Acceptance and Rejection of Tomato Batches in the Chain: The Influence of Harvest Maturity and Temperature

R.E. Schouten[1], T.P.M. Huijben[1], L.M.M. Tijskens[1,2] and O. van Kooten[1]
[1]Horticultural Production Chains
Wageningen University
The Netherlands
[2]Agrotechnology & Food Innovations
The Netherlands

Keywords: modelling, tomatoes, colour, firmness, maturity, storage, acceptance period

Abstract

Current practice in the horticultural chain is to harvest tomatoes just after they reach the breaker stage and transport them at the lowest temperature that will not induce chilling injury. Is this practice correct, or should this depend on the stage of maturity of each batch and the transport/storage temperature? This paper proposes a combination of quality measurements per batch, modelling and consumer limits with regard to quality attributes to solve this question. Quality of tomatoes is mostly limited by colour and firmness. Consumer limits were determined by supplying a group of consumers with tomatoes differing in maturity and asking them which tomatoes were acceptable with regard to consumption overnight or consumption over the weekend. Tomatoes were rated acceptable when colour and firmness were between the consumer limits for consumption overnight and consumption over the weekend. In a separate experiment a total of six tomato batches were harvested, differing in harvest maturity (breaker, normal, red) and from two growers. Tomatoes were stored at three different temperatures. Colour was measured non-destructively by image analysis and firmness by a non-invasive limited-compression technique. Firmness and colour batch models were calibrated to describe the variation in colour and firmness over time and with temperature as a function of the maturity at harvest expressed either in terms of colour or of firmness. By combining consumer limits and the colour or firmness maturity at harvest for each batch it was possible to estimate the time when the majority (80%) of a batch gets accepted (ripe) and the time when the majority is rejected (overripe). The acceptance period was defined as the time of rejection minus the time of acceptance. The acceptance period was calculated for all six batches as a function of storage temperature. As expected, with increasing storage temperature the acceptance period generally diminished. However, the combination of a breaker stage and a low storage temperature is not always the best choice: when the colour becomes (finally) acceptable the firmness might (already) be too soft, resulting in a batch that will never be accepted. Interestingly, the acceptance period for tomatoes from both growers is almost the same for batches harvested at the red and normal maturity. There is, however, a large difference between growers: the acceptance period for these batches varies for the first grower between 11 and 17 days and for the second grower between 4 and 14 days at 12°C. This difference is indicative of the large biological variation present. Measuring and applying these biological variation components in combination with temperature management may be an appealing criterion to optimise the tomato chain in terms of quality and profitability.

INTRODUCTION

Current practice in the horticultural chain is to harvest tomatoes just after they reach the breaker stage and transport them at the lowest temperature that will not induce chilling injury. This may result in an insufficient colour (pink colour stage) and firmness development (too firm) at the moment of consumption. On the other hand, when tomatoes are harvested and transported over long distances or stored too long in retail shops, firmness can become a limiting quality attribute, now due to tomatoes being too soft. In other words: the quality attributes of both colour and firmness are of importance for consumers (Tijskens and Evelo, 1994).

A generally accepted definition of keeping quality is the time a commodity remains acceptable. Keeping quality depends on the product quality and on the level of the consumer limits. Consumer limits depend largely on the level of economical and psychosocial circumstances and product quality depends on the intrinsic product properties. Acceptability is closely linked to keeping quality, the difference being that when acceptability is discussed specific product properties and consumer limits quality limits need to be stated while keeping quality is a much more general concept (Tijskens, 2001). Determining the acceptability for a batch of tomatoes is complex as it depends on **(a)** consumer limits that indicate that the batch is ripe enough for consumption and consumer limits that indicate the batch being overripe (also unfit for consumption) **(b)** initial colour and firmness at harvest **(c)** colour and firmness behaviour as function of storage time and storage temperature.

The aim of this paper is to build an acceptability model for tomatoes and use it to investigate the effect of harvest maturity and storage temperature on acceptability for two growers. To do so, experiments to acquire the consumer limits, colour and non-destructive, limited-compression firmness measurements and quality models are combined.

MATERIALS AND METHODS

Tomatoes

Tomatoes (*Lycopersicon esculentum* cv. 'Bonavista') were obtained from two commercial growers and harvested with either five or six tomatoes on the truss. Colour stage at harvest was assigned by comparing the third tomato of the truss with a colour card. This colour card shows predefined colour stages for tomatoes, 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 pink (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.

Tomatoes were harvested at the breaker, pink or red colour stage from two growers. Each of the six batches consisted of four tomato trusses. Each batch was separated into three sub-batches and stored in the dark using climate chambers at 16.0, 19.9 or 24.5°C and 70% RH.

Consumer Limits

About 50 tomato trusses of varying maturities were offered for inspection to three consumer groups of four persons each. All groups were asked to classify trusses into acceptable or rejected for purchase on the basis of colour (sight) and firmness (touch) for tonight's consumption. After randomisation of the trusses, the question was repeated except not for tonight's consumption but consumption after the weekend (in 3-4 days). Consequently, the colour and firmness of all tomatoes were measured individually to assess the consumer limits.

Colour and Firmness Measurements

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 and 24.5°C) or every other day (16°C), starting one day after harvest (day 0) up to day 30.

Firmness was measured with a Zwick Z2.5/TS1S materials testing machine (Ulm, Germany) using a cylinder probe (Ø 15 mm). Tomatoes were placed on the plastic ring to keep the tomatoes upright during measurement. Firmness was determined as the maximum force needed to compress the skin 1 mm at 40 mm/min after lowering the probe quickly (400 mm/min) until the tomato skin was touched.

Individual Colour Model

A logistic curve has been used to describe the green to red colour change process in tomato (Tijskens and Evelo, 1994; Hertog et al., 2004). The proposed logistic 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 ethylene (E). The amount of precursor at the moment of harvest determines the extent of postharvest colouring (Eq.1).

$$prec + E \xrightarrow{k_R} 2 \cdot E + Red \qquad \text{Eq.1}$$

with k_R (in day^{-1}) the reaction rate constant for the colour change. Applying the fundamental laws of mass conservation the postharvest behaviour of a tomato can then be expressed in terms of time after harvest and the initial colour at harvest, Red_0 (Eq 2).

$$Red(t) = Red_{max} - \frac{Red_{max} - Red_{min}}{1 + \frac{Red_0 - Red_{min}}{Red_{max} - Red_0} \cdot e^{-t \cdot k_R \cdot (Red_{max} - Red_{min})}} \qquad \text{Eq.2}$$

Tomatoes were harvested at different maturities. It might be assumed that the tomato colouring reaction after harvest is also occurring before harvest, as tomatoes will also ripen attached to the plant. In that case the colour at harvest, Red_0, can be expressed according to Eq. 3.

$$Red_0 = Red_{max} - \frac{Red_{max} - Red_{min}}{1 + \frac{Red_{ref} - Red_{min}}{Red_{max} - Red_{ref}} \cdot e^{-\Delta t_C \cdot k_{Rpre} \cdot (Red_{max} - Red_{min})}} \qquad \text{Eq. 3}$$

with k_{Rpre} (in day^{-1}) the reaction rate constant for the colour change during preharvest and Red_{ref} an arbitrary reference colour. Δt_C is the (colour) biological age expressed as the time (in day) needed to change the colour from Red_{ref} to Red_0. Red_{ref} has been chosen as the average pink colour. This means that a tomato with a positive Δt_C value is riper and a tomato with a negative Δt_C value is less ripe than a pink tomato with regard to colour. Substituting Eq. 3 into Eq. 2 results in an expression for the postharvest colour behaviour as function of the preharvest growing conditions with regard to colour formation, the colour at harvest, the storage time after harvest and the (colour) biological age at harvest. The reaction rate constants k_R is assumed to depend on temperature according to Arrhenius' Law.

Individual Firmness Model

Lana et al. (2005) used the approach that firmness is built up by a variable part (e.g. pectin originated firmness) that changes according to a first order (exponential) mechanism and a fixed part (e.g. structure based firmness). Here, it is assumed that tomatoes that have reached the commercial size are already predominantly losing firmness, while the loss of firmness after harvest will be even faster, given that the firmness generation during preharvest no longer takes place. Mathematically, this can be represented as two first order reactions (Eq. 4, Eq. 5).

$$F \xrightarrow{k_{Fpre}} \text{(irrelevant breakdown products)} \qquad \text{Eq. 4}$$

$$F \xrightarrow{k_{Fpost}} \text{(irrelevant breakdown products)} \qquad \text{Eq. 5}$$

with k_{Fpre} and k_{Fpost} the reaction rate constants for the firmness breakdown before and after harvest respectively. The differential equation describing the firmness decay during postharvest (Eq. 9) was solved analytically (Eq 6):

$$F(t) = (F_0 - F_{fix}) \cdot e^{-k_{Fpost} \cdot t} + F_{fix} \qquad \text{Eq. 6}$$

with F_0 the firmness at harvest (in N) and F_{fix} the invariable part at infinite time (in N).

The firmness at harvest, F_0, can be described by the firmness decay during preharvest (Eq. 5) accoding to Eq. 7

$$F_0 = (F_{ref} - F_{fix}) \cdot e^{-k_{Fpre} \cdot \Delta t_F} + F_{fix} \qquad \text{Eq. 7}$$

with F_{ref} an arbitrary reference firmness and Δt_F the (firmness) biological age expressed as the time (in day) needed to change the firmness from F_{ref} to F_0. F_{ref} has been chosen as the average firmness at harvest for all tomatoes harvested at the pink colour stage. Substituting Eq. 7 into Eq. 6 results in an expression for the postharvest firmness behaviour as function of the preharvest growing conditions with regard to firmness breakdown, the firmness at harvest, the storage time after harvest and the (firmness) biological age at harvest. The reaction rate constants k_{Fpost} is assumed to depend on temperature according to Arrhenius' Law.

Batch Quality Models

The variation in postharvest storage behaviour can be interpreted as the expression of the same generic product behaviour, with only the moment of harvest as a cause of random variation (Hertog et al., 2004; Tijskens et al., 2005). This random variation as a result of harvesting products within a short time period, from one cultivar and one grower might be regarded as batch variation. In case of tomatoes, batches of tomatoes might be characterised as function of grower and harvest maturity with regard to colour and firmness. The generic mathematical representation of batch models has been described in detail in Schouten et al. (2004) and describes the probability that quality measurements described by a quality model belong to a frequency class, with certain class borders, and assuming that the biological age is normally distributed. The colour batch model characterises colour behaviour over time as function of the average biological age at harvest (μ_C), the standard deviation for colour (σ_C), the storage temperature and storage time. The firmness batch model characterises batch behaviour as function of the average biological age at harvest (μ_F), the standard deviation (σ_F), the storage temperature and storage time.

Statistical Analysis

The equations and mathematical description of the colour and firmness models were developed using Maple V (release 10, Waterloo Maple Software, Canada). For the statistical analysis of the individual colour and firmness models, the nlme (non-linear mixed-effects) library of R (http://www.R-project.org) was used. Batch models were calibrated applying the non-linear regression routine of Genstat 5 (release 3.2, Lawes Agricultural Trust, Rothamsted Experimental Station, UK).

RESULTS AND DISCUSSION

Consumer Limits

Fig. 1 shows the results of the classification of tomatoes for consumption either tonight or over the weekend for whole trusses, meaning that if one tomato of the truss was rejected the whole truss was rejected too. Tomatoes deemed acceptable were sorted from lowest to highest ranking on either colour or firmness. The consumer limits for firmness were determined at the 5% (ripe->overripe) and 95% (unripe->ripe) level, the consumer limits for colour at the 5% (unripe->ripe) level, as no upper limit (very dark red) was apparent (Fig. 1). Clearly, tomatoes for tonight's consumption need to be in a riper stage than for consumption over the weekend.

Individual Colour and Firmness Model

The colour data, expressed as 1000/G, were used to calibrate the colour model. Table 1 shows the parameter estimates of the non-linear mixed effects regression analysis for the colour and the firmness model. Fig. 2 shows the colour and firmness development of a sample of the tomatoes together with model simulations applying the models.

Batch Quality Models

All colour and firmness distributions obtained during postharvest storage belonging to one batch were analysed to assess the batch parameters at harvest (Table 2). For grower 1 the colour- and firmness biological age are of comparable size and they follow, in general, the same trend as function colour stage at harvest. This trend is also observed for grower 2. However, the firmness biological age appears to have shifted about 5 days compared to the colour biological age. This means that the tomatoes of grower 2 at harvest are less firm than those of grower 1, irrespective of colour stage at harvest.

Acceptability Model

By combining consumer limits (Fig. 1), batch parameters (Table 2) and parameters regarding the temperature dependence of the colour and firmness process (Table 1) it is possible to estimate the time before the majority of the batch gets accepted (is ripe enough) and the time before the majority of the batch is rejected (overripe) as a function of temperature. This is estimated by calculating the moment when the cumulative percentage of all tomato fruit in the batch exceeds the consumer limits for the majority of the batch, here chosen to be 80%. The moment of rejection depends only on firmness parameters but the moment of acceptance depends on firmness and colour parameters. The acceptance period is defined as the moment of rejection minus the moment of acceptance and indicates the timeframe for each batch to be acceptable for consumers as a function of the storage temperature (Fig. 3).

As expected, with increasing storage temperature the acceptability and rejection thresholds generally diminish. However, exceptions exist: to become acceptable a breaker batch from grower 2 needs to be stored at minimally 15°C. A lower storage temperature means that when the colour becomes (finally) acceptable the firmness is already too soft, resulting in a batch that will never be accepted. Interestingly, this phenomenon will not happen for grower 1. This means that the commercially advised storage temperature (12°C) may be not be suited in terms of reaching the acceptability threshold.

The acceptance period for tomatoes from both growers is almost the same for batches harvested at the red and normal maturity. There is, however, a large difference between growers: the acceptance period for these batches varies for the first grower between 11 and 17 days and for the second grower between 4 and 14 days at 12°C that is indicative of the large biological variation present. From an export viewpoint acceptability and rejection thresholds needs to be large and quite different to have a long acceptability period. For short chains the situation may be quite different. For the highest storage temperature (25°C) the acceptability and rejection thresholds are minimal but the acceptance period is relatively constant, regardless of grower and colour stage at harvest. To be able to work with relative constant acceptability periods may be a considerable advantage, especially when no heating is required such as in tropical countries.

Literature Cited

Hertog, M.L.A.T.M., Lammertyn, J., Desmet, M., Scheerlinck, N. and Nicolaï, B.M. 2004. The impact of biological variation on postharvest behaviour of tomato fruit. Postharvest Biol. Technol. 34: 271-284.

Lana, M.M., Tijskens, L.M.M and van Kooten, O. 2005. Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol. Technol. 35: 87-95.

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. Postharvest Biol. Technol. 32: 299-310.

Tijskens, L.M.M. and Evelo, R.G. 1994. Modelling colour of tomatoes during postharvest storage. Postharvest Biol. Technol. 4: 85-98.

Tijskens, L.M.M. 2001. Acceptability. In: Shewfelt R.L., Brückner B. (eds). Fruit and vegetable quality: an integrated view. 125-143. Technomic Press, USA.

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.

Tables

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

Colour model	Estimate	s.e.	Firmness model	estimate	s.e.
$k_{R,ref}$ (day^{-1})	0.02355	0.00033	$k_{Fpost,ref}$ (day^{-1})	0.0509	0.0001
E_R ($J.mol^{-1}$)	40553	1213	E_{Fpost} ($J.mol^{-1}$)	22320	1180
k_{Rpre}			F_{fix} (N)	0.816	0.057
Red_{min} (1000/G)	4.086	0.076			
Red_{max} (1000/G)	17.308	0.017			
Red_{ref} (1000/G)	10.487		F_{ref} (N)	9.96	
T_{ref}	285.15K	(12°C)			
R^2_{adj} (%)	97.2		93.5		

Table 2. Overview of the colour and firmness batch parameters (average: μ, standard deviation: σ) expressed in days to reach Red_{ref} and F_{ref} respectively) for tomatoes from two growers and three different colour stages at harvest. Standard errors are indicted within parentheses.

	Grower 1				Grower 2			
Colour stage at harvest	colour		firmness		colour		firmness	
	μ_C	σ_C	μ_F	σ_F	μ_C	σ_C	μ_F	σ_F
breaker	0.31 (0.12)	4.75 (0.18)	1.43 (0.16)	3.606 (0.13)	-3.24 (0.08)	5.60 (0.19)	2.06 (0.17)	4.35 (0.15)
pink	1.963 (0.11)	3.474 (0.14)	2.29 (0.16)	3.369 (0.13)	0.260 (0.08)	3.12 (0.12)	4.86 (0.17)	3.919 (0.16)
red	6.33 (0.24)	4.121 (0.38)	4.76 (0.20)	4.37 (0.17)	3.96 (0.15)	4.24 (0.22)	7.67 (0.22)	3.927 (0.18)

Figures

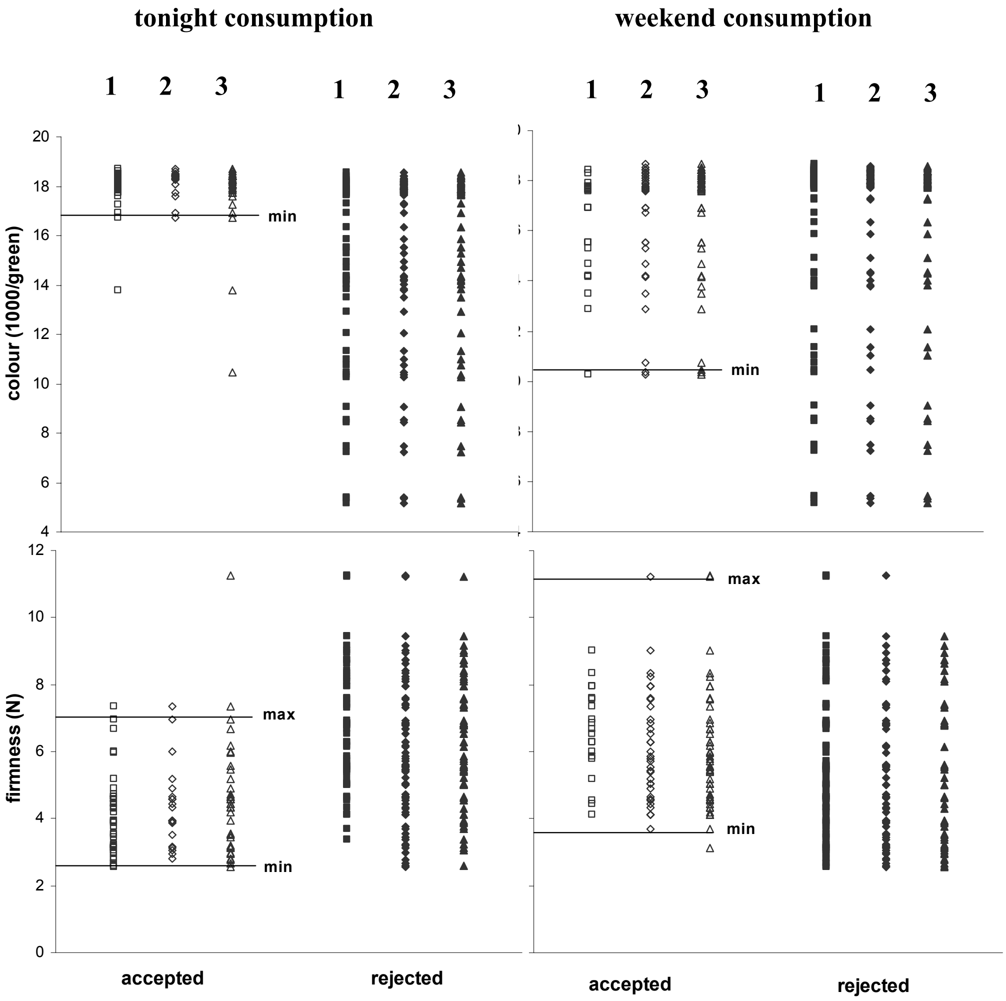

Fig. 1. Acceptance or rejection of truss tomatoes for consumption tonight or consumption after the weekend evaluated by three consumer groups (column 1, column 2 and column 3) as function of colour and firmness measurements. Minimal colour and minimal and maximal firmness limits are indicated.

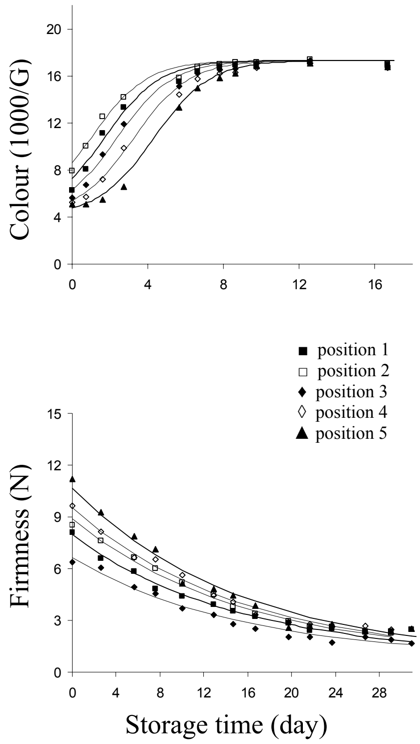

Fig. 2. Example of the colour and firmness behaviour for breaker tomatoes as function of number in the truss (lower position number indicates closer to the plant)

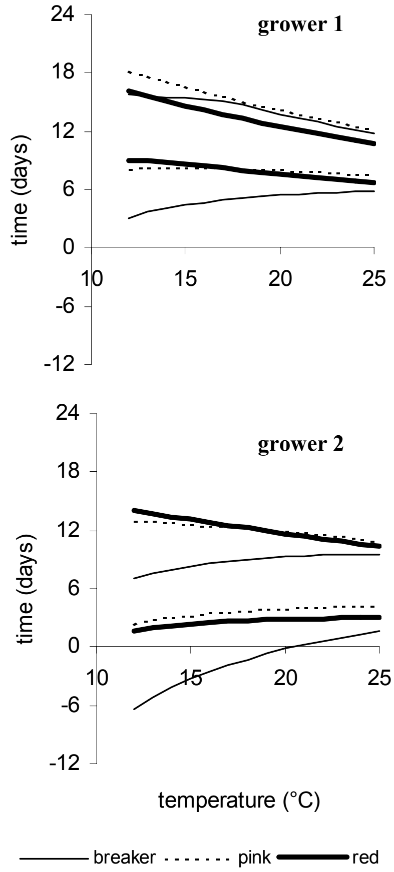

Fig. 3. The acceptance period in days as function of temperature for 80% of the batch for tomatoes from two growers and three colour stages at harvest.