Assessing the Harvest Maturity of Brazilian Mangoes

T. Pereira[1], L.M.M. Tijskens[1, a], M. Vanoli[2, 3], A. Rizzolo[2], P. Eccher Zerbini[1], A. Torricelli[3], L. Spinelli[3] and H. Filgueiras[4]
[1]Horticultural Supply Chains, Wageningen University, The Netherlands
[2]CRA-IAA, Agricult. Research Council - Food Technology Research Unit, Milan, Italy
[3]Politecnico di Milano, Department of Physics, Milan, Italy
[4]Embrapa, Fortaleza, Brazil

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Abstract

No clear criterion exists to determine the optimum time to harvest mango. Some empirical relations are used to assess maturity, such as shoulder development. Moreover, as a result of the typical growing conditions in tropical climates, a huge variation in maturity and ripeness exists, seriously hampering the export of fruit in the global chain. The consequence for consumers in western countries is that sometimes mangoes are overripe at the retailer, or have to be kept for several days, even weeks, to reach the edible state, provided they do not rot in the meantime. To ensure an edible quality, the chlorophyll content in the fruit flesh, measured at harvest by Time-resolved Reflectance Spectroscopy (TRS), could be used as a maturity criterion for mango fruit. Commercially grown fruit were harvested in Brazil and transported to Italy by plane. Fruits were measured using TRS at 630 nm for absorption coefficient (μ_a) and skin colour. The development of μ_a was followed on 60 fruits during 15 days of storage at 20°C. The remainders of fruit were used to measure firmness destructively. Absorption coefficient decreased during shelf life according to a logistic pattern, as expected for colour development. Taking the variation between the individual fruit into account, 72% of the variation was accounted for. Nevertheless, μ_a assessed at harvest could be converted into a biological shift factor (BSF), as an expression of the maturity at harvest of each individual fruit. This biological shift factor explained about 70% of the variation in firmness development in individual fruit. These preliminary results indicate that TRS methodology coupled with BSF theory could be useful in assessing maturity at harvest and assuring acceptable eating quality of mango.

INTRODUCTION

Mangoes are produced in over 90 countries worldwide. Asia accounts for 77% of global mango production, and the Americas and Africa account for 13 and 9%, respectively. Mexico is the world's largest exporter of mangoes followed by India and Brazil. Mexico is the major supplier for the USA while Brazil is the major supplier for Europe (Anonymous, 2009). The current world market is dominated by the cultivar 'Tommy Atkins', due to its exceptional productivity, disease resistance, shelf-life, and appealing colour. In Brazil, around 80% of the area cultivated for mangoes comprises the 'Tommy Atkins' cultivar (Pinto et al., 2002).

A fair amount of knowledge is available regarding maintaining fruit quality after harvest, but for a number of commodities the index for harvest maturity is still ill defined. For mangoes, one of the major difficulties for harvesting at a predefined state is the lack of harvest criteria. Usually the time of harvest is determined by a number of factors, including amongst others: shape of the fruit ("shoulders" should be full), skin and flesh colour (Cocozza et al., 2004; Jha et al., 2007) and time elapsed since flowering (Rocha et al., 2001). As a result, it is not only very difficult to assess optimal harvest date, but also the time it will take for individual fruit to reach an edible state.

To predict fruit quality, batch behaviour models capable of quantifying the natural

[a] Pol.Tijskens@wur.nl

heterogeneity are used. A number of approaches that include the presence of biological variance can be found in the literature. By introducing biological variance into models, both the analysis and the subsequent prediction of postharvest batch behaviour can be improved considerably. The index, which represents the age of individual fruit, can be determined by non-linear mixed effects regression analysis (Tijskens et al., 2005), as is already applied to the colour of cut tomatoes (Lana et al., 2005) and colour and firmness of nectarines (Tijskens et al., 2007). According to Tijskens et al. (2003) it is important that the methodology used is based on underlying biological processes.

Non-destructive techniques can provide information on the quality of individual fruit by characterizing biological variance within a batch. Time Resolved Reflectance Spectroscopy (TRS) is a technique capable of probing flesh colour (chlorophyll content) in intact fruit. The absorption coefficient μ_a is related to chemical components such as pigments, water and sugars. The transport scattering coefficient μ_s is related to structural characteristics (Cubeddu et al., 2001). TRS has been used as a non-destructive method of evaluating quality and maturity of a range of fresh fruit such as pear, kiwi, nectarine, and apple (Eccher Zerbini et al., 2002, 2006; Valero et al., 2004; Vanoli, et al., 2009). The aim of this research was to develop a maturity index for mango based on TRS values and to explore the potential of prediction of the non-destructive index.

MATERIALS AND METHODS

Experimental Setup

Mango fruit, 'Tommy Atkins' were harvested in two neighbouring commercial orchards in Vale do Açú, RN, Brazil. Maturity stage was determined in the orchard by measuring the shoulder development and total sugar content. After harvest, fruits were transported by plane to the laboratory in Milan, Italy. Fruit were individually weighed and skin colour was measured. A Sartorius precision balance was used to weigh fruit individually during storage. Skin colour of all individual fruit was measured using a colorimeter (CM-2600d, Minolta Corp., Japan) on opposite sides at the equatorial region of fruit.

Using TRS, fruits were ranked by decreasing absorption coefficient at 630 nm (μ_a) averaged over two sides of each fruit. Ranked fruits were divided into 30 groups of 11 fruit (corresponding to 30 levels of μ_a), and one fruit of each group was randomly assigned to one of 11 batches (30-fruit sample sets for different times of destructive analysis). Development of μ_a was followed on one set of 30 fruits during 15 days of storage at 20±2°C and 75±5% RH.

The remainder of the fruit were used in destructive measurements of firmness during ripening, measured with an 8 mm diameter plunger mounted on an Instron Universal Testing Machine (model 4301, Instron Ltd., Great Britain), on two opposite peeled sides in the equatorial region of each fruit (same spots as for TRS readings).

Modelling

Skin and flesh colour and firmness of fruit often develop and decay according to a sigmoidal behaviour, frequently modelled as a logistic function. The equation used in the analyses was:

$$y = \frac{y_{max} - y_{min}}{1 + e^{k_y \cdot (y_{max} - y_{min}) \cdot (t + \Delta t_y)}} + y_{min} \quad (1)$$

where y represents either firmness or colour (μ_a or a^*-value). Subscripts max and min are the maximum and minimum values possible (at + or – infinite time), while k_y is the rate constant of the process and t the time. Δt_y, i.e. the biological shift factor, is a stochastic variable that contains all the information concerning maturity at harvest for each individual fruit in the whole batch.

Colour of mango fruit flesh changes to pink/orange (carotenoids, anthocyanins) at the end of ripening and the absorption coefficient μ_a increases slightly. The increase in

absorption coefficient μ_a at the end of the experiment was therefore analysed with a simple exponential increasing towards an asymptotic end value as shown in Eq. 2.

$$ca = ca_{min} + (ca_{ref} - ca_{min}) \cdot e^{-k_{ca} \cdot (t + \Delta t_{ca})} \quad (2)$$

where ca represents the effect of carotenoids on the absorption coefficient. The remaining variables (k_{ca}) and the subscripts min and max have the same meaning as explained at Eq. 1. The orange colouration of fruit did not develop all at the same time, so a value for Δt_{ca} had to be estimated for each fruit individually, using only data at the end of the experiment. The measured values for μ_a were corrected with these simulated values and analysed using Eq. 1.

Statistics

All models were developed using Maple (Release 12, Maplesoft, Waterloo Maple Inc. Waterloo, Canada). Data analysis of non-destructively measured data was conducted using nonlinear indexed regression analysis (procedure nls) in the statistical package R (freely available at http://www.r-project.org/). Analysis of destructively measured data was conducted using simple nonlinear regression analysis (procedure nls) in the statistical package R.

RESULTS AND DISCUSSION

Flesh Colour (TRS Absorption)

Fruit ripening is characterised by the decrease in chlorophyll content or change of flesh colour. When performed in the 600-700 nm spectral region, the absorption coefficient (μ_a), measured by TRS, can be related to chlorophyll content in the pulp and maturity, without disrupting the natural structure of the fruit. The absorption coefficient at 630 nm was followed in one of the batches during storage at 20ºC.

Measured μ_a values were first corrected for the estimated development of carotenoids. The maximum ($\mu_{a,max}$) and minimum value ($\mu_{a,min}$) of the corrected values could not be estimated, and had to be fixed to plausible values (0.4 and -0.08 respectively) based on visual observation of the available corrected data. Estimating the rate constant (k_μ) in common for all the individual fruit (fixed effects), while estimating the biological shift factor (Δt) separately for each individual fruit (random effects), resulted in an explained part of 78% (Table 1). The raw data versus storage time is shown in Figure 1A and versus estimated biological time ($t+\Delta t$) in Figure 1B. The improvement and identification of the variance present in the data is made clear, although the remaining variance not explained or included by the model, is still large, as can be taken from the width of the cloud of points in Figure 1B. Probably the TRS system is somewhat less robust and sensitive at 630 nm as compared to the 670 nm used to assess the stage of maturity of peaches and nectarines (Eccher Zerbini et al., 2003, 2005). Absorption at 670 nm is mainly caused by chlorophyll a, while at 630 nm it is mainly caused by chlorophyll b absorbing at a lower intensity than chlorophyll a at 670 nm. In contrast, the absorption coefficient measured at 630-690 nm was linked to fruit maturity as found in pears and apples (Eccher Zerbini et al., 2002; Vanoli et al., 2005).

Skin Colour

Current practice for instrumentally measuring colour changes of fruit is through use of a colorimeter, which present data in L*a*b* system. The green background colour in mango epidermis changes gradually to a yellow/orange pigmentation during ripening. Thus the most important information in the data on skin colour is to be found in the a* value, changing from green to yellow/orange/red by decay of chlorophyll in fruit skin. The pattern of change is the same as for the TRS absorption coefficient, but now increasing in value. That is reflected in a negative sign for the rate constant. A number of mango fruit did not show any change at all in skin colour during the experiment. To get

good parameter estimates for the non linear regression analysis these 'flat liners' were temporarily removed and the remaining data were analysed per side (green or blush side) in a non linear indexed regression, estimating the asymptotes and the rate constant in common. The biological shift factor was estimated for each individual fruit for both sides of the fruit separately. Using these estimates as starting values, the same analyses were run again but now for all the data per side, including the flat liners (Table 2). The two sides differ in both asymptote values (col_{max} and col_{min}) but the range of changes (col_{max}-col_{min}) were almost exactly the same. Also the rate constant of the process (k_{col}) can be considered the same. The mean value for Δt is somewhat different, probably reflecting some minor effects of the red pigments (anthocyanins) but the standard deviation is the same. All this information leads to the conclusion that the change in skin colour during storage is mainly caused by degreening, and not by becoming more red coloured (Medlicott et al., 1986). Unfortunately, the biological shift factor of both sides do not appear to be related to one another.

Fruit Firmness

Puncture test still remains the reference method for fruit firmness evaluation for both growers and physiologists (Harker et al., 1997). However, puncture tests are by definition destructive. The eventual consequence is that for each measuring point in time, another fruit has to be used, thereby blocking completely the analysis of biological variation. Two strategies were followed, both based on the TRS absorption coefficient (μ_a) measured for each fruit at the start of the experiment. The first strategy assumed that the rank number in a batch, at the start graded in each sample set from high to low μ_a, can be used as a pseudo fruit number. All fruit with the same rank in each sample batch had about the same μ_a value. Applying indexed nonlinear regression analysis and using the batch rank number as random cause, resulted in explained part of 79% (Table 3). The second strategy was based on the assumption (as proven for nectarines and described in Tijskens et al., 2007), that for the same fruit, the biological shift factor for firmness (Δt_F) was linearly related to the biological shift factor for μ_a ($\Delta t_{\mu a}$) as shown in Eq. 3.

$$\Delta t_F = \alpha \cdot \Delta t_{\mu_a} + \beta \qquad (3)$$

Using this assumption, the measured data on firmness was analysed together using simple nonlinear regression analysis. The obtained explained part is somewhat less than for previous analysis (Table 4). The asymptote values had to be fixed to the values obtained in previous analysis (Table 3). The rate constant estimated was virtually the same as in previous analysis. The behaviour of firmness versus biological time is shown for both strategies in Figure 2. Amazingly, the analysis based on batch rank number (Table 3) has a larger explained part than the expected correct approach (Table 4). The biological shift factor for firmness is highly related to the biological shift factor for firmness estimated based on batch rank number, since they are both based on the TRS absorption coefficient measured at the start of the experiment. The value estimated for β is large and negative. That means that chlorophyll in fruit flesh starts to decrease about 10 days earlier than the fruit start to soften (for nectarines, it was about 4 days).

CONCLUSIONS

TRS absorption as an expression of fruit flesh colour, measured at harvest, can be used to predict the firmness behaviour of mango. This opens new alleys to predict more precisely the time at which mango will reach an edible state. The obtained explained part is reliable enough to achieve an improvement in grading and predicting an edible state. Skin colour can be described and predicted much more reliably (R^2_{adj} >95%). In all attributes analysed (flesh and skin colour, firmness) the effect of the variation between individual fruit was of utmost importance. To achieve an optimisation of the mango supply chain, the sources of this variation must to be explored and understood.

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Tables

Table 1. The absorption coefficient μ_a at 630 nm as a function of time on both sides of 60 individual mango fruit following indexed nonlinear regression analysis, based on Eq. 1 (legend see there).

	Value	Std. error
$\mu_{a,max}$	0.4	fixed
$\mu_{a,min}$	-0.08	fixed
mean(Δt)	9.759	0.935
k_μ	0.222	0.009
$\sigma(\Delta t)$	2.938	
N_{obs}	715	
N_{group}	120	
R^2_{adj}	0.78	

Table 2. Results of intact fruit skin colour for both green and blush sides of mango fruit following indexed nonlinear regression analysis, based on Eq. 1 (legend see there).

	Green side		Red side	
	Value	Std. error	Value	Std. error
col_{max}	22.73	0.88	38.37	0.78
col_{min}	-6.51	0.11	11.24	0.40
mean(Δt)	-18.88	0.87	-12.26	0.92
k_{col}	-0.0081	0.0005	-0.0090	0.0009
$\Sigma(\Delta t_{col})$	6.09		6.56	
N_{obs}	720		659	
N_{group}	60		60	
R^2_{adj}	0.95		0.86	

Table 3. Firmness analysis of mango fruit based on rank number in a sample batch ranked from high to low colour.

	Value	Std. error
F_{max}	133.11	fixed
F_{min}	5	fixed
k_F	0.0049	0.0002
mean(Δt)	-3.56	0.82
σ(Δt)	2.962	
N_{obs}	1273	
N_{group}	120	
R^2_{adj}	0.793	

Table 4. Firmness analysis of mango fruit based on biological shift factor for μ_a.

	Estimate	Std. error
F_{max}	133.11	fixed
F_{min}	5	fixed
k_F	0.0041	0.0002
α	0.402	0.014
β	-10.31	0.246
N_{obs}	1273	
R^2_{adj}	0.693	

Figures

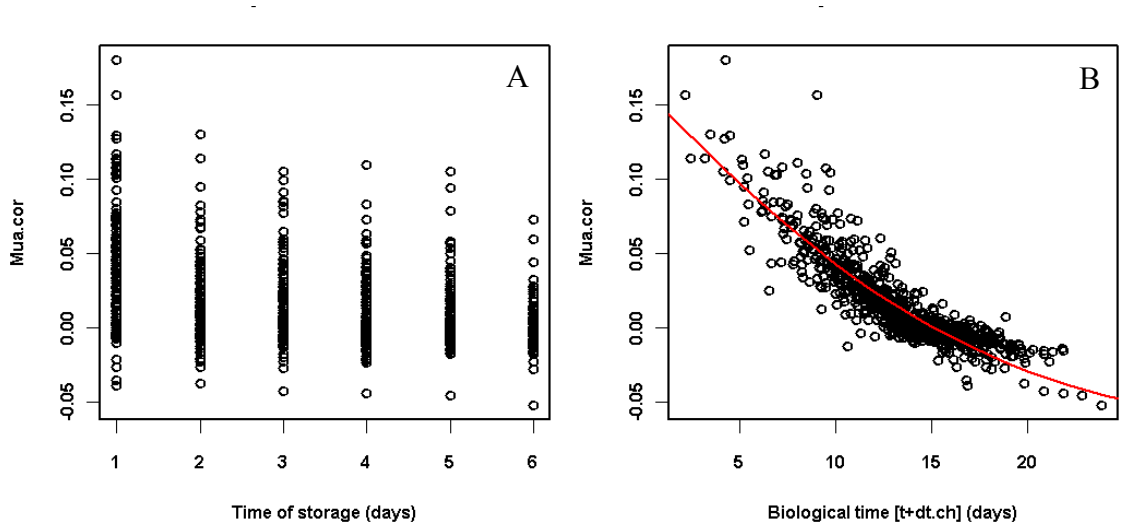

Fig. 1. Raw data of TRS absorption coefficient, corrected for orange colour development on two sides of each fruit, at 630 nm, A: versus storage time; B: versus biological time.

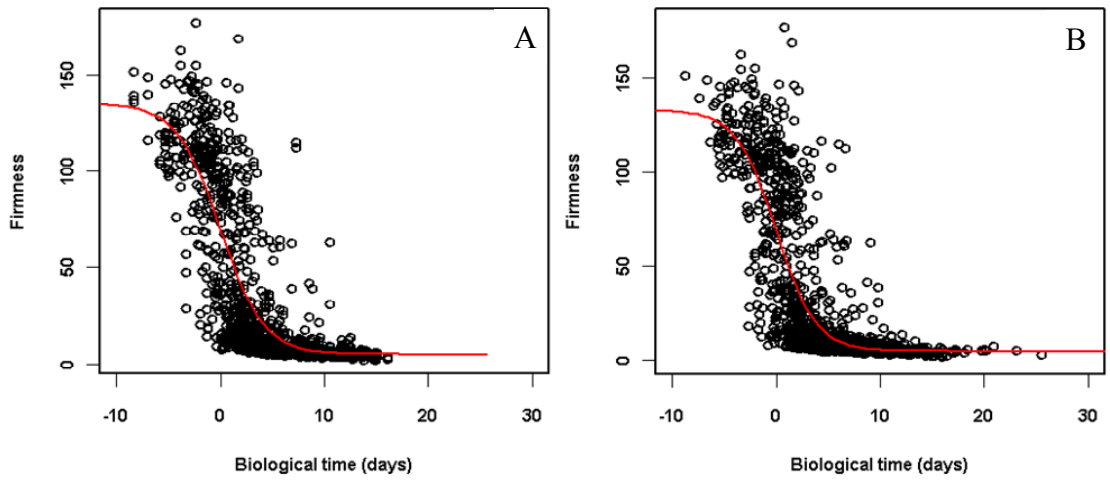

Fig. 2. Measured (points) and simulated (lines) behaviour of destructively measured firmness as a function of biological time. (A) As estimated according to the rank number in the ordered batch (Table 3), (B) as related to the estimated biological shift factor of μ_a (Table 4).