# The Relation between Physiological Maturity and Colour of Tomato Fruits

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**Keywords:** fruit colour, fruit harvest, model, simulation

**Abstract**

**Simulation of the colour of tomato fruits assists in more accurate prediction of harvest time of individual fruits, and provides the possibility to link a crop growth model with a post-harvest model that uses fruit colour as dominant decision variable, enabling the application in agri-chain management. Dates of anthesis and colour development were recorded on 12 plants over a period of 7 weeks. Temperature sums were derived, and quantitative relations with fruit colour were derived per 2 fruits within a truss. These relations were validated against observations on a commercial planting. Simulated colours stages were in general slightly lower than observed colour stages. However, considering the fact that part of the green tomatoes had been removed before observation, the under-estimation could be considerably reduced. Colour observations show a more stable pattern than simulated colour stages. This can be explained by the fact that the model does not simulate variation among plants, but considers all plants identical. The described model for physiological development of tomato fruits appears suitable in production planning and management. In addition, fruit colour provides the possibility to link such a pre-harvest model to a post-harvest (storage) model that may contain fruit colour as essential character.**

## INTRODUCTION

Physiological maturity and moment of fruit harvest for tomato (*Lycopersicon esculentum* Mill.) can be simulated in a number of ways. One variable representing physiological age of the entire truss can be used, resulting in simulation of harvest of all fruits of a truss at the same date (e.g., Heuvelink, 1996). Alternatively, variation in development stage within a truss can be obtained by assigning a certain distribution around the development stage of the middle flower. A specific form of the latter approach is to convert fruit age to fruit colour. An advantage of this approach is that it corresponds with the decisions that a grower takes at harvest. A second advantage is that the introduction of fruit colour as descriptive variable to a crop growth model provides the possibility to link such a pre-harvest model to a post-harvest (storage) model that may contain fruit colour as essential character (Tijskens and Polderdijk, 1996).

This text quantifies the relation between physiological maturity, in terms of temperature sum, and colour of tomato fruits.

## MATERIALS AND METHODS

### Relation Between Temperature Sum and Fruit Colour

Tomato cultivar 'Capita' was sown at January 6$^{th}$, 2001 and seedlings were placed on a nutrient solution (Steiner, 1984) in an air-conditioned greenhouse compartment of Plant Research International at Wageningen, The Netherlands. The nutrient solution was renewed periodically as to prevent nutrient shortages for the plants. Day and night temperature set points were 20 and 16 $^oC$, respectively; set point of air $CO_2$ concentration inside the greenhouse was 350 ppm; and set point of relative air humidity was 70%. Screens were closed if temperature rose above 23 $^oC$. Actual climate characteristics were recorded every 10 minutes.

Measurements were taken on twelve plants. Defining the onset of anthesis (referred to as 'anthesis' in the remaining of this text) as opening of a flower, fruits on a tomato truss



Proc. Int'l. WS on Models Plant Growth &
Contr. Prod. Qual. in Hort. Prod.
Eds. M. Fink and C. Feller
Acta Hort. 654, ISHS 2004

flower from the proximal towards the distal side of the truss. The number of the most distal flower of each truss that reaches anthesis was recorded weekly (in principle each Tuesday) at the 12 plants during the first seven weeks of the experiment. This resulted in 149 flowers of which the date of anthesis was known precisely.

Double observation of anthesis and therefore determination of the average period between the dates of anthesis of two adjacent flowers within one truss (the anthesis interval) could be established for 27 trusses that were flowering longer than one week. For the trusses on which anthesis date of only one flower had been observed, anthesis date was estimated for 810 other flowers on these trusses, on the basis of the single observation and the anthesis interval.

Fruit colour was observed on the same trusses as on which anthesis had been observed, approximately three times per week spread over 11 days of observation between May 16$^{th}$ (day of the year 136) and June 19$^{th}$ (day 170). Fruit colour was classified following the so-called CBT1-scale, which assigns values 1 and 12 to fully green and fully red fruits, respectively. Practice learns that the scale functions well in the range of 1 to 8, but that scores 9, 10 and 11 are hard to distinguish. Score 12 can be distinguished from score 11, but was not observed in the experiment as fruits were harvest before this colour had developed. A total of 1027 fruits were scored 2 or higher (all colours except fully green). Anthesis date of 68 fruits (= 1027 – 810 – 149) was unknown, therefore, these colour observations had to be discarded.

Temperature sums were computed with a linear model that assumes a base temperature of 4 $^{o}$C, for the 149 fruits of which the date of anthesis of its flower was known precisely. Temperature was integrated between hours of observation of anthesis and colour.

$$T_{sum} = \sum_{t=flowering}^{t=harvest} (T_{av} - 4) \qquad (1)$$

in which:

$T_{sum}$ : temperature sum since the onset of anthesis (d$^{o}$C)
$T_{av}$ : average daily temperature ($^{o}$C)
$t$ : time (d)

From this, the average anthesis interval was computed.

**Simulation**

**1. Model Description.** The INTKAM crop growth model for tomato of Plant Research International is based on the HORTSIM model (Gijzen et al., 1998). It computes photosynthesis rate on the basis of the detailed Farquhar equations (Farquhar, 1980; Farquhar and Caemmerer, 1982), that account for the effects of radiation, and temperature, $CO_2$ concentration and vapour pressure deficit of the air. Using a dry matter partitioning based on relative sink strengths of plant organs, their actual growth rates are computed. Combining dry matter weights and dry matter contents, fresh organ weights are computed.

Crop development of tomato is simulated on a daily basis through the temperature-dependent development of nodes, which consist of one fruit truss and three surrounding leaves. Approximately one node, and therefore one truss, develops per week under normal growing conditions. The number of fruits per truss can be defined according to the actual situation, being in the case of this experiment six fruits per truss. The remaining of the fruits that normally set is considered thinned in order to permit optimum growth of the fruits that are not thinned.

The average anthesis date of a truss is simulated as the date at which two nodes (the youngest ones at the top of the plant) above the node with the truss have just developed. It is also assumed that this date is equal to the anthesis date of the third flower. Applying the

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1 CBT: "Centraal Bureau van Tuinbouwveilingen in Nederland", now "Verenigde Tuinbouwveilingen Nederland".

anthesis interval, temperature sum of flowers one and two are computed, and temperature sums of all flowers are computed during subsequent days. As a last step, temperature sums are converted to fruit colour.

**2. Model Validation.** The model was validated on the basis of observations on the commercial planting of tomatoes in 2000 at the farm of Marrewijk van Mil in Honselerdijk, The Netherlands. The greenhouse was planted to cultivar 'Clothilde' (a truss tomato) on December 4, 1999 (day 338) at a density of 2.38 plants $m^{-2}$. A second shoot was maintained on March 31, 2000 (day 90) on half the number of plants, the crop was topped on October 6 (day 279), and the greenhouse was cleared on November 10 (day 315). Due to the absence of climate data for the first two weeks after planting, the simulation model was initialised on December 18, 1999 (day 353). Records show that trusses were thinned to an average of 6.19 fruits $truss^{-1}$, while on average 5.63 fruits $truss^{-1}$ were harvested. Six fruits $truss^{-1}$ were used in the validation.

Records on harvests show that the harvest criterion varied over time. Colour observations were only available for the harvests of April 20 (day 110), May 30 (day 150), June 22 (day 173) and August 7 (day 219). At these dates, minimum colour scores of harvested fruits were 6, 5, 4 and 6, respectively. Colour observations were made one day after harvest, during which period fruits had been stored at approximately 16 $^{o}C$. Colour change for fruits on a plant at positions 1-6 at this temperature is one stage (e.g., from colour stage 6 to 7, see Results section). If the same dependency on temperature during this first day of storage is assumed, fruit colour at harvest can be estimated by reducing colour observations with one stage. After this correction, minimum colour for harvest of fruits was defined as 5, 4, 3 and 5, for the months January through April, May, June through mid-July, and from mid-July onwards, respectively, and added to the simulation model. It should be noted that a modest selection in favour of red fruits has been made.

Harvest of a truss was simulated whenever the harvest criterion was fulfilled. As the node development rate was on average 0.9 node $week^{-1}$, also on average 0.9 harvested truss $week^{-1}$ was simulated.

## RESULTS AND DISCUSSION

### Relation Between Temperature Sum and Fruit Colour

The daily average temperature over the entire experimental period is given in Fig. 1. As outside air temperature and global radiation increased, so did inside air temperature and daily temperature sum. Assuming a base temperature of 4 $^{o}C$, the average daily temperature sum was 15.40 $d^{o}C$.

The average anthesis interval was 21.12 $d^{o}C$ (s.d. 3.27 $d^{o}C$). This corresponds with an average of 1.37 d (anthesis interval/average daily temperature sum = 21.12 $d^{o}C$ / 15.40 $^{o}C$). A possible source of imprecision might be the fact that the moment of anthesis was observed with a precision of one day, or 15.40 $d^{o}C$. Observations were mostly not taken at the very moment of onset of anthesis. It should also be added that the anthesis interval is stable up to and including the ninth flower, but that visual impression suggests that it increases towards the distal end of the truss. However, as fruits at those positions are removed in a commercial crop, their anthesis interval is not relevant.

The frequency distribution of the number of observations on fruit colour, over the position of the fruits within the truss, is given in Fig. 2, for the 149 fruits of which the date of anthesis of its flower was known precisely, and for the 810 fruits of which the date of anthesis of its flower was obtained through extrapolation. Colour stage 1, the most green colour, was never observed. Direct observations dominate in the lower and middle positions, while the interpolated observations dominate on positions 4 and 5 (proximal fruits have a low position number). We do not draw any conclusion from this fact.

The relations between colour stage (*CS*) and temperature sum since anthesis for fruits of which the date of anthesis of its flower was known precisely, and for fruits of which the date of anthesis of its flower was obtained through extrapolation, did not differ systematically (figures not shown). This justifies merger of the two data sets. The relations between colour stage and temperature sum since anthesis are given per two positions on a truss in Fig. 3. Their quadratic fits are as follows:

Positions 1 and 2: $T_{sum} = 1.3211 * CS^2 + 4.5635 * CS + 898.65$ (2a)
Positions 3 and 4: $T_{sum} = 1.5000 * CS^2 + 5.5957 * CS + 921.05$ (2b)
Positions 5 and 6: $T_{sum} = 1.3905 * CS^2 + 5.0089 * CS + 934.20$ (2c)
Positions 7 and 8: $T_{sum} = 0.8218 * CS^2 + 0.3363 * CS + 948.10$ (2d)

This results in the following relations:

Positions 1 and 2: $CS = (0.7569 * T_{sum} - 677.246)^{0.5} + 1.7272$ (3a)
Positions 3 and 4: $CS = (0.6667 * T_{sum} - 610.554)^{0.5} + 1.8652$ (3b)
Positions 5 and 6: $CS = (0.7192 * T_{sum} - 668.601)^{0.5} + 1.8011$ (3c)
Positions 7 and 8: $CS = (1.2168 * T_{sum} - 1153.645)^{0.5} – 0.2046$ (3d)

**Model Validation**

The course of greenhouse temperature is given in Fig. 4. Apart from a strong temperature drop just before the end of the season when heating was switched off, average day time temperature varied between 19 and 20 $^{o}$C, and between 20 and 25 $^{o}$C in winter and summer, respectively, and night time temperature rarely fell below 16 $^{o}$C.

Simulated distribution of fruit colour at harvest, over the entire season, is given in Fig. 5. The largest number of simulated harvest colours is 7-10, with a peak at colour stage 9. Colour observations on a seasonal basis were not available, and therefore, a season-based validation was not possible.

Colour observations corrected for one day of storage, for the four days at which they were available, dominate in the red colour stages 9-11 (Fig. 6). Very few green fruits appear to be harvested. However, as a modest selection in favour of red fruits has been made, the frequency of green colour stages can be considered higher than observed.

Harvests were not simulated on exactly the same four dates, but on dates very near, *viz.*, April 18 (day 108), May 30 (day 150 – which is the same date as at which was observed), June 20 (day 171) and August 8 (day 220). Six fruits per truss were simulated, based on grower's registration; however, at harvest only 5 fruits per truss were counted. Whether this is due to the above-mentioned selection process, or due to some other elimination process, could not be established. In any case, frequencies of simulated colours per truss were multiplied by 5/6 before comparison with observed colours.

Simulated colours stages were in general slightly lower than observed colour stages (Fig. 6). Average observed and simulated colour stages for the four harvests were 9.0 and 8.7, 9.3 and 7.2, 9.6 and 7.8, and 9.3 and 7.8, respectively. This would imply an under-estimation of the colour stage by on average 1.4 stage. However, considering the fact that part of the green tomatoes had been removed before observation, the under-estimation could be considerably reduced.

Colour observations show a more stable pattern and lack a number of colour stages (but are still characterised by a distinct peak) in comparison with simulated colour stages. This can be explained by the fact that the model does not simulate variation among plants, but considers all plants identical. In reality, plant-to-plant variation does exist, causing smoothing of the colour distribution pattern.

**Application**

Simulation of variation in anthesis dates within a truss reduces the peaks in harvest that are simulated if an entire truss is considered mature at the same date. This will bring the model more in line with commercial practice, in which a tomato crop is harvested several times per week, and fruits are picked from a truss whenever they are considered ripe.

Introduction of fruit colour as a variable for fruit maturity makes the model even more correspond with reality, as this criterion corresponds with the decisions that a grower takes at harvest.

The described model for physiological development of tomato fruits therefore appears suitable in production planning and management.

In addition, fruit colour provides the possibility to link such a pre-harvest model to a post-harvest (storage) model that may contain fruit colour as essential character. This enables agri-chain management with regards to crop management, storage conditions, and retail approach.

**ACKNOWLEDGMENTS**

The research was conducted as part of project DWK355, funded by the Dutch Ministry of Agriculture, Fisheries and Food Quality.

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**<u>Figures</u>**

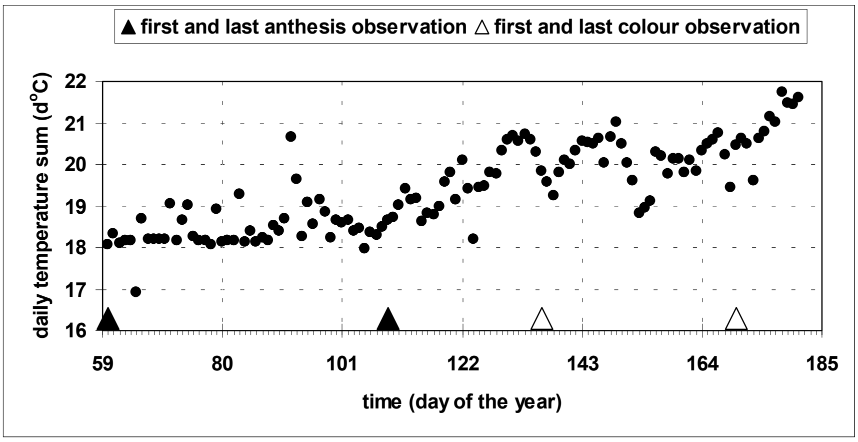


Fig. 1. Daily average temperature over the entire experimental period during which the relation between temperature sum and fruit colour was established.

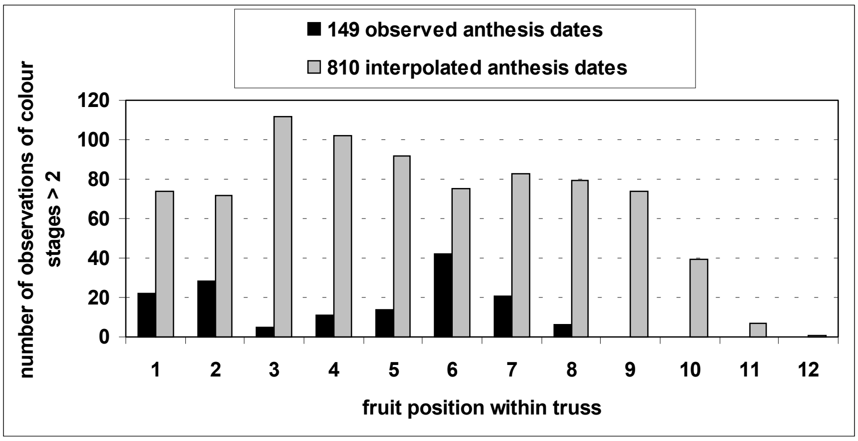


Fig. 2. Frequency distribution of the number of observations on fruit colour, over the position of the fruits within the truss, for the 149 observations on fruits of which the anthesis date of its flower was known precisely, and for the 810 observations on fruits of which the anthesis date of its flower was obtained through extrapolation.

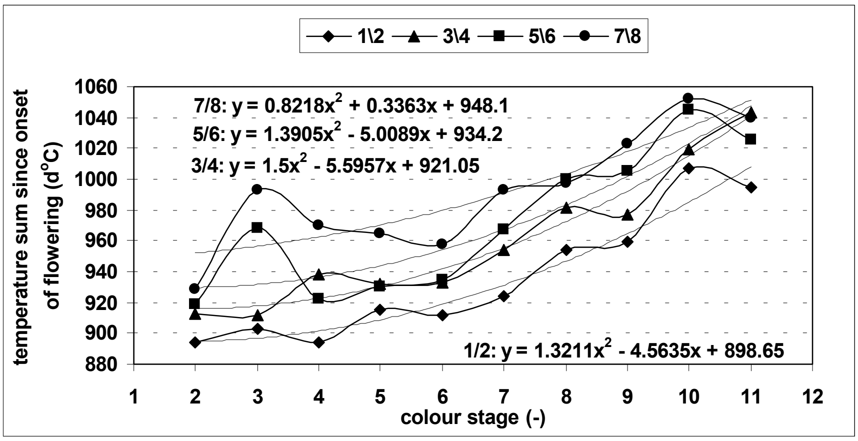


Fig. 3. The relations between colour stage and temperature sum since anthesis per two positions on a truss.

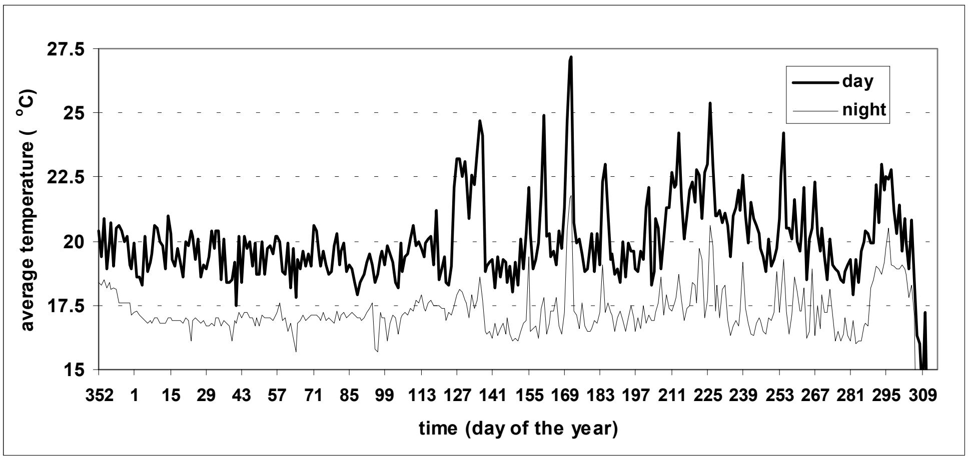


Fig. 4. The course of average day and night time temperatures in the greenhouse of Marrewijk van Mil in Honselerdijk, The Netherland, in 2000.

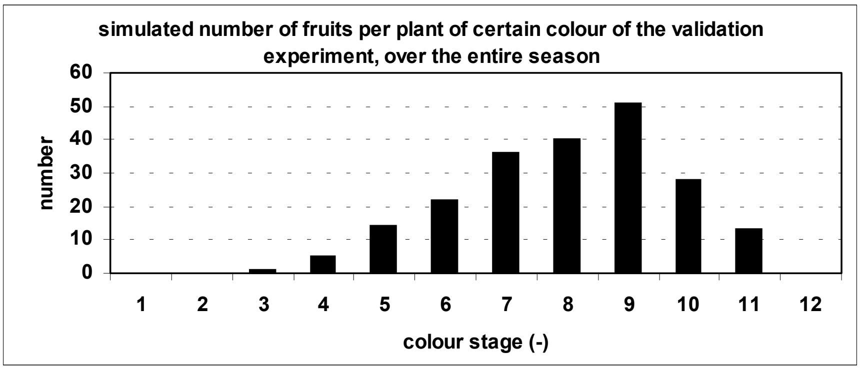


Fig. 5. Simulated distribution of colour stages of all fruits at harvest during the entire growing season of the validated experiment.

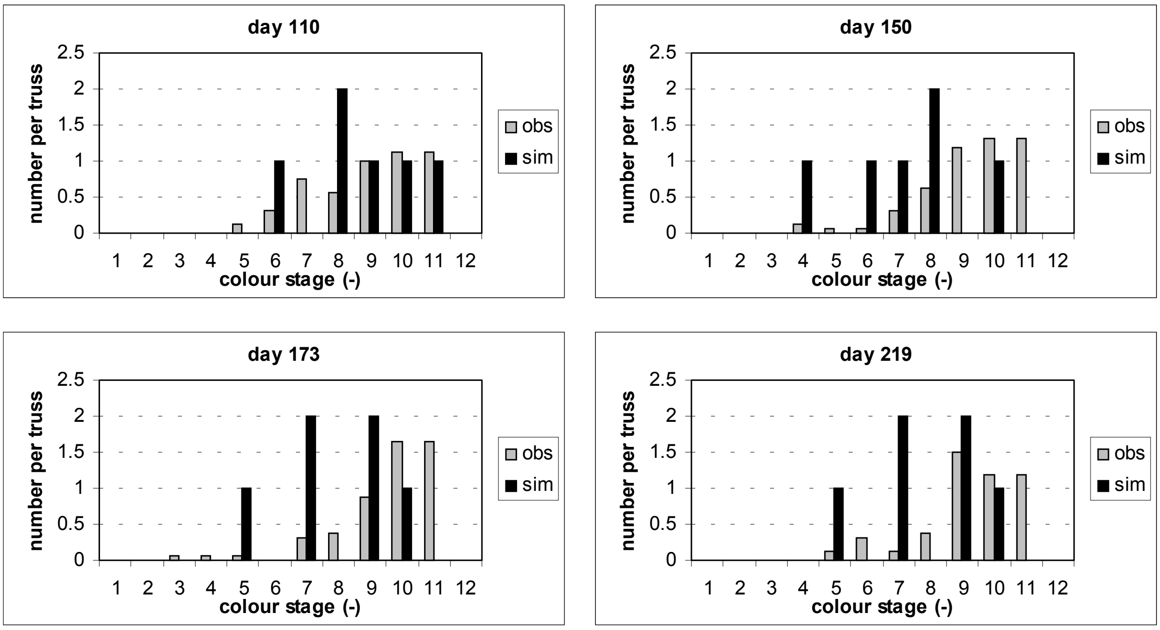


Fig. 6. Observed and simulated distribution of colour stages at day numbers 110, 150, 173 and 219. Observed colours 11 and 12 were bulked at moment of observations, and have been distributed 50/50 in the figure.