Preharvest-Postharvest Interactions – the Case of Translucency and Colour in Tomatoes

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Abstract

Standard colour measurements can pose a serious problem for interpretation. For tomatoes the maturity at harvest does affect the colour that can maximally be obtained during postharvest storage. For more mature fruit up to 2 units (compared to 18 units tops) were found. This effect was ascribed to the level of a precursor produced during growth. More mature fruit also exhibit a more pronounced sensitivity to becoming translucent upon storage. This effect was also ascribed to the stage of development at harvest. Models were derived on plausible mechanisms to account for both effects of maturity at harvest in tomatoes.

INTRODUCTION

Preharvest information is the main determining factor for postharvest product response. It is generally accepted that postharvest quality attributes are determined by the growth conditions during preharvest. Even commercial companies start looking in that direction (Gorny, 2005). How these preharvest growth conditions affect the postharvest quality attributes is, however, largely unknown. The influence of preharvest growth conditions may be investigated by varying the stage of ripening at the moment of harvest and by comparing the postharvest response as a function of the stage of ripening. The stage of ripening at the moment of harvest is one of the most crucial aspects for understanding and describing postharvest behaviour (Tijskens et al., 2005). In this paper the results of two experiments on colour and translucency in tomatoes are investigated that use this system in one way or another. The first experiment describes the postharvest colour development of whole tomatoes as a function of the stage of ripening at the moment of harvest. The second experiment describes the postharvest development of both translucency and colour of cut tomatoes as a function of the stage of ripening at the moment of harvest. The aim of this paper is to show the need to assess and incorporate preharvest information regarding the stage of ripening in postharvest models for better product understanding. Also the propagation of the effects of harvest maturity from pre-harvest over postharvest to processing is highlighted.

WHOLE TOMATOES

Colour is a major postharvest quality attribute for whole tomatoes. Consumers do assess the quality of the product based, among others, on colour. Current practice in the horticultural chain is to harvest tomatoes just after they reach the breaker stage. Tomatoes in the breaker stage are unacceptable for consumption because of insufficient softness (too firm), insufficient color development (too green) and insufficient taste development. However, harvested tomatoes will mature during postharvest storage and during transport both in the chain and at the supermarket. The effect of the stage of ripening and the effect of the postharvest storage temperature on the postharvest color development is not known quantitatively. Here, color development over time and temperature of whole tomatoes will be investigated as a function of harvest maturity by applying repeated color measurements on individual tomatoes. Color data will be analyzed using a color model that expresses the extent of the postharvest coloring as a function of the initial maturity.

Colour Measurements of Whole Tomatoes

Tomatoes (*Lycopersicon esculentum* 'Bonavista') were obtained from a commercial grower and harvested with either five or six tomatoes on the truss by comparing the third tomato of the truss with colour cards ranging from 1 (dark green) to 12 (dark red). A tomato truss was assigned either as green (colour card value 1-3), breaker (4-5) or light red (6-8). After harvest, tomatoes were transported within four hours to the measuring facility, individually labelled opposite of the calyx and separated from the truss to enable colour and firmness measurements. Four tomato batches, each consisting of 16 trusses, were harvested at three different harvest maturities (green, breaker or light red). Each batch was separated into four sub-batches and stored in the dark using climate chambers at 12.0°C, 16.0°C or 19.9°C and 70% RH.

Image analysis was used for the RGB colour measurements. Colour was measured on individual tomatoes using a colour video camera in a controlled light environment (Schouten et al., 1997). After a measurement, the tomato image is separated from the background and the calyx and the light intensities for the red (R), green (G) and blue (B) colour are separately averaged over all pixels belonging to the tomato image. Tomatoes were measured every day (storage at 19.9°C) or every other day (storage at 12 and 16°C), starting one day after harvest (day 0) up to day 17.

Colour Modelling of Whole Tomatoes

The tomato colour model will only focus on the synthesis of red components in the tomato skin. The model assumes that a colourless precursor is converted into red components (Red) (mainly lycopene) by an autocatalytic enzyme or by ethylene (E). The amount of precursor at the moment of harvest determines the extent of postharvest colouring (Eq. 1).

$$prec + E \xrightarrow{k_r} 2 \cdot E + Red \qquad (1)$$

with k_r (in day^{-1}) the reaction rate constant for the colour change. Another assumption of the colour model is that the precursor production is light dependent (Eq. 2), just as was proposed for the cucumber colour precursor (Schouten et al., 2004).

$$\xrightarrow{k_{prec}} prec \qquad (2)$$

with k_{prec} (in day^{-1}) the reaction rate constant for the precursor production. By this combined mechanism the postharvest colour behaviour of tomatoes is now also dependent on the precursor accumulation during the preharvest phase as it assumed that tomatoes will be stored in the dark after harvest. To describe the postharvest behaviour of Red over time the ordinary differential equation derived from Eq. 1 by applying the rules of chemical kinetics needs to be solved analytically incorporating the initial conditions at harvest. Applying the fundamental laws of mass conservation the postharvest behaviour of colour of a tomato can then be expressed in terms of time after harvest (t), the biological age at harvest (t_{age}), the initial colour at harvest (Red_0) and the asymptotic colour value Red_{max} and Red_{min} at respectively plus and minus infinite time (Eq. 3). t_{age} is the biological age expressed as the time (in days) that differentiates each tomato in terms of preharvest precursor accumulation.

$$Red(t) = (Red_{max} + k_{prec} \cdot t_{age}) - \frac{(Red_{max} + k_{prec} \cdot t_{age}) - Red_{min}}{1 + \frac{Red_0 - Red_{min}}{(Red_{max} + k_{prec} \cdot t_{age}) - Red_0} \cdot e^{-t \cdot k_r \cdot ((Red_{max} + k_{prec} \cdot t_{age}) - Red_{min})}} \qquad (3)$$

Reaction rate constants are assumed to depend on temperature according to

Arrhenius' law. However, the temperature dependency can only be determined when different temperatures are used. As no temperature treatments were applied during preharvest, the temperature dependence could only be determined for k_r and not for k_{prec}.

Table 1 shows the results of the non-linear, mixed effects, regression analysis using the colour data and the model equation of Eq. 3 applying the nlme package of the R-Project (R Development Core Team, 2003). Fig. 1 shows the red colour development of tomatoes within one truss as a function of storage temperature and maturity at harvest. Within one truss the tomatoes show a large variation in colour development; tomatoes closer to the first position (closest to the plant) show a more pronounced colour development after postharvest storage than tomatoes further away from the tomato plant (Tijskens et al., 2003). Furthermore, the final colour after postharvest storage appears to depend on the position in the truss; tomatoes closer to the first position (closest to the plant) show a higher final colour than after postharvest storage than tomatoes further away from the tomato plant. The position in truss is strongly linked to maturity, as the tomatoes closest to the plant emerge earlier and develop faster during preharvest than tomatoes further away from the plant. As the tomatoes within a truss are less mature for a green batch compared to those in a light red batch, the final colour for tomatoes in a light red batch will be higher (more dark red) than those in a green batch. The effect on the final colour depends on the biological age at harvest (t_{age}) times the value of k_{prec} (Eq. 3). Interestingly, the value of k_{prec} depends on the season; the value in summer is twice as high as the value in winter (data not shown). It is tempting to link k_{prec} with the induction of the phytochrome signal transduction pathway during the preharvest period. Alba et al. (2000) have also reported that red light treatment of mature green fruit resulted in increased lycopene accumulation that could be reversed by exposure to far red light thereby showing that light plays a crucial role in the phytochrome mediated carotenoid biosynthesis.

CUT TOMATOES

For cut tomatoes, colour and translucency are important quality attributes. Translucency can be observed as glassiness in products due to changes in light reflection by physical and structural changes within the product. A nice example that you all know is the darker colour of jeans when wet. The total amount of colouring matter did not change, only the physical state. From this example, it is already clear that colour and translucency can be considered as the two sides of appearance. So, when measuring RGB values (and L*a*b* values for that matter) we have to consider changes in both chemistry and physics. In the next example an attempt is made to highlight this interaction.

Translucency

Details for materials and methods of this experiment can be found in Lana et al. (2006). Tomatoes ('Belissimo') were harvested at three stages of maturity: green, pink and red. RGB values of cut tomato slices and intact tomatoes were measured using the same video technique as in previous experiment. The appearance or visual quality of fresh-cut tomatoes, especially the development of translucency in the pericarp tissue, was highly dependent on the ripening stage of the fruit at harvest. Based on a very simple but plausible mechanism (Eq. 4), the behaviour of visual observed translucency (tr) can be deduced (chemical kinetics) and analysed as a simple exponential function (Fig. 2) increasing towards an asymptote (Eq. 5).

$$ST + st \xrightarrow{k_t} tr + st \tag{4}$$

$$tr = (tr_{max} - tr_0) \cdot (1 - e^{-k_t \cdot st_0 \cdot t}) + tr_0 \tag{5}$$

The parameter st_0 represents the sensitivity to translucency, which depends on the stage of maturity at harvest of tomatoes, while tr_0 is the initial translucency (=0) and st represent the susceptibility to become translucent. ST is the potential translucency (=tr_{max}-tr_0). In Table 2 the results of the analysis are shown. Its rate of translucency development increased about 12 times from breaker (stage I) to full red stage (stage III), as can be taken from the values of the susceptibility to become translucent (st) at these stages. So during growth of tomatoes, not only the colour changes upon ripening, but also the susceptibility to translucency. The effect of storage temperature was minimal (data not shown). So, the rate of the postharvest, post-cutting process of translucency development does depend strongly on the maturity at harvest.

Combined RGB Colour Aspects + Translucency: Appearance

At the same time translucency develops, the colour aspects (RGB values) change more pronouncedly the riper the fruits were. RGB values reflect the changes in overall appearance, not only the colour aspect. And overall appearance is a combination of the chemical and the physical state of the item.

A model was developed to include both aspects to describe changes in RGB values. It is based on a plausible mechanism. Its deduction can be found in Lana et al. (2006) and is further omitted here. The analytical solution simplified for measurements against a white background only is given by Eq. 6. Basically, it is again a simple exponential behaviour, however, with initial ($_0$) and final ($_{fin}$) values depending on the colour aspect (ca) under consideration (R, G or B), combined with the changing susceptibility to translucency depending on the stage of maturity at harvest.

$$ca = \left(ca_0 - ca_{fin}\right) \cdot e^{-\left(k_c + k_t \cdot st_0\right) \cdot t} + ca_{fin} \qquad (6)$$

In this equation, k_t is the rate constant of translucency development (physical) found earlier (Table 2) while k_c is the rate constant for the colour change (chemical). The results of the nonlinear regression analysis (for a white background only) can be found in Table 3. The behaviour is shown in Fig. 3.

The development of translucency was clearly separated from normal colour changes in the R value (Lana et al., 2006). The B and G value do also reflect translucency development, but less clearly separated. On visual inspection of the data, the effect of stage of maturity seemed to be expressed in the amplitude of change of the colour aspect R, rather than in its rate constant. However, nonlinear regressions analysis showed (Table 3) that the range was more or less the same (Table 4) but the effect has to be found again in the rate constant, greatly increasing with maturity at harvest as can be taken from the range in st value (Table 2). An exception to this is the range for the G value (Fig. 3). Here, both rate and range seem to depend on maturity at harvest.

DISCUSSION

Although the results of both studies seem to indicate completely different behaviour, the similarities are nevertheless striking. Development of colour of whole tomatoes depends on the maturity at harvest, increasing the range over which colour can change with increasing maturity. In other words: tomatoes harvested at the green stage will not turn as dark red as a tomato harvested at the full red stage due to different amounts of precursor present at harvest.

The colour development of cut tomatoes seems to be independent of maturity, at least at the rather low temperatures applied (k_c is very low). There are, however, indications that also here the range of change depends on the maturity (G value). Development of translucency after harvesting and cutting is characterised by an increased sensitivity to translucency with increasing maturity at harvest, increasing the rate of change about 12 times from green to mature red tomatoes.

The generic importance of these findings lies primarily in the preharvest-post-harvest interactions. Understanding these interactions and integrating them in postharvest handling and processing procedures seem to become a major issue for agricultural research. In conclusion, maturity at harvest has a clear effect on the postharvest colour development of tomatoes.

Literature Cited

Alba, R., Cordonnier-Pratt, M.M. and Pratt, L.H. 2000. Fruit-localized phytochromes regulate lycopene accumulation independently of ethylene production in tomato. Plant Physiol. 123:363-370.

Gorny, J.R. 2005. Leveraging innovative fresh-cut technologies for competitive advantage. Acta Hort. 687:141-148.

Lana, M.M. and Tijskens, L.M.M. 2006. Modelling colour aspects (RGB) and translucency of fresh cut tomatoes. Postharv. Biol. Technol. (in press).

R Development Core Team. 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, URL http://www.R-project.org.

Schouten, R.E., Otma, E.C., van Kooten, O. and Tijskens, L.M.M. 1997. Keeping quality of cucumber fruits predicted by the biological age. Postharv. Biol. Technol. 12:175-181.

Schouten, R.E., Jongbloed, G., Tijskens., L.M.M. and van Kooten, O. 2004. Batch variability and cultivar keeping quality of cucumber. Postharv. Biol. Technol. 32:299-310.

Tijskens, L.M.M., Veltman, R.H., Heuvelink, E.P. and Simčič, M. 2003. Modelling post-harvest quality behaviour as affected by preharvest conditions. Acta Hort. 599:469-477.

Tijskens, L.M.M., Heuvelink, E., Schouten, R.E., Lana, M.M. and van Kooten, O. 2005. The biological shift factor. Biological age as a tool for modelling in pre- and post-harvest horticulture. Acta Hort. 687:39-46.

<u>Tables</u>

Table 1. Overview of parameter estimates and their standard error (s.e.) for the whole tomato colour model.

	Dim	estimate	s.e.
$k_{r,ref}$	day^{-1}	0.02861	0.00043
E_r	J/mol	5016	155
k_{prec}	day^{-1}	0.1584	0.0047
Red_{min}	-	4.085	0.067
Red_{max}	-	17.109	0.014
R^2_{adj}	%	97.2	
T_{ref}	K	285 (12°C)	

Table 2. Results on non-linear analysis of mean translucency development in cut tomato slices as a function of fruit maturity stage at harvest.

	Dim	Mean	
		estimate	s.e.
tr_0	-	0	fixed
tr_{max}	-	3.924	0.2
st_I	-	0.0778	0.0195
st_{II}	-	0.2059	0.0453
st_{III}	-	1	fixed
kt	day^{-1}	0.897	0.201
R^2	-	93.3	
N_{obs}	-	21	

Table 3. Results of the nonlinear regression analysis based on Eq. 6.

	Dim	Mean					
		R		G		B	
		estimate	s.e.	estimate	s.e.	estimate	s.e.
$ca_{0,I}$	-	180.241	0.857	152.65	1.44	74.883	0.689
$ca_{0,II}$	-	179.848	0.842	124.82	1.43	69.412	0.639
$ca_{0,III}$	-	170.161	0.897	97.86	1.41	60.704	0.647
$ca_{fin,I}$	-	162.34	3.99	114.11	3.85	61.22	2.76
$ca_{fin,II}$	-	167.42	2.04	97.84	2.23	59.49	1.45
$ca_{fin,III}$	-	157.93	1.4	81.05	1.59	52.676	0.998
k_c	day^{-1}	-0.03009	0.00584	0.0552	0.0105	-0.05174	0.00841
$k_t{}^a$	day^{-1}	0.897	0.201	0.897	0.201	0.897	0.201
$R^2{}_{adj}$	-	97.7		97.5		94.7	
N_{obs}	-	84		84		84	

Note: $St_{0,I}$ to $st_{0,II}$ were fixed at values from Table 2

Table 4. Difference between initial and final condition (white background).

Stage	ca_0-ca_{fin}		
	R	G	B
I	17.901	38.54	13.663
II	12.428	26.98	9.922
III	12.231	16.81	8.028

Figures

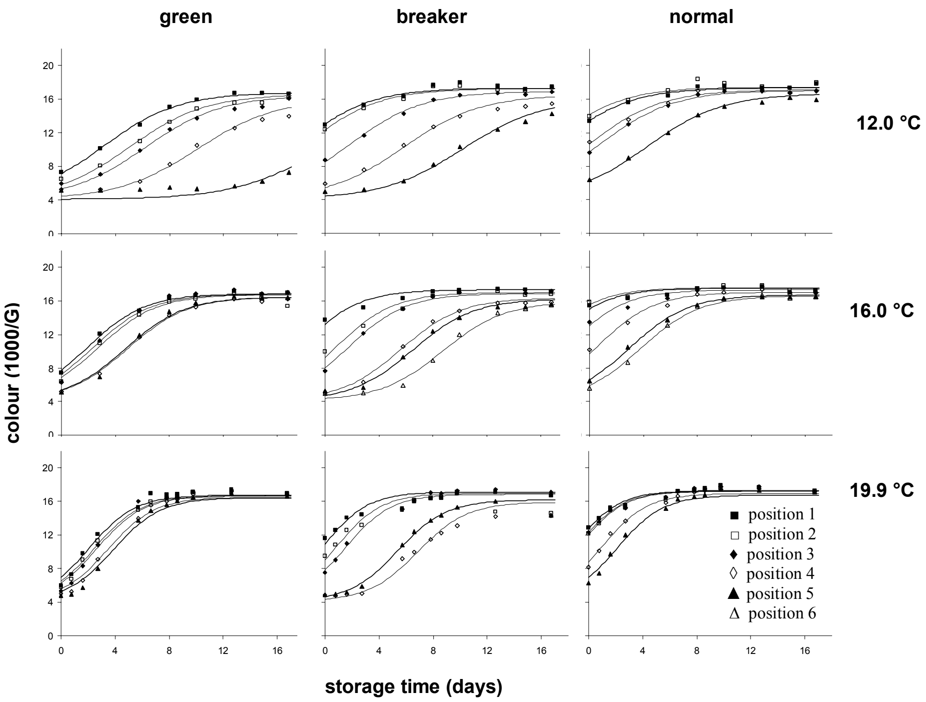

Fig. 1. Simulated and measured colour behaviour during postharvest storage for tomatoes from one truss as a function of temperature, storage time and position in the truss.

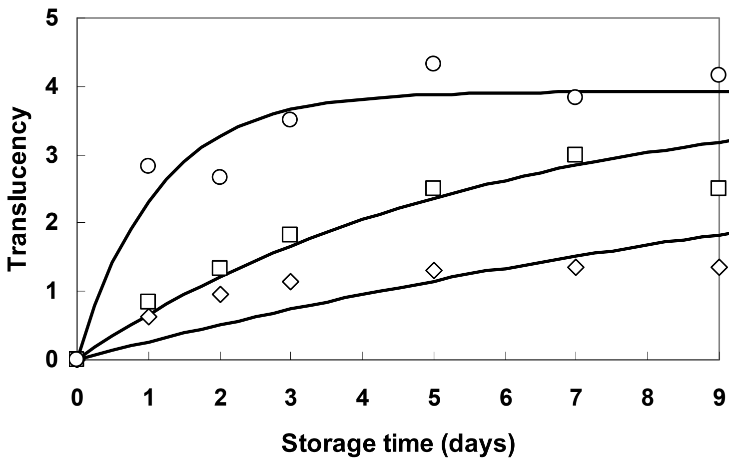

Fig. 2. Translucency grade of cut tomato slices obtained from fruit harvested at three maturity stages. Symbols represent measured values for ◊ (stage I), □ (stage II) and ○ (stage III). Solid lines represent values simulated according to Eq. 5 and the parameter values in Table 3.

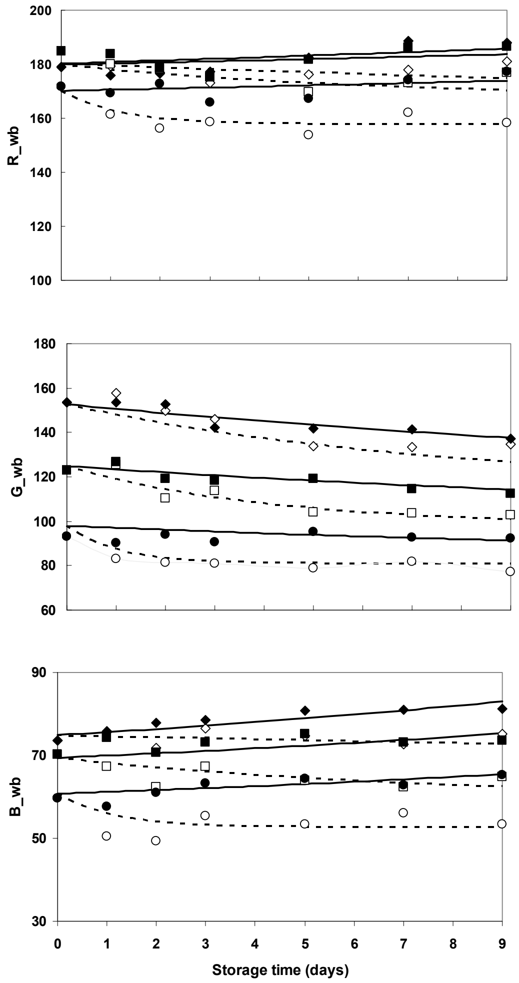

Fig. 3. Red (R), Green (G) and Blue (B) values on white (wb) background of intact (black symbols) and cut (white symbols) tomato fruit harvest at successive maturity stages I (♦ ◊), II (■ □) and III (● ○) and stored at 5°C.