

Materials and Methods: Tomatoes were 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). Fruits were divided in five groups of 120 fruits each (~ 22 kg) and stored at 2º, 5º, 10º, 15º, 20 ºC and 90% RH. For each temperature, different storage times were evaluated. Table 1 represents the initial tomatoes quality attributes values.

Table 1 – Initial values of tomatoes quality attributes.

Quality attributes		
Colour	**L***	51.04 ± 4.10
	a*	-10.71 ± 0.42
	b*	22.21 ± 3.13
	ºh	110.67 ± 3.36
Firmness	**Maximum force (N)**	10.98 ± 1.47
Total phenolics	**(mGAE.100 g^{-1})**	25.36 ± 1.59
Titratable acidity	**(g citric acid.100 g^{-1})**	0.59 ± 0.03
pH		4.22 ± 0.02
Solids soluble content	**ºBrix**	4.43 ± 0.05

Colour evaluation: Colour was evaluated with a tristimulus colorimeter (Minolta chroma Meter, CR-300, Osaka, Japan). Four determinations for each fruit were made in the equatorial zone. The instrument was calibrated against a standard white tile (L*=97.10, a*=0.19, b*=1.95), using the illuminate C. A CIE colour space co-ordinates, L*a*b* values, were determined. L* values represent the luminosity of samples (0-black to 100-white), a* and b* values indicate the variation of greenness to redness (-60 to +60) and blueness to yellowness (-60 to +60), respectively. From these, the hue colour (*ºh*, Equation 1) was calculated.

$$^{o}h = arctg\left(\frac{b*}{a*}\right) \qquad \textbf{(Equation 1)}$$

Firmness evaluation: Texture was determined by penetration test with a Texture Analyzer (TA.HDi, Stable Microsystem Ltd, Godalming, UK), using a 50 N load cell and a cylinder probe with a diameter of 2 mm. The TPA / penetration test was performed at 3 mm.s^{-1} of speed and at 7.5 mm of distance penetration. Twenty-four measurements were determined for each sample.

Kinetics parameters: The development of tomatoes colour (a* and *ºh* colour parameters) and firmness (maximum force) was described by the fractional kinetic model (Equation 2).

$$\frac{C - C_e}{C_0 - C_e} = e^{-kt} \qquad \textbf{(Equation 2)}$$

Where C is the dependent variable (a*, *ºh* or maximum force) and t the independent variable (time), C_0 the corresponding initial value at time equal to zero, and C_e the final value at equilibrium, and k is the reaction rate.
The reaction rate temperature dependence followed the Arrhenius behaviour:

$$k = k_{ref}\, e^{\left[-\frac{Ea}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]} \qquad \textbf{(Equation 3)}$$

Where k_{ref} is the reaction rate at the reference temperature, Ea the activation energy, R the universal gas constant, T the absolute temperature, and T_{ref} the reference temperature (T_{ref}=20ºC).
By substitution, Equation 2 can be expressed as:

$$\frac{C - C_e}{C_0 - C_e} = e^{\left\{-k_{ref}\, e^{\left[-\frac{Ea}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]t}\right\}} \qquad \textbf{(Equation 4)}$$

Data analysis: The effects of temperature and storage time were analyzed using Statistic v.7.0 Software (StatSoft, Inc., 2004). The differences between samples were detected through Scheffé test (significant at $p < 0.05$).

Results and Discussion: Initial a* mean value of tomatoes was -10.71 ± 0.42. The a* values increased (Fig. 1) significantly ($p<0.05$) during storage at all temperatures. These alterations represent tomato colour development from green to red. As expected, at higher temperatures the colour changes are more evident.

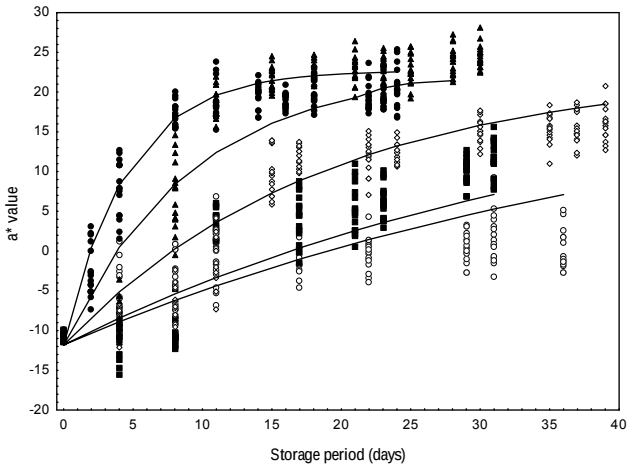

Fig. 1 – Tomatoes a* colour parameter as a function of temperature and storage time: (o) 2ºC, (■) 5ºC, (◇) 10ºC, (▲) 15ºC, (●) 20ºC. The lines represent model fits (Equation 4) to experimental data.

Initial *ºh* mean value of tomatoes was 110.67 ± 3.36. At all studied storage temperatures and times a significant decrease ($p<0.05$) of *ºh*, was observed (Fig. 2). This reflects an increase of red colour intensity on stored tomatoes.

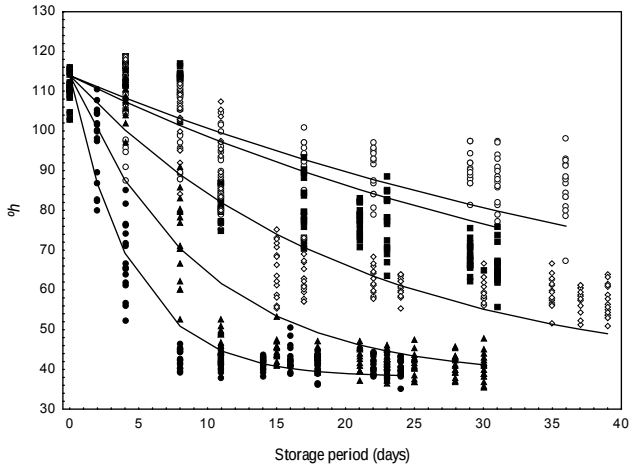

Fig. 2 – Tomatoes *ºh* colour parameter as a function of temperature and storage time: (o) 2ºC, (■) 5ºC, (◊) 10ºC, (▲) 15ºC, (●) 20ºC. The lines represent model fits (Equation 4) to experimental data.

Fig. 3 shows the maximum force of stored tomatoes at all studied temperatures. The initial mean value of maximum force was 10.98 ± 1.47 N. Tomatoes firmness decreased significantly ($p<0.05$) during storage at all temperatures, but at lower temperatures (2º and 5 ºC) the decrease was minimal when compared to the higher ones (10º, 15º and 20 ºC), where the decrease was more pronounced.

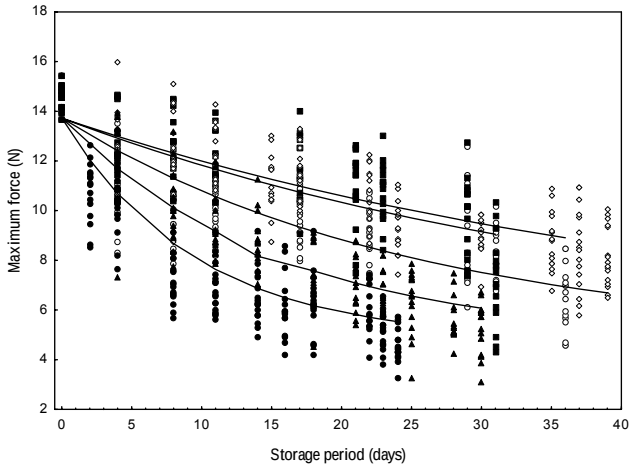

Fig. 3 - Tomatoes maximum force (N) as a function of temperature and storage time: (o) 2ºC, (■) 5ºC, (◊) 10ºC, (▲) 15ºC, (●) 20ºC. The lines represent model fits (Equation 4) to experimental data.

Table 2 presents the estimated kinetic parameters for the studied quality attributes. The fractional kinetic model and temperature Arrhenius dependence were appropriate to describe the experimental results, denoting a good normality and randomness of residuals and a high proportion of variance, of 0.94 for a* and *ºh* and of 0.84 for maximum force of tomatoes.

Table 2 – Kinetic parameters and corresponding confidence intervals at 95% of the colour parameters (a* and *ºh*) and firmness variations during storage.

Quality attribute		Kinetic parameters
Colour	a*	C_e 22.71±0.81 C_0 -11.80±0.71 $k_{20ºC}$ 0.22±0.02 min^{-1} Ea 97.01±4.50 $kJ.mol^{-1}$
	ºh	C_e 38.10±1.81 C_0 113.93±1.53 $k_{20ºC}$ 0.22±0.02 min^{-1} Ea 103.38±4.69 $kJ.mol^{-1}$
Firmness	Maximum force (N)	C_e 4,81±0.74 N C_0 13.73±0.27 N $k_{20ºC}$ 0.08±0.02 min^{-1} Ea 60.27±6.31 $kJ.mol^{-1}$

Hue colour parameter was the quality attribute that showed to be more sensitive (Ea=103.38±4.69 $kJ.mol^{-1}$) to storage temperature, contrasting with the firmness which was the less sensitive quality attribute (Ea=60.27±6.31 $kJ.mol^{-1}$).

Conclusion: During tomatoes storage, significant changes occurred in respect to its colour and texture, which are considered by consumers as important quality attributes. The obtained results could be modelled by a fractional kinetic equation which assists to the description and simulation of the behaviour of these attributes quality in tomatoes as a function of storage temperature and time.

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