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Relationship between air temperature and degreening of lemon (C*itrus lemon* L. Burm. f.) peel color during maturation

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Abstract

This study describes the relationship between air temperature and the loss of greenness in lemon peel and the appearance of the typical yellow color in the lemon varieties Eureka Frost, Lisbon Frost and the Fino 49, all on *Citrus macrophylla* rootstock. The change in the colorimetric coordinate a was studied, and the hue angle and chroma were calculated to ascertain the influence of temperature on these parameters. The study covered six campaigns (2003-2009), with measurements being made every week or fortnight in 10 fruit per tree and 4 trees per variety. The results show that the values of the colorimetric coordinate a (of the HunterLab) was most closely correlated with the mean of the minimum daily temperature of the 21 days prior to the measurement (adjusted R^2 >0.93). Identical results were obtained for Chroma and hue angle. It was determined that the color of the peel begins to change from green to yellow when the minimum temperature falls below 15 ºC, reaching full "lemon yellow" below 6 ºC. This means that in areas where the mean of the minimum temperatures of the 21 days prior to the measurement do not reach 15 ºC, natural degreening will not occurr. As a consequence, artificial degreening, with the increased expense that this entails for the crop, will be necessary. The knowledge gained with this study will be of interest for determining the suitability of areas of the world where lemon tree plantations are being considered, so that prospective growers will not have to resort to artificial degreening.

Keywords: *Citrus macrophylla;* Eureka; Fino 49; Lisbon; HunterLab; Chroma; hue.
Abbreviation: h_{ab} – hue angle, $C_{\mathbf{ab}}$ – chroma.

Introduction

Commercial harvesting of lemons (*Citrus lemon* Burm. f) in Spain for the fresh fruit market begins when the size exceeds 56-58 mm and the percentage of juice is greater than 30% (García Lidón et al., 2003). In mid-September, the fruits considered ready for picking are green in color and must be submitted to a de-greening process in special chambers before they can be sent to market. When nights get colder, between the end of October and mid-November, the chlorophylls present in the peel are degraded and previously masked carotenes are freshly synthesized (Sinclair, 1984; Soni and Randhawa, 1969), imparting the characteristic "lemon yellow" color to the fruit. This indicates the stage of ripeness and stimulates the perception of freshness on the part of the potential customer (Hutchings, 2003; Joshi, 2001). The number of carotenoids in citrus fruit is very high (Gross, 1977; Casas and Mallent, 1988a; Lee and Coates, 2003; Meléndez-Martínez et al., 2007a, b, 2010) but in lemon the total concentration of carotenoids is lower than in other citrus (Yokoyama and Vandercook, 1967; Kato et al., 2004). The principal carotenoid is β-cryptoxanthin (Kato et al., 2004). The decline in rind chlorophyll takes several months and the onset of carotenoid accumulation almost coincides with the disappearance of chlorophyll (Spiegel-Roy and Goldschmidt, 1996). Degreening with ethylene is practised in the latter case, especially with early cultivars (Grierson et al., 1986).Several authors have studied the effect of climate on citrus fruit quality (e.g. Reuther, 1973), but few studies correlate the color change of fruit on the tree with temperature, although it is known that a tropical climate tends to produce a high total soluble solid content, which is an advantage for the processing industry (González-Sicilia, 1960; Reuther, 1973; Spiegel-Roy and Goldschmidt, 1996). Color and color uniformity are two of the main parameters that define the direct quality of vegetables (Hutching, 1994). Color is often taken as an index of freshness, palatability and nutritional value (Haisman and Clarke, 1975). In fact, color perception is the first criterion in determining the acceptability of any kind of fruit and of many other foods. It is therefore of great interest to know when fresh fruit becomes available without the need for degreening in special chambers. In experiments carried out in Florida with the oranges Hamlin, Parson Brown and Pineapple on the relation of climatic conditions with peel color, it was concluded that the color does not turn until 12.8 ºC is reached (Stearns and Young, 1942). The rapidity with which the hue reaches a maximum depends upon the severity of the temperature drop and the continued occurrences of minimum temperatures below 12.8 ºC (Agustí and Almela, 1991; Davies and Albrigo, 1994). The external color of lemons can be determined in many ways, from the merely visual to using compact color analysers of surface reflection, known as tristimulus colorimeters, which are easy to use and provide rapid, non-destructive measurements. From the tristimulus values, X, Y and Z, the values L, a and b, which closely correspond to the color observed by the human eye, are obtained mathematically (Hutchings, 1994; MacDougall, 2002; Westland, 2002; Joshi and Brimelow, 2002). Among the different colorimetric coordinates provided by the colorimeter that measures greenness is a, which is influenced by the temperatures of the days preceding the day on which the measurement is made (Manera et al., 2008). A more appropriate measure of color can be obtained from hue angle (h_{ab}) and chroma $C_{\mathbf{ab}}$ which are calculated from the values **a** and b (McGuire, 1992). Mentioned above are only some of the numerous studies that have been made on the carotenoid content of citrus fruit. Although there are also many studies on de-greening in the laboratory or during storage (Artés et al., 1997, 1999), studies on the physical process of color change and its relation with temperature are scarce. Continuing the field studies of Stearns and Young (1942) and Manera et al. (2008), we look more deeply into the perceived color change, that is, when the process begins, and its relation with temperature. In this study, we attempt to use the color data taken from fruit while still on the tree, to determine the temperature (maximum, minimum or mean) that is best correlated with the parameters a, C_{ab} and h_{ab}, and so has most influence on the loss of greenness in the fruit. The data were taken during six growing seasons. We determined the number of days that must be used in order to obtain the mean value that most influences the change in lemon peel color, and to determine whether it is the minimum temperature or mean temperature that most influences the loss of green color. We also determined the influence of a change of 1 ºC on the above mentioned variables and the extent to which the new measurements are affected by the value of the preceding measurement. We determine the range of temperatures in which the green color of the peel is reduced, accompanied by a corresponding increase in yellow, and, lastly, whether the value of the colorimetric coordinate a is explained solely by the temperature or whether the value of the previous observation influences it. We look at when the color change process begins in the field in order to help growers determine whether artificial degreening will be necessary. The results obtained should also be of interest for planning lemon plantations in new areas, bearing in mind the possibility of natural degreening or the likelihood that artificial degreening will be necessary.

Results

Changes in chroma and hue angle (h_{ab})

The color change from green to yellow in lemon peel is a gradual process (Spiegel-Roy and Goldschmidt, 1996). In previous studies, we calculated that the mean minimum temperatures for the preceding 21 days are closely correlated with the measurement of the color coordinate a (Manera et al., 2008). Figs. 1, 2 and 3 show that the evolution of the color coordinate a, the C_{ab} index and hue angle for the 2003/04 season. It can be seen how a remains constant at the beginning of the growing season before beginning to increase (less negative values of a, corresponding to a less green color). The chroma values increase and the hue angle decreases from the beginning of the growing season. The figures (not shown) for all the other years studied are similar.

Figs. 4 and 5 show the relation between the minimum temperatures for the six campaigns studied and $C_{\mathbf{ab}}$ and $h_{\mathbf{ab}}$, for the variety Eureka. Fig. 4 shows how chroma increases with the fall in temperature as autumn progresses due to the increase in the coordinate b, which influences chroma more strongly than coordinate a. Eventually, chroma varies very little as the characteristic yellow color of lemon is reached (Table 1). The hue angle is 125º, that is, it reflects the green-yellow colors (Fig. 5). With the decrease in temperature as autumn progresses, the hue degree falls as the green color of the lemons diminishes. Generally and in almost all the campaigns studied, the hue angle is slightly less than 90º in December when the temperature is 6 ºC, indicating that the lemons have lost all their chlorophylls as the fruit takes on its characteristic yellow color. Neither chroma nor hue angle show an inflection point, that is, neither provides an indication of exactly when the loss of chlorophylls begins in the peel (Fig. 4 and 5). For this reason, a study of the influence of temperature on the evolution of the colorimetric coordinate a should indicate when this parameter begins to rise (reflecting at the same time the moment when the green color begins to be lost and the yellow color begins to impose itself).

Changes in color coordinate a.

In our experiment, from August and as winter progressed, the decrease in temperatures was matched by increases in the colorimetric coordinate a of the varieties Eureka, Fino and Lisbon (it decreased in absolute values). Fig. 1 shows the evolution of the above mentioned variables in the period of study, where “minimum temperature” refers to the average minimum temperature for the 21 days preceding the day on which a was measured during the 2003/04 season (vertical left axis) and variable a refers to the colorimetric coordinate a of the variety Eureka for the same campaign (vertical right axis). It can be seen that as the temperatures fell, the coordinate a increased. A similar pattern was observed in the varieties Fino and Lisbon (figures not shown). From the series of mean and minimum temperatures we sought that which would best explain the value of the colorimetric coordinate a for the varieties Eureka, Fino and Lisbon. For this, a data set consisting of observations of the colorimetric coordinate a, the mean temperatures and the minimum temperatures for the seasons 2003/04, 2005/06, 2007/08, 2008/09 and 2009/2010 was analyzed (a total of 77 observations). We first show the results obtained for the different years in Fig. 6, 7 and 8. Fig. 4 depicts the coordinate a for Eureka during the six seasons studied. Their x-axis shows the mean of the minimum temperatures of the previous 21 days, in reverse order, in degrees Celsius. Each point of the graph reflects the observation for a given day of the colorimetric coordinate a and the mean of the minimum temperatures for the 21 days preceding the measurement. The ordinate axis represents the color coordinate a. As can be seen, there is a negative relation between the two variables: below 15 ºC the negative values of the color coordinate a decreased to reach zero at about 6 ºC, that is, the chlorophyll of the peel was gradually degraded and yellow tones (color coordinate b) gradually appear (although green is still predominant). These tones were already positive in the first measurement but were masked by the green tones of the chlorophyll (Table 1). At about 6 ºC, when the value of the color coordinate a is closest to zero, the yellow tones continue to increase (coordinate b) until the peel takes on the

Table 1. Evolution of temperatures and the colorimetric variables L, a and b, hue angle and chroma index during 2003/04 season in variety Eureka. The column Date shows the dates on which measurements were made and the second column shows the daily minimum temperature (mean for the previous 21 days). The other columns refer to the variables L, a, b, chroma and hue.

Variety Eureka						
Date	Average of minimum temperatures (21 days preceding)	L	a	b	Chroma	Hue
22/09/2003	18.72±1,14	46.33	-14.75	20.90	25.58	125.21
14/10/2003	16.69±0,86	48.61	-15.88	23.43	28.31	124.12
21/10/2003	15.71±1,08	50.71	-15.56	24.10	28.69	122.84
03/11/2003	12.56±0,94	55.95	-15.11	27.60	31.47	118.70
11/11/2003	11.78±0,83	64.29	-11.67	33.18	35.17	109.38
19/11/2003	11.01±0,74	65.91	-9.62	34.47	35.79	105.60
28/11/2003	10.44±1,00	69.25	-6.62	34.91	35.53	100.73
04/12/2003	8.88±1,30	70.48	-4.57	36.77	37.05	97.09
10/12/2003	7.66±1,37	71.19	-3.63	37.03	37.21	95.59
22/12/2003	6.34±0,82	72.35	-2.98	37.54	37.66	94.53
20/01/2004	6.24±1,37	72.18	-1.67	38.19	38.23	92.50
10/02/2004	6.79±1,49	71.62	-1.89	38.01	38.06	92.84

L, a y b the coordinates of the HunterLab; [C= $(a^2 * b^2)^{1/2}$]; (hue= arctg (b/a).

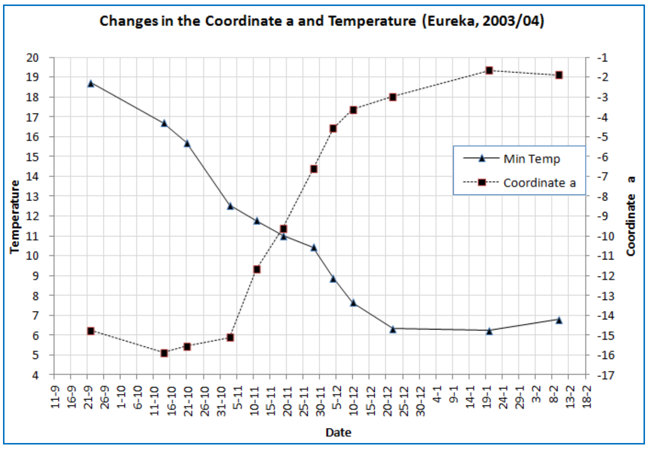

Fig 1. Changes in the colorimetric coordinate **a** and the average of the minimum temperatures of the previous 21 days in the season 2003/04.

characteristic lemon yellow color. Table 1 shows the values of coordinates L, a and b for the 2003-2004 growing season to illustrate how they change (the data for the rest of the seasons, not shown, are similar). Based on Fig. 6, 7 and 8, we sought to identify the best relationship to explain the evolution of color coordinate a. It was found that this coordinate could be explained well if, besides considering the minimum temperatures, the coordinate a delayed an observation (a-1) is also introduced as an explained variable. As the data set consists of observations of the same variables in different years (transversal dimension) during ripening (temporal dimension), an overall calculation was made for the six years, in which it was considered that both the independent term and the coefficient of the variables could vary from year to year. The following relationship was estimated for the minimum and mean temperatures referring to the 7, 14, 21 and 28 days preceding he measurement for the colorimetric coordinate **a** for the three varieties.

$$a = \alpha + \beta \cdot Temp + \gamma \cdot a(-1) + e \qquad (1)$$

where a is the colorimetric coordinate a for each observation of the varieties Eureka, Fino and Lisbon; Temp, is the mean of the daily minimum temperatures of the 7, 14, 21 and 28 days prior to the measurement; a(-1) is the colorimetric coordinate **a** for the observation made immediately preceding the date in question in Eureka, Fino or Lisbon, according to the variety considered for the independent variable in expression (1); and α, β, and γ are the parameters being estimated and e is the term error. Measurements of coordinate a were analyzed taking into account that as the period considered for calculating the mean temperature increases from 7 to 28 days, so the influence of temperature on the color change from green to yellow becomes stronger. However, any improvement in the correlation for longer times (21 to 28 days) is of little significance. On the other hand, the colorimetric coordinate a is best explained by taking the minimum temperatures rather than the mean temperatures as the independent variable. Finally, the best fit is obtained when the explicative variable is the minimum temperatures and improves with the number of days to which the average refers. The improvement from 21 to 28 days is of little significance (and negative in some cases). We conclude, then, that the effect of minimum temperature on the colorimetric coordinate a is greatest for the lemon variety Eureka, followed by Lisbon and then Fino. The mean values for each variety are shown in Table 2. In the case of Eureka,

Table 2. Mean estimation of colorimetric parameter a for each variety (Eureka, Fino and Lisbon), considering minimum temperatures (mean for the 21 days prior to the measuring date, Tmin) and the value of the colorimetric parameter a in the previous measurement, a(–1), as independent variables.

Variety	Estimation
Eureka	$a = 5.240810 - 0.700018xT\min + 0.615191xa(-1)$
Fino	$a = 5.524280 - 0.692374xT\min + 0.730172xa(-1)$
Lisbon	$a = 1.224784 - 0.609126xT\min + 0.639747xa(-1)$

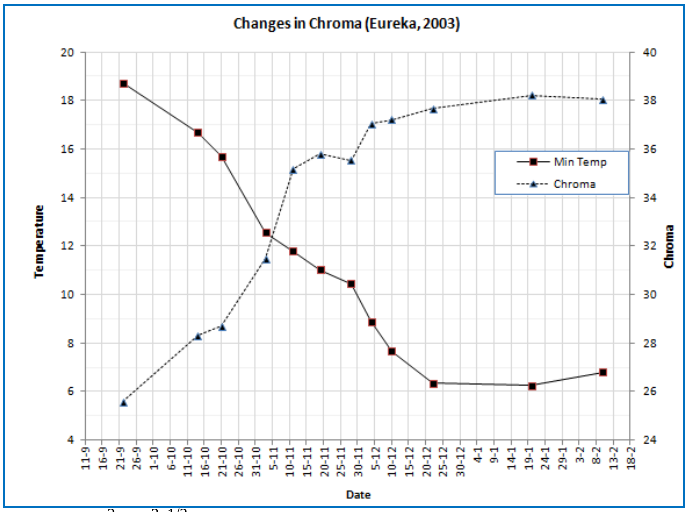

Fig 2. Changes in variable Chroma [C= $(a^2 * b^2)^{1/2}$] and the average of the minimum temperatures of the previous 21 days in the period 2003/04.

for example, the value of a decreases by 0.700018 for each 1 ºC fall in temperature. The effect was similar in the other varieties, where each 1 ºC fall in temperature was responsible for a decrease of 0.692374 and 0.609126 in Fino and Lisbon, respectively, in all cases, with an adjusted-R^2 greater than 0.95. As can be appreciated, the immediately preceding measurement strongly influenced the readings – in Eureka the value of a is (on average) 61.52% of the previous reading, in Fino 73.02% and in Lisbon 63.97% (considering the temperature stable). Indeed, the value of coordinate a can be explained by the value of the previous reading and by the mean temperature of the last 21 days. This is not surprising because, once a high value of a is reached, a drop in temperature will have little influence. Similarly, an unchanging mean temperature may give rise to two different values of **a** (as a function of the value reached in the previous reading).

Relation between the chroma index and mean temperatures of the preceding 21 days.

The relation (2) was estimated considering the data as a pooled time series and introducing fixed factors and cross-section specific coefficients both for mean and minimum temperatures, and considering a period of 7, 14, 21 and 28 days for each case.

$$C = \alpha + \beta \cdot Temp + \gamma \cdot C(-1) + e \qquad (2)$$

The variables are the same as for equation (1), with C_{ab} being the chroma index. Calculations were made for all three varieties both for mean and minimum temperatures, taking for these the means of the preceding 7, 14, 21 and 28 days (a total of 24 estimates). As in the case of the colorimetric variable a, the best estimate was obtained for the mean minimum temperature of the preceding 21 days, with an adjusted-R^2 greater than 0.93 in all three varieties. The mean estimates for each variety are shown in Table 3. As can be seen, a 1 ºC drop in temperature leads to a fall of between 0.53 and 0.57, depending on the variety. An increase of one point in this index affects the subsequent observation by between 0.34 and 0.41 points. This suggests that mean minimum temperature of the preceding 21 days strongly influences the changing chroma values measured on a given day and hence lemon peel color during ripening.

Relation between hue angle and mean temperatures of the preceding 21 days.

Equation (3) was estimated as in the above section.

$$h = \alpha + \beta \cdot Temp + \gamma \cdot h(-1) + e \qquad (3)$$

where h is the hue angle, and h(-1) the value of the previous reading. For all three varieties, the best fit for the preceding 21 days was obtained with an adjusted R^2 above 0.96. The results are shown in Table 4. A fall of 1 ºC leads to a decrease in the hue angle of between 1.18 and 1.33 depending on the variety. As above, a decrease in hue angle of one degree lowers the following reading by between 0.57 and 0.66 degrees. In other words, changes in hue angle are strongly influenced by the mean minimum temperature of the preceding 21 days.

Discussion

In a previous study, Manera et al. (2004) correlated the change in lemon color with minimum temperatures below 18 ºC. In a subsequent study and using data for two years (Manera et al., 2008), the same authors determined that the correlation of mean and minimum temperatures for the seven days preceding measurement of the color coordinate a was

Table 3. Mean estimation of chroma index (C) for each variety (Eureka, Fino and Lisbon), considering minimum temperature (mean for the 21 days prior to the measuring date, Tmin) and the value of the index in the previous measurement, C(–1), as independent variables.

Variety	Estimation
Eureka	$C = 4.026683 - 0.573824xT\min + 0.341964xC(-1)$
Fino	$C = 25.649013 - 0.581550xT\min + 0.416904xC(-1)$
Lisbon	$C = 26.550560 - 0.537984xT\min + 0.388750xC(-1)$

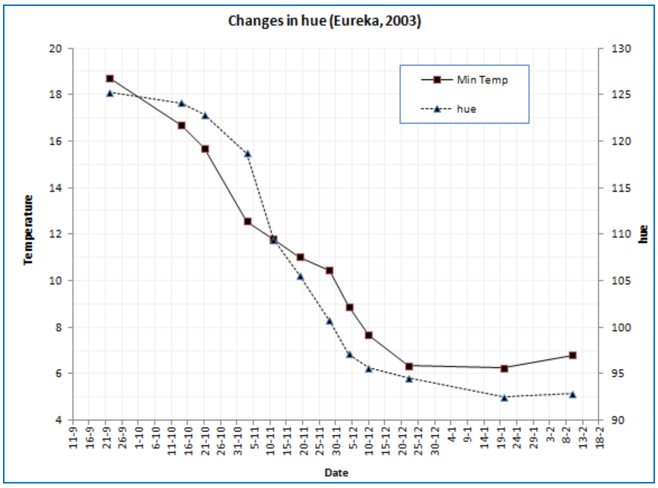

Fig 3. Modification of variable hue (hue= arctg (b/a) and the average of the minimum temperatures of the previous 21 days in the period 2003/04.

highest between the second week of November and the first week of December. Here, using the data referring to six years, we found the fit to be better with the minimum temperatures than with the mean temperatures, and that the more days to which these minimum values referred the better the fit. This is related with chlorophyll degradation. Chlorophylls are a mixture of chlorophyll a and b (Gross, 1991), the former degrading more rapidly. The color of citrus is due to three principal groups of natural pigments: chlorophylls, carotenoids and anthocyanins (Artés et al., 2002). The color of lemons basically comes from carotenoids, some of which coexist with chlorophyll but are masked by it, some of which diminish and some are synthesized at low temperatures. The changes which occur during maturation of the flavedo take several months (Spiegel-Roy and Goldschmidt, 1996). The color of the different carotenoids is the consequence of differences in their chemical structure (Meléndez-Martínez et al., 2007b, 2010). As the fruit ripen and chlorophyll disappears, the carotenoids gradually increase their concentrations as they are synthesized during ripening (Miller et al., 1941; González-Sicilia, 1960; Casas and Mallent, 1988b), although not to a great extent in lemons (Kato et al., 2004). The loss of chlorophyll described by the above authors coincides with an increase in the coordinate a (green), a decrease in hue angle and a rise in chroma (increased b) in our study. In the lemon cultivars studied, the color coordinate a takes on values close to 0 (yellow) (Fig. 6, 7 and 8), and h_{ab} shows values close to 90º, the process being completed when the temperatures fall to about 6ºC. Stearns and Young (1942) observed that the longer the temperatures were below 12.8 ºC the faster oranges reached maximum coloration. In our study (Figs. 6, 7 and 8), we observed that when the minimum temperatures fall below 15ºC the negative values of color coordinate a begin to fall, that is, the chlorophyll begins to degrade (lemons become less green) and carotenes begin to appear (color coordinate **b**), although they remain masked, along with the characteristic lemon yellow color (Table 1). It is to be expected that the coefficients will vary between years (Table 2) since the weather conditions also vary. In this study, we have only taken into account the mean and minimum temperatures, although a multiplicity of factors intervene in fruit coloration, among them fertilization, irrigation, rootstock and maximum summer temperatures (Casas and Mallent, 1988 a, b). The coefficients of the different varieties are also expected to vary since their behavior and adaptation to the environment mean that some will be preferred over others in new plantations (Davies and Albrigo, 2004; García Lidón et al., 2003).

Materials and methods

Plant material

The three lemon cultivars (Eureka Frost, Fino 49 and Lisbon Frost on *Citrus macrophylla* rootstock) used in this study are designated as autumn-winter harvesting varieties. Worldwide, Eureka and Lisbon are the most widely grown varieties (Saunt, 1990), while Fino 49 is the most widely grown cultivar in Spain (García Lidón et al., 2003) and shows good performance in Arizona (Wright and Peña, 2000).

Site description and experimental conditions

The three varieties were planted in April 1983 in a plot at I.M.I.D.A (Murcia Institute of Agriculture and Food Research and Development), La Alberca (Murcia, SE Spain). Trees were spaced 6 x 6 m and drip irrigation was provided by 5

Table 4. Mean estimation of hue angle (h) for each variety (Eureka, Fino and Lisbon), considering minimum temperature (average of the 21 days prior to the measuring date, Tmin) and the value of the hue angle in the previous measurement, h(−1), as independent variables.

Variety	Estimation
Eureka	$h = 29.0149068 + 1.2983995 x T\min + 0.5747555 x h(-1)$
Fino	$h = 20.0282117 + 1.3354845 x T\min + 0.6683780 x h(-1)$
Lisbon	$h = 31.1281753 + 1.1833343 x T\min + 0.5775333 x h(-1)$

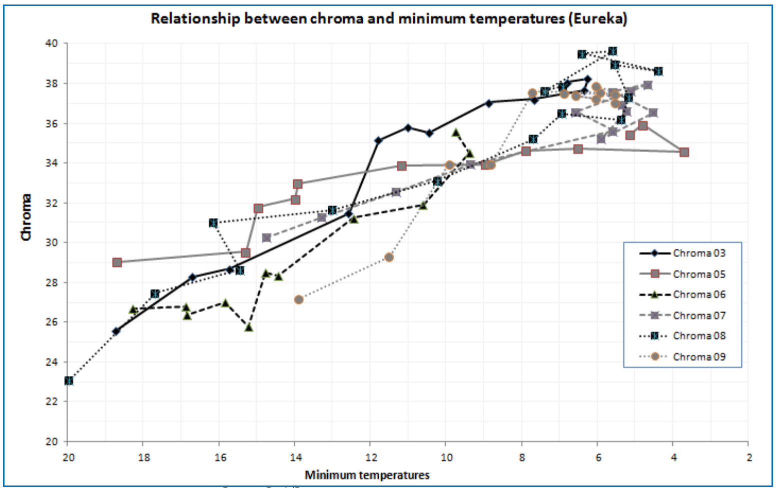

Fig 4. Relationship between chroma index [C= $(a^2 * b^2)^{1/2}$]and the average of the minimum temperatures of the previous 21 days for the six years (Chroma 03, …, Chroma 09).

emitters per tree with a flow rate of 4 l/h. The annual average temperature is 18.4 ºC, the mean maximum temperature is 31.1 ºC and the mean minimum de 4.5 ºC; mean annual rainfall is 321 mm. The soil is permeable and calcareous (17.1 % total calcium carbonate). All the trees used in the study were healthy and in full production. The soil texture of the plot was silt (17.6% coarse sand, 37.6% fine sand, 23.8% silt, 22% clay), the sand content increasing below 30 cm (27.4% coarse sand, 36.9% fine sand, 18.7% silt, 17% clay). The soil had a pH of 8.7 and EC of 3.9 dS m^{-1}, as determined in the saturation extract. The cation exchange capacity in the surface 60 cm of the profile ranged from 17.83 to 15.80 meq/100g. The trees were submitted to identical cultural practices. Drip irrigation was used with five emitters per tree, with a flow rate of 4 l/h. Water pH was 7.15, electrical conductivity 3.8 dS/m, Cl^- 8.63 mmol/l, Na^+ 12.28 mmol/l, Ca^{2+} 10.70 mmol/l, K^+ 0.79 mmol/l, and Mg^{2+} 10.65 mmol/l.

Color measurements

The external color of the fruit was measured in the HunterLab color space (Hunter, 1967) through colorimetric coordinates L, a y b which measure the color of the rind of the lemon fruit, using a Minolta C-300 Chroma Meter (Minolta Corp., Osaka, Japan) coupled to a Minolta DP-301 data processor. The measuring area had a diameter of 8 mm. Standard illuminant C ($Y_o = 100$; $X_o = 98.072$; $Z_o = 118.225$) was used as reference. This Minolta CR-300 is a reflection colorimeter: standard observer angle CIE-2º and white calibration plate. With the colorimeter Minolta CR-300 three measurements were made around the equatorial l zone of each fruit. In each measurements , the colorimetric coordinates L, a and b were measured in the HunterLab color space (Hunter, 1967), using illuminant C as representative of daylight (MacDougall, 2002). The color coordinate L measures lightness (100 for white and 0 for black). The color coordinate a corresponds to the green-red axis, where the negative values correspond to green and the positive to red (-60 green, +60 red) (Hutchings, 1994; MacDougall, 2002), and the color coordinate b measures variations from blue to yellow (-60 blue, +60 yellow). Any decrease in the chlorophyll content of the fruit is associated with coordinate a (Kidsome et al., 2002; Manera et al., 2008). Chroma C_{ab} is calculated as $(a^2 + b^2)^{1/2}$ and represents the hypotenuse of a right-angled triangle created by joining points (0, 0), (a, b), and (a, 0). Hue angle (h_{ab}) may be defined as the angle between the hypotenuse and 0º on the a (bluish-green/red-purple) axis; $\mathbf{h_{ab}}$ is calculated from the arctangent of b/a (Little, 1975; McGuire, 1992).

Experimental design and statistics

To determine the influence of the mean and minimum temperatures on the development of external color in lemon fruit, ten fruit (five from the north face and five from the south face) were randomly chosen and labeled on each of the four trees of each variety, at the beginning of the assay period in the 2003-2009 growing seasons that run from September to February of the following year. Measurements were made approximately every ten days (about 710 measurements in total). The temperatures used in the study refer to those taken by a weather station in the same experimental orchard (MU62, La Alberca, Murcia, see www.IMIDA.es). The minimum temperature refers to the daily absolute minimum and the mean temperature was calculated from the hourly measurements. We took into consideration the mean and absolute minimum temperatures of the 7, 14, 21 and 28 days preceding the day on which coordinate **a** was measured. The starting point was a pooled time series of data referring to the

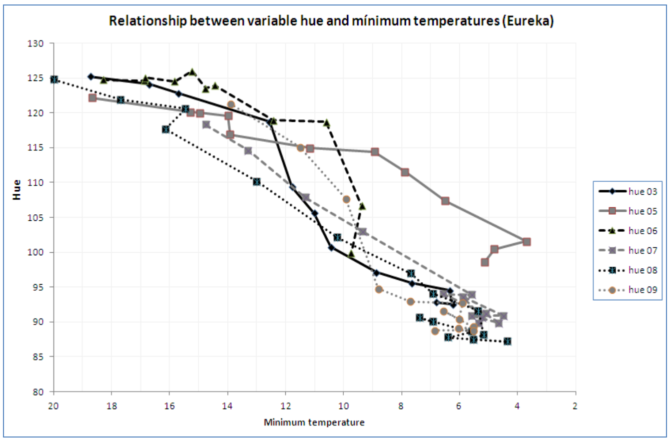

Fig 5. Relationship between hue angle (hue= arctg (b/a) and the average of the minimum temperatures of the previous 21 days for the six years (hue 03, …, hue 09).

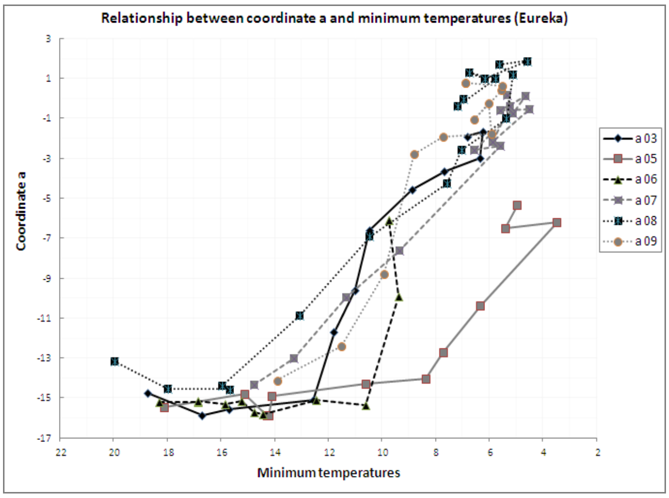

Fig 6. Relationship between colorimetric coordinate a and the average of the minimum temperatures of the previous 21 days in variety Eureka for the six years (a 03, …, a 09).

ripening period of lemons over six years. That is, the data refer to two dimensions, one temporal (period of ripening) and the other a list of the years under study (analysis units). To select the best correlations between the variables, we used the coefficient adjusted R^2, which identifies the models closest to unity taking into account the number of explicative variables. For this purpose we shall use fixed factors and cross-section specific coefficients, that is, a joint estimation covering the six years studied, in which we consider that both the independent term and the coefficients of both variables can vary from year to year. The statistical package Eviews v.5.1. was used to treat the data. We are aware that other factors may affect the changes in color, such as type of irrigation applied, fertilization, soil type, light, etc. However, previous analyses showed that temperature has the strongest influence in this respect, and it is for this reason that we concentrate on this parameter in this study. In future works, we intend to look at these aspects in greater depth, using suitable statistical analyses, including ANOVA after dividing the plot into corresponding study units.

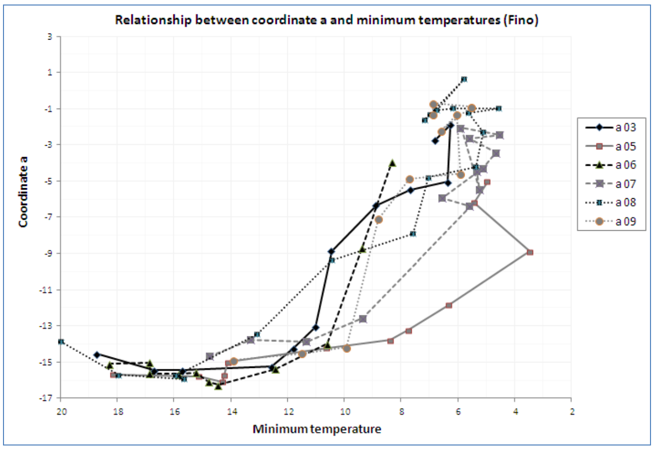

Fig 7. Relationship between colorimetric coordinate a and the average of the minimum temperatures of the previous 21 days in variety Fino for the six years (a 03, …, a 09).

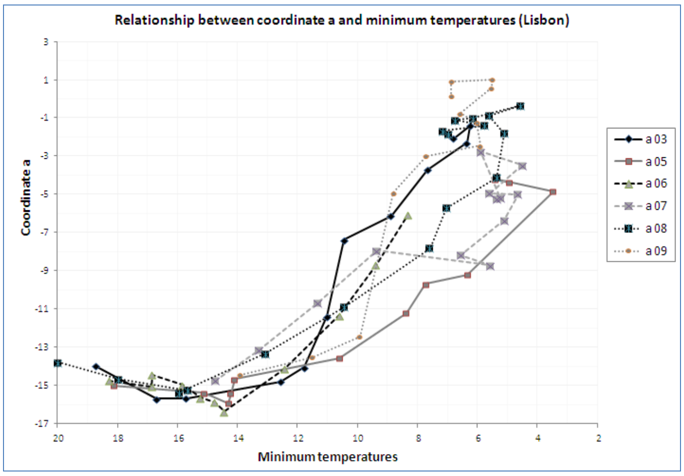

Fig 8. Relationship between colorimetric coordinate a and the average of the minimum temperatures of the previous 21 days in variety Lisbon for the six years (a 03, …, a 09).

Conclusions

The color measured in lemon is not only influenced by the temperature of the day the measurement is taken a by the temperatures of the immediately preceding days. Rather, the best correlation as regards the change of color of lemon peel (coordinate a, chroma and hue angle) is obtained when the mean temperatures of the 21 days prior to sampling day are taken into account.

- The minimum temperature has a greater effect on the loss of greenness than the mean temperature.
- Color change begins when the minimum temperature falls below 15 ºC; the green color disappearing at about 6 ºC.
- The values represented by colorimetric coordinate **a** are not only explained by the mean temperature of the preceding 21 days, but also by the previous value of this parameter; for example, as the mean temperature falls from 14º to 6 ºC the green color does not diminish immediately (color coordinate a and values h_{ab}) but does so gradually, and will become noticeable in successive samplings as a consequence of the gradual degradation of the chlorophylls and the gradual synthesis of carotenoids.

- In areas of the world where the minimum temperature does not fall below 15 ºC, the degreening process will not begin and any fruit grown there will need artificial processing if the lemons are to take on their characteristic yellow color.

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