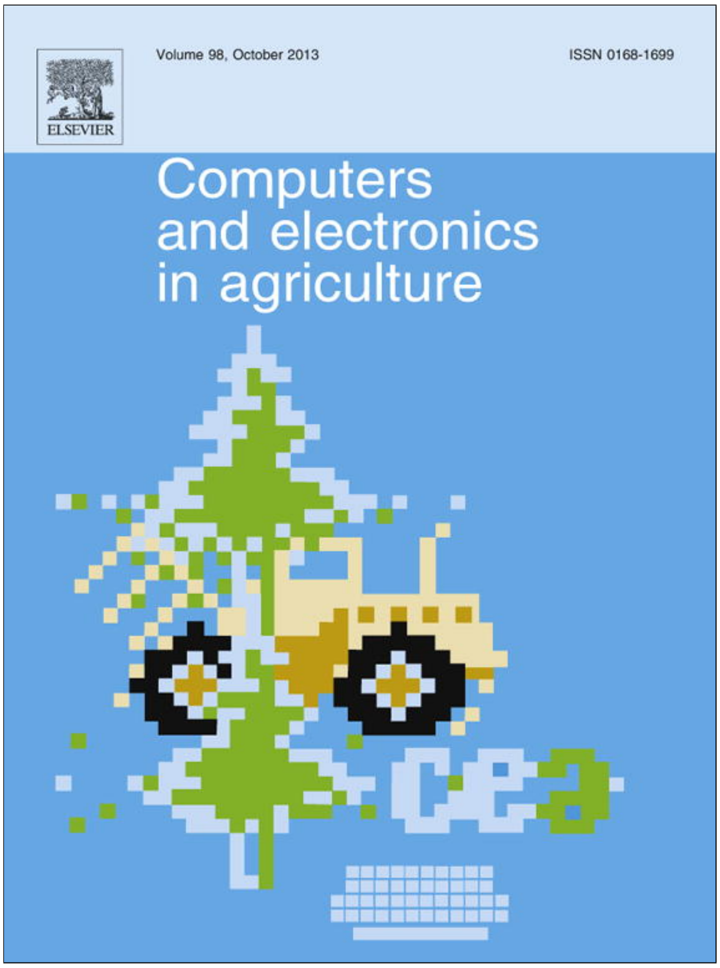
Volume 98, October 2013
ISSN 0168-1699
ELSEVIER
Computers
and electronics
in agriculture
cea

Computers and Electronics in Agriculture 98 (2013) 222–232

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

A fuzzy approach to the loss of green colour in lemon (*Citrus lemon* L. Burm. f.) rind during ripening

José M. Brotons [a,*], Javier Manera [b,1], Agustín Conesa [c,2], Ignacio Porras [d,3]

[a] Department of Economic and Financial Studies, Miguel Hernández University, Avda. de la Universidad, s/n, 03202 Elche, Alicante, Spain
[b] Department of Physics and Architecture of Computers, Miguel Hernández University, Ctra de Beniel, km 3.2, 03312 Orihuela, Alicante, Spain
[c] Department of Vegetable Production and Microbiology, Miguel Hernández University, Ctra de Beniel, km 3.2, 03312 Orihuela, Alicante, Spain
[d] Department of Citriculture, Murcian Institute of Agriculture and Food Research and Development, Estación Sericícola, Calle Mayor s/n, 30150 La Alberca, Murcia, Spain

ARTICLE INFO

Article history:
Received 18 February 2012
Received in revised form 31 July 2013
Accepted 11 August 2013

Keywords:
Eureka
Citrus macrophylla
Rind colour
Temperature
Fuzzy
Regression

ABSTRACT

This study describes the relationship between air temperature and the loss of greenness in lemon rind and the appearance of the typical yellow colour in the lemon varieties Eureka Frost on *Citrus macrophylla* rootstock. Lemon rind loses its green colour naturally in temperate climates when air temperatures fall. Greenness can be measured as the loss of "**a**" in reflection colorimetry. For each data recording session, while the mean air temperature is a certain fact, measurements of the coordinate **a** may show substantial variability despite the fact that they are made with an instrument of great accuracy. We propose a fuzzy methodology combining two elements: (a) possibilistic regression by means of trapezoidal fuzzy numbers, the estimate of which will provide a range of values that the variable in question could attain for a given mean temperature, and (b) the use of rules of the type *if*… *then*; this provides greater accuracy to the estimate because the degreening process only occurs between given temperatures. Until these temperatures fall below 11.5–16 °C, degreening cannot be considered to have begun and the temperature will not influence the coordinate **a**. Finally, the aim of this kind of study is not to obtain one isolated estimate but rather a range of possible values that reflect reality.

1. Introduction

Colour and colour uniformity are two of the main attributes that define the direct quality of citrus fruits. Colour is often taken as an index of freshness, palatability and nutritional value (Haisman and Clarke, 1975).

Commercial harvesting of lemons (*Citrus lemon* Burm. f) in Spain for the international fresh fruit market, especially destined for northern European countries, begins when fruit diameter exceeds 56–58 mm and the percentage of juice is greater than 30% (García Lidón et al., 2003). In mid-September, fruits are harvested when their external rind colour is still green and are commercially degreened after harvest by exposing them to ethylene for a few days (Porat, 2008). When nights get colder, between the end of October and mid-November, the chlorophylls present in the rind are degraded and previously masked carotenes are freshly synthesised (Soni and Randhawa, 1969; Sinclair, 1984), imparting the characteristic "lemon yellow" colour to the fruit. The number of carotenoids in citrus fruit is very high (Gross, 1977; Casas and Mallent, 1988a; Lee and Coates, 2003; Meléndez Martínez et al., 2007, 2010a, 2010b), mainly due to a complex mixture of carotenoids (Ting and Attaway, 1971; Stewart, 1980; Spiegel-Roy and Goldschmidt, 1996).

In lemon, the total concentration of carotenoids is lower than in navel orange (*Citrus sinensis* Osbeck), (Yokoyama and Vandercook, 1967). More recently, Kato et al. (2004) showed that the lemon Lisbon accumulates carotenoids, the principal one being β-cryptoxanthin although at lower levels than in Satsuma and Valencia orange. 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). Citrus fruit are routinely degreened by a process in which the fruit are exposed to ethylene before packing (Petracek and Montalvo, 1997). Degreening is considered to be essential to produce marketable early season citrus fruits.

Environmental, nutritional and hormonal signals appear to be involved in the control of chlorophyll-chromoplast interconversions (Casas and Mallent, 1988a, 1988b; Richardson and Cowan, 1995; Spiegel-Roy and Goldschmidt, 1996; Navarro et al., 2010).

Abbreviations: TrFN, Trapezoidal Fuzzy Number.

* Corresponding author. Tel.: +34 966658967.
E-mail addresses: jm.brotons@umh.es (J.M. Brotons), fco.manera@umh.es (J. Manera), agustin.conesa@umh.es (A. Conesa), ignacio.porras@carm.es (I. Porras).
[1] Tel.: +34 966749629.
[2] Tel.: +34 966749689.
[3] Tel.: +34 968366758.

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http://dx.doi.org/10.1016/j.compag.2013.08.011

Many studies have looked at the effect of climate on citrus fruit quality, the classic work in this respect being that of Reuther (1973). However, few authors have looked at the correlation between changes in colour on the tree and temperature.

In experiments carried out in Florida with the orange cultivars Hamlin, Parson Brown and Pineapple rind colour turned at 12.8 °C. The speed with which the fruit reached maximum colouration depended on the severity of the decrease in temperature, and the number of days that temperatures remained below 12.8 °C (Stearns and Young, 1942). Grierson et al. (1986) suggested that during cool nights (<12.5 °C) fruit are subjected to a mild stress that triggers endogenous ethylene production, resulting in chlorophyll degradation and the unmasking and/or synthesis of other natural pigments.

Rind colour of lemon can be determined by several non-destructive methods, among them colorimetry and tristimulus colorimetry, which are both easy and rapid. Among the different colorimetric coordinates provided by the colorimeter, the coordinate that measures greenness is **a**, which is influenced by the temperatures experienced on the days preceding measurement (Manera et al., 2012a).

Studies related with the degreening of citrus in the laboratory or during storage are frequent (Artés et al., 1997, 1999; Eaks, 1977; John-Karuppiah and Burns, 2010; Petracek and Montalvo, 1997; Tietel et al., 2010; Zhou et al., 2010), but few deal with the physical process of change and its correlation with temperature. In the present study, we take a fresh look at the works of Stearns and Young (1942), Manera et al. (2012b), and Manera et al. (2013) and attempt to deepen our knowledge of perceived colour change and its relation with temperature, using fuzzy mathematics.

The degradation of chlorophylls permits the unmasking of other natural pigments that already exist in the lemon rind, such as carotenoids, which are responsible for its characteristic yellow colour. For this reason, to study the appearance of yellow colour in lemons, it is sufficient to study chlorophyll degradation by measuring the colorimetric parameter **a**.

Degreening, measured by parameter a is mainly influenced by air temperature, although the relation is very difficult to delimit mathematically since:

(1) it is very difficult to control all field conditions of soil, irrigation, fertilisation, etc.,
(2) the parameters measured in the fruit are also influenced by their height above the ground, position on the branch, orientation, etc.,
(3) rind colouring is not homogeneous,
(4) while temperature is the most important variable, other environmental conditions are also influential – radiation, relative humidity, rainfall, etc.

In short, the relation between temperature and lemon rind colour presents many uncertainties, not only due to the above mentioned factors, but also due to differences in the methods used to explain the relation. Even though we may know the relation between temperature and the evolution of parameter **a**, this relation occurs within a certain range of temperatures since when temperatures are high any variation in the same does not affect the coordinate **a**, and the same applies when temperature same excessively low. However, "high" and "low" are ambiguous concepts and difficult to delimit, especially since degreening is not triggered at a fixed temperature, but rather between a given maximum and minimum, it being practically impossible to exactly predict the value at which the process will start each year.

Uncertainty can be defined as any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system. Walker et al. (2003) distinguished three dimensions of uncertainty, while Janssen et al. (2010) distinguished six kinds of uncertainty: context, model structure, model technical, input, parameter and aggregated uncertainty.

Several authors have dealt with uncertainty using fuzzy sets (e.g. Klir and Yuan, 1995; Zimmermann, 2000; Zadeh, 2005; Terceño-Gomez et al., 2009, Brotons and Terceño, 2010). The application of fuzzy set theory is a suitable approach in cases in which uncertainty is due to incompleteness or imprecision. Fuzzy methodology has been used to explain agronomic phenomena, including an evaluation of varieties of water melon (Hou et al., 2009), to evaluate soil productivity (Duru et al., 2010) and to analyse soil-landscape (Schmidt et al., 2005). Mazloumzadeh et al. (2010) carried out a study to improve date palm yield using maps of the variation in tree properties. The Mamdani fuzzy inference system was used to classify the productive trees based on yield, fruit length and visual appearance, and to produce a tree total quality map for each grove. In the same way, Tremblay et al. (2010), developed a fuzzy logic methodology to determine optimum rates of N for corn on the basis of field and crop features.

In our case, fuzzy methodology allows us to introduce this uncertainty into a model, and to treat it. In the first place, it enables punctual estimation through defuzzification of the results, while bearing in mind the uncertainty, secondly, it permits the range in which the value of parameter **a** can vary for each temperature to be obtained. In this way, a first range is provided that indicates all the possible values that coordinate **a** might show, and a second range (included in the first) that indicates the values that coordinate **a** is more likely to reach.

In this work, therefore, we use fuzzy methodology to explain the correlation between the natural degreening of lemon fruits on the tree (parameter **a**) and temperature, in an objective and practical way, identifying when the process begins. This should help growers and the citrus industry in general to decide whether or not artificial degreening will be needed after harvest to satisfy the strict timetable of lemon marketing and to save the costs involved in this process. As long as meteorological data are available for a given region, the results will also be of great interest for deciding whether new sites are suitable for lemon tree cultivation or whether artificial degreening will add to the costs involved.

2. Materials and methods

2.1. Plant material and data gathering

The cultivar used in this study is Eureka Frost, one of the most important on a worldwide scale, on *Citrus macrophylla* rootstock (Saunt, 1990). The trees were planted in April 1983 in a plot at Murcian Institute of Agriculture and Food Research and Development, La Alberca (Murcia, SE Spain). Tree spacing was 6 × 6 m, and drip irrigation was provided by 5 emitters per tree with a flow rate of 4 l/h. Annual average temperature is 18.7 °C and annual rainfall 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 external colour of the fruit was measured in the HunterLab colour space (Hunter, 1967) with illuminant C (representative of daylight), using a colorimeter Minolta CR-300 reflection colorimeter, double-beam tristimulus in the visible light range, standard observer angle, CIE-2° and a white calibration plate, taking three readings in the equatorial zone of each fruit. For each reading, the colorimetric coordinates **L**, **a** and **b** were measured. Colour coordinate **L** measures luminosity (100 for white and 0 for black). Colorimetric coordinate **a** corresponds to the green–red axis, where negative values are related with green and positive with red (−60 green, +60 red) (MacDougall, 2002), and **b** measures variations from blue to yellow (−60 blue, +60 yellow). Any decrease in the chlorophyll content of fruit is associated with coordinate **a** (Kidsome et al., 2002), which is the only coordinate we analyse in this work.

To determine the influence of mean and minimum temperatures on the development of external colour in lemon fruit, ten fruit (five from the north face and five from the south face) were randomly chosen and labelled on each of four trees at the beginning of the assay period in the 2003/04, 2005/06, 2006/07, 2007/08, 2008/09, 2009/10 and 2010/11 seasons that run from September to February of the following year. Measurements were made approximately every ten days (about 3600 measurements in total). The temperatures data were collected from a weather station in the same experimental orchard: MU62, la Alberca, Murcia, (SIAM, 2011). Minimum temperature and mean temperature were calculated from hourly measurements. For this study, we have worked with simple moving averages (the unweighted mean of the previous 7, 14, 21 and 28 days).

2.2. Fuzzy concepts

A fuzzy set of a set X is defined by a membership function $\mu(x)$ that takes for each value of x a membership value in the range $[0,1]$. A fuzzy set of R is called a fuzzy number if the membership function $\mu(x)$ is convex and normalised. A trapezoidal fuzzy number can be defined by its support and its kernel bounds $A = (K_A, R_A) = ([K_A^-, K_A^+], [S_A^-, S_A^+])$, where support: $S_A = [S_A^-, S_A^+]$, Kernel: $K_A = [K_A^-, K_A^+]$ (see Fig. 1). The α-cut of a trapezoidal fuzzy number is defined as $[A]_\alpha = [(A^-)_\alpha, (A^+)_\alpha]$, $(A^-)_\alpha = \inf\{x/\mu(x) \geqslant \alpha; x \geqslant S_A^-\}$, $(A^+)_\alpha = \inf\{x/\mu(x) \geqslant \alpha; x \geqslant S_A^+\}$.

2.3. Trapezoidal fuzzy regression

Let us consider a set of N observed data samples defined on an interval $D = [x_{\min}, x_{\max}]$. Let the jth sample be represented by the couple $(x_j, Y_j), j = 1, \ldots, N$, where x_j are crisp and Y_j are the corresponding fuzzy output. The objective is to determine a predicted functional relationship

$$Y(x) = A_0 \oplus A_1 \cdot x \tag{1}$$

defined on the domain D. The parameters A_0 and A_1 are trapezoidal fuzzy coefficients. As a result, the output is fuzzy, as well. In order to identify the parameters A_0 and A_1, it must be imposed that all the observed data are included in the predicted data for any α-cut. As the output of the model is a trapezoidal fuzzy number, two constraints must be taken into consideration in order to guarantee the total inclusion of the data in the predicted one for each level α:

$$[Y_j]_{\alpha=0} \subseteq [\widehat{Y}_j]_{\alpha=0}, \text{ and } [Y_j]_{\alpha=1} \subseteq [\widehat{Y}_j]_{\alpha=1} \tag{2}$$

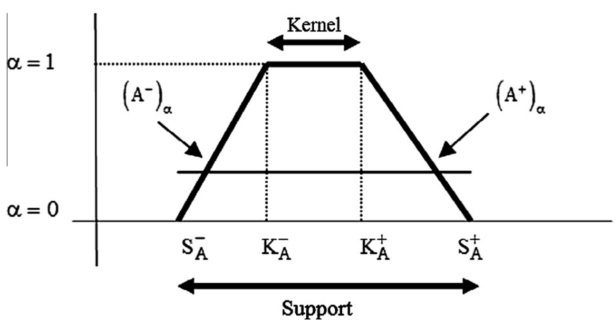

Fig. 1. Fuzzy trapezoidal number.

The output model tendencies are not taken into account in the conventional method. In order to solve this problem, Bisserier et al. (2010) propose a modified model expression in which the model output can have any kind of spread variation for any sign of x by introducing a shift on the original model input.

$$Y(x) = A_0 \oplus A_1(x - shift) \tag{3}$$

When the model has an increasing radius, $shift = x_{\min}$ will be taken, and $shift = x_{\max}$ will be taken in the contrary, if the model has a decreasing radius. Denoting $w_j = x_j - shift$, the output of the fuzzy model is a trapezoidal interval given by:

$$\forall w \in D : \begin{cases} K_{\hat{Y}}^- = K_{A_0}^- + (M(K_{A_1}) - R(K_{A_1}).\Delta)w \\ K_{\hat{Y}}^+ = K_{A_0}^+ + (M(K_{A_1}) + R(K_{A_1}).\Delta)w \\ S_{\hat{Y}}^- = S_{A_0}^- + (M(S_{A_1}) - R(S_{A_1}).\Delta)w \\ S_{\hat{Y}}^+ = S_{A_0}^+ + (M(S_{A_1}) + R(S_{A_1}).\Delta)w \end{cases} \tag{4}$$

where $\Delta = \text{sign}(w_{\min} + w_{\max})$, and $M()$ is the midpoint and $R()$ is the radius (for example, $M(K_{A_1}) = (K_{A_1}^- + K_{A_1}^+)/2$ and $R(K_{A_1}) = (K_{A_1}^- - K_{A_1}^+)/2$, and the output spread is given by $R([S_{Y_j}]) = R([A_0]) + R([A_1])w_j$.

The optimisation program (Bisserier et al., 2010) is:

$$\min(w_{\max} - w_{\min})(R(K_{A_0}) + R(S_{A_0})) + \frac{1}{2}(w_{\max}^2 - w_{\min}^2)(R(K_{A_1}) + R(S_{A_1}))\Delta \tag{5}$$

$$\text{For } \alpha = 1, K_{Y_j} \in [K_{\hat{Y}_j}^-, K_{\hat{Y}_j}^+] \iff |M(K_{\hat{Y}_j}) - K_{Y_j}| \leqslant R(K_{\hat{Y}_j}) \tag{6}$$

$$\text{For } \alpha = 0, [K_{Y_j} - R_{Y_j}, K_{Y_j} + R_{Y_j}] \subseteq [S_{Y_j}^-, S_{Y_j}^+] \iff |M(S_{\hat{Y}_j}) - K_{Y_j}| \leqslant R(S_{\hat{Y}_j}) - R_{Y_j} \tag{7}$$

The inclusion of the kernel in the support gives:

$$[K_{\hat{Y}_j}^-, K_{\hat{Y}_j}^+] \subseteq [S_{\hat{Y}_j}^-, S_{\hat{Y}_j}^+] \iff |M(S_{\hat{Y}_j}) - M(K_{\hat{Y}_j})| \leqslant |R(S_{\hat{Y}_j}) - R(K_{\hat{Y}_j})| \tag{8}$$

where

$$\begin{aligned} M(K_{\hat{Y}_j}) &= M(K_{A_0}) + M(K_{A_1})w_j \\ R(K_{\hat{Y}_j}) &= R(K_{A_0}) + R(K_{A_1})w_j\Delta \\ M(S_{\hat{Y}_j}) &= M(S_{A_0}) + M(S_{A_1})w_j \\ R(S_{\hat{Y}_j}) &= R(S_{A_0}) + R(S_{A_1})w_j\Delta \end{aligned} \tag{9}$$

2.4. Fuzzy rules

In accordance with Gil-Aluja (1999), one can define a relation to every kind of association capable of revealing the levels of connection between physical or mental objects belonging to the same set or between objects belonging to different sets.

A fuzzy relation R from a fuzzy set A in X to a fuzzy set B in Y is a fuzzy set, and is the Cartesian product $A \times B$ in Cartesian product space $X \times Y$. R is characterised by the membership function expressing various degrees of strength of relation, such as (using min T-norm):

$$R = A \times B = \sum \mu_R(x,y) \big/ (x,y) = \sum \min(\mu_A(x), \mu_B(y)) \tag{10}$$

The rules in the fuzzy knowledge base are of the shape "if x, then y", with x and y fuzzy sets represented by membership functions. We denote the membership functions of the temperature of the above described regions as $\mu_1(x)$, $\mu_2(x)$ and $\mu_3(x)$. Assuming that the value x^* belongs to the three regions, the value of the colorimetric coordinate **a** must be estimated according to expression (3) using expressions (5)–(8).

The extremes of the aggregated TrFN are:

$$A = a_1\mu_1(x^*) + a_2\mu_2(x^*) + a_3\mu_3(x^*) \quad (11)$$

and *B*, *C* and *D* are obtained in a similar way.

2.4.1. Defuzzification

The centre of gravity determines the centre of the area below the combined membership function, and the defuzzified value of a fuzzy number is,

$$x = \frac{\int \mu(x) \cdot x \cdot dx}{\int \mu(x) \cdot dx} \quad (12)$$

3. Results and discussion

3.1. Evolution of parameter a

From August and until the end of winter, **a** values of the varieties Eureka, Fino and Lisbon increased simultaneously with decreases in the temperatures (Fig. 2). In other words, as the temperatures fell, the **a** value increased.

Fig. 3 shows the relationship between **a** values and the temperatures for all the years covered by the study. While temperature is a certain value, the value of **a** is not certain, since, although it can be measured exactly with a colorimeter, it does not take on one value for each date, but a range of values which must be related with the corresponding temperature. The values obtained with the colorimeter depend on, among other factors, the size of the fruit, its position on the tree, whether or not it is exposed to direct sunlight, distance above the ground, etc.

As can be seen from Fig. 4, as the process begins when the difference between the maximum and minimum value of colorimetric coordinate **a** becomes more pronounced and only at the end does this difference decrease until it reaches zero. Temperature has no effect on lemon colour until it falls below 13 °C. Similarly temperatures below 7 °C do not influence colour because the fruit will already be totally yellow.

In an attempt to predict **a** value at a given temperature, we shall consider three regions: region 1, with high temperatures, where the process has not yet begun, region 2, with intermediate temperatures, where the degreening process has begun and where the evolution of **a** is related with the temperature changes taking place, and region 3, with low temperatures, when the degreening process has finished. However, it is no easy task to separate these three regions since degreening does not always begin on the same date but depends on several factors, such as temperature, humidity, luminosity, etc. In this study we analyse the effect of temperature on **a**, assuming that the other variables are constant, even though this does not happen in reality. Even assuming that the rest of the variables remain constant, the coordinate **a** takes different values for each temperature. This means that degreening does not always start in the same region or at the same values of the variable, and also the end values differ from year to year. For this reason, the relation between colorimetric coordinate **a** and the temperature in the intermediate region also differs from year to year.

To correctly design the model, the first aim will be to determine the range of temperatures that influences the evolution of **a**, since degreening does not begin until the temperature begins to fall from approximately 13 °C, while, once a minimum temperature has been exceeded, further falls have no effect on the degreening process. Thus, for each data-taking session in which only one mean temperature exists, the coordinate a takes on a wide range of values. Given that we are dealing with the data for seven years, the problem becomes even more acute, because, for each temperature, the difference between minimum and maximum values of **a** become more pronounced.

The aim, therefore, is to determine the relationship between temperature and the colorimetric coordinate **a** using possibilistic regression. In this respect, several fuzzy regression approaches have been proposed. The first was introduced by Tanaka et al. (1982, 1989), who subsequently proposed the use of quadratic membership (Tanaka and Ishibuchi, 1991) functions to estimate the parameters, due to the problem arising from the fact that the spread of the output increases around a central point. In this way, Bisserier et al. (2010) proposed a tendency problem solution, introducing the term shift.

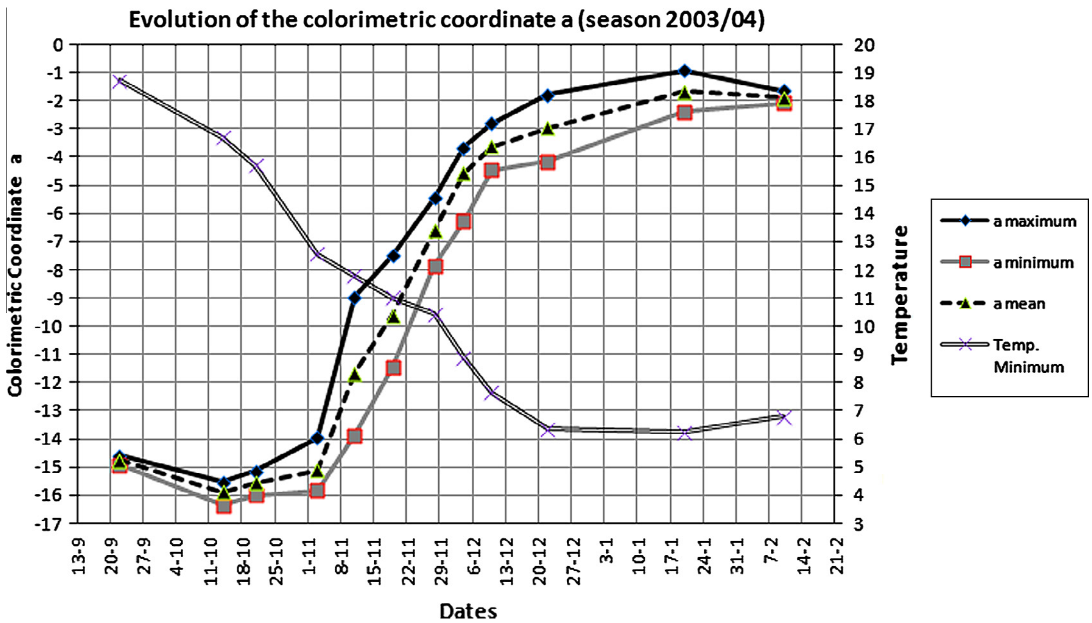

Fig. 2. Evolution of the colorimetric coordinate **a** and temperatures in the period 2003/04. For the variable temperature we show the mean of the daily minimum values for the 21 days preceding the day on which measurements were made. For coordinate a, we show the maximum, minimum and mean values obtained for each sampling date.

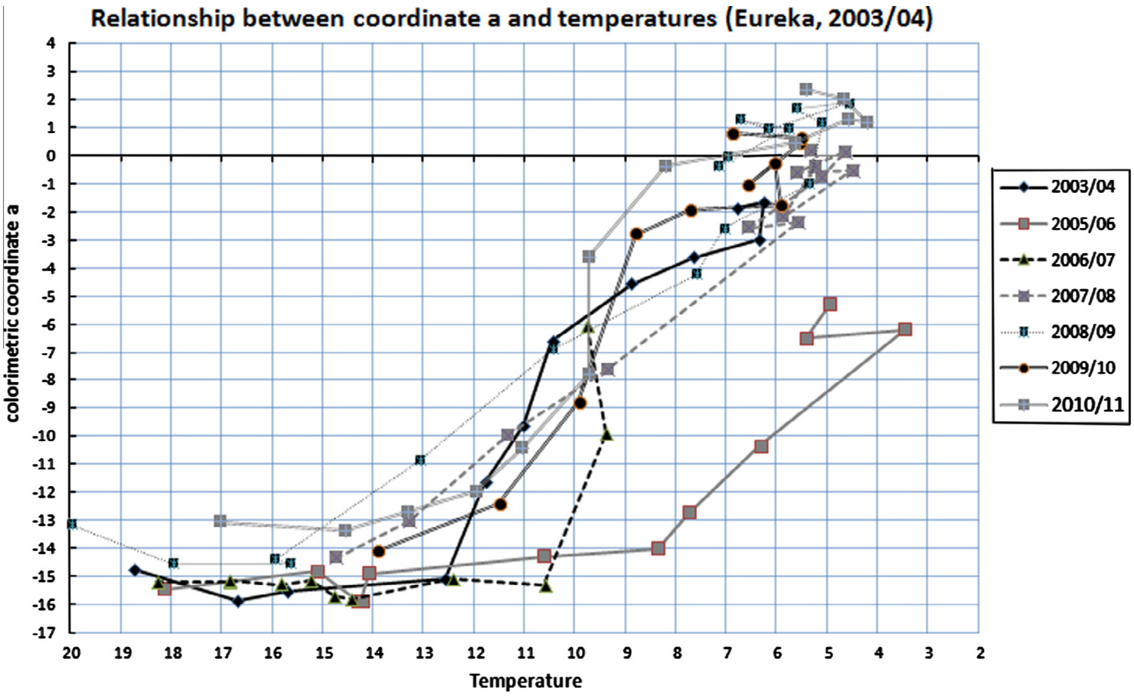

Fig. 3. Relationship between colour coordinate **a** and temperatures during the seven season of the study. Each of the series shows the evolution of the coordinate **a** in the season indicated.

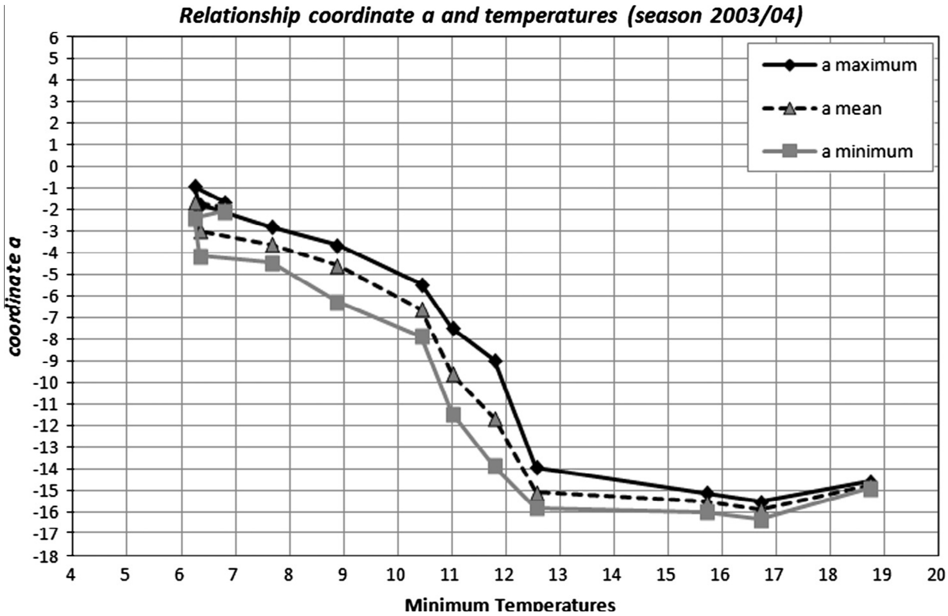

Fig. 4. Relationship between colorimetric coordinate **a** and minimum temperatures for season 2003/04. The minimum temperatures are the mean of the daily minimum values for the 21 days preceding the day on which measurements were made. For coordinate a, we show the maximum, minimum and mean values obtained for each sampling date.

Fuzzy regression has been developed from possibility theory and statistical regression has been developed from probability theory. When the dependent variable is obtained as fuzzy numbers, the application of fuzzy regression is most suitable (Tanaka et al., 1982). According to Kim et al. (1996), in terms of predictive and descriptive capabilities, the choice between possibility and statistical will depend on various factors, in particular, when insufficient data are available or the aptness of the regression model is poor. For the situation proposed in this paper, possibilistic regression is most suitable because: (1) input date are taken as fuzzy numbers, (2) the relationship between temperatures and colorimetric variable **a** is vague and imprecise and (3) the regions to use regression or fixed number are delimited in an imprecise way.

To complete the study, we shall use an expert fuzzy system composed of a knowledge base, an inference engine and a data base. The knowledge base describes the inference rules, and the second component links the data from the data base to the rules. As a result, an outcome value is obtained. The rules in the fuzzy knowledge base are generally of the shape "if *x*, then *y*", being *x* and *y* fuzzy sets.

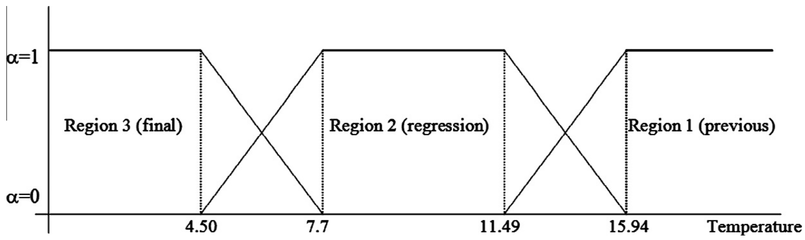

Fig. 5. Representation of the membership functions of regions 1, 2 and 3 as a function of the mean minimum temperatures of the last 21 days. α indicates the "level of belonging" of a given temperature to each of the regions indicated.

3.2. The regions studied

Fig. 3 illustrates the evolution of the colour coordinate **a** during the different years in variety Eureka in the degreening period (approximately September to February, when the mean temperature falls from 18–20 °C to approx. 5–6 °C). As can be seen, the value of **a** increases as the temperature falls. This figure also shows the three regions studied, the first one with high temperatures, where the value of **a** is always low, an intermediate series of temperatures, where the value of **a** increases as the mean temperature falls and another region in which the value of **a** is high and does not depend on the evolution of temperature.

The regions mentioned above (Fig. 5) can be defined as follows:

- Region 1. Degreening has not yet begun and the value of **a** remains below −12. Temperatures are above 13–14 °C.
- Region 2. Degreening, which began at approximately 13–14 °C, is under way.
- Region 3. Degreening has finished and there is no relation between temperature and the value of **a**. Temperatures are below 6–7 °C.

It is difficult to determine whether a mean temperature belongs to region 1, 2 or 3. The separation between regions 1 and 2 occurs for the values shown in Table 1. Since temperature were not taken daily, the process of degreening begins between two observations, one when the process has not yet started and the second one, when it is considered to be under way.

Based on Table 1, temperatures above 15.94 °C are considered to belong to region 1 and those below 11.49 °C to region 2.

Similarly, the limit between regions 2 and 3 is defined by the moment that the value of a stops falling. As in the previous case, it is not possible to say the exact time when degreening stops, so that the last observation in which **a** is still increasing and the first when it has stopped (or decreases) are taken (see Table 2).

It is clear that temperatures below 4.5 °C place us within region 3 and that temperatures above 7.7 °C situate us in region 2. Nothing can be said *a priori* about temperatures between these values.

As a consequence, we shall partition the temperatures, considering that a temperature below 4.5 °C belongs to region 3, with a level of membership of 1. A temperature of 4.5–7.7 belongs to region 1, with a membership level between 0 and 1, but at the same time belongs to region 2 with a different level of belonging, in agreement with Fig. 5, etc. The membership to each region is delimited by expressions (13)–(15).

Temperatures membership function, region 1.

$$\mu_1(x) = \begin{cases} 1 & x > 15.94 \\ \frac{x-11.49}{15.94-11.49} & 11.49 < x < 15.94 \\ 0 & 11.49 < x \end{cases} \quad (13)$$

Temperatures Membership function, region 2.

$$\mu_2(x) = \begin{cases} \frac{x-4.5}{7.70-4.5} & 4.50 < x < 7.70 \\ 1 & 7.70 < x < 11.49 \\ \frac{x-15.94}{11.49-15.94} & 11.49 < x < 15.94 \\ 0 & otherwise \end{cases} \quad (14)$$

Temperatures Membership function, region 3.

$$\mu_3(x) = \begin{cases} 1 & x < 4.5 \\ \frac{7.70-x}{7.70-4.5} & 4.5 < x < 7.70 \\ 0 & 7.70 < x \end{cases} \quad (15)$$

3.3. Estimation of the colorimetric coordinate a

For this estimate, we shall first study the peculiarities of each of the three regions before proceeding to the global estimate.

Table 1
Delimitation of regions 1 and 2. Previous temperature observation refers to the temperature recorded immediately before degreening begins. Following temperature observation refers to the temperature recorded immediately after the process has begun. The maximum and minimum are calculated from each column.

Year	Previous temperature observation	Following temperature observation
2003/04	15.71	12.56
2005/06	14.22	14.09
2006/07	14.43	12.42
2007/08	14.74	13.29
2008/09	15.94	13.06
2009/10	13.9	11.49
2010/11	14.54	13.3
Maximum	15.94	14.09
Minimum	13.9	11.49

Table 2
Delimitation of regions 2 and 3. Previous temperature observation refers to the temperature recorded immediately before degreening finishes. Following temperature observation refers to the temperature recorded when parameter **a** is considered to have no relation with temperature.

Year	Previous temperature observation	Following temperature observation
2003/04	–	–
2005/06	–	–
2006/07	–	–
2007/08	5.58	4.50
2008/09	5.61	4.55
2009/10	7.70	5.90
2010/11	5.62	4.59
Maximum	7.7	5.9
Minimum	5.58	4.5

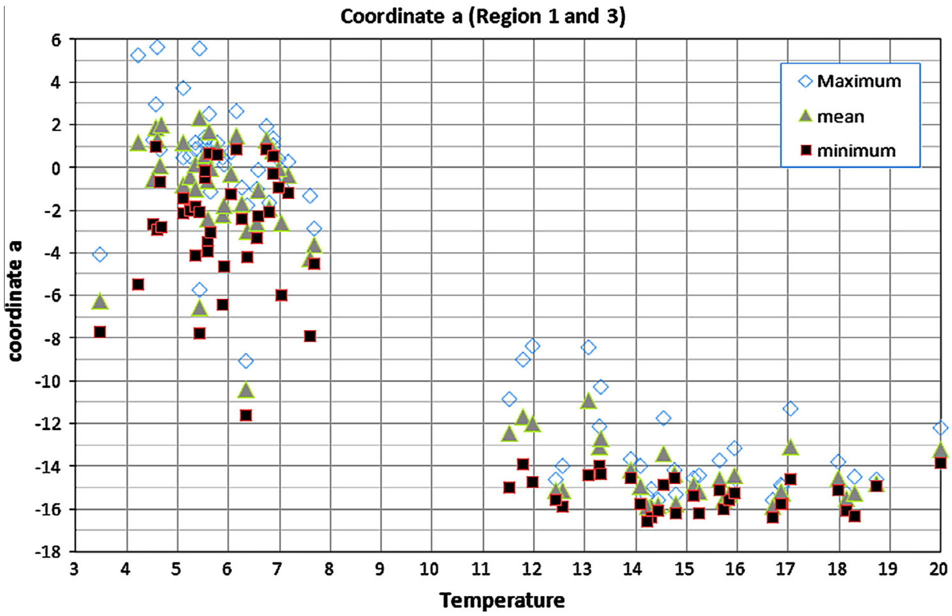

Fig. 6. Coordinate **a** and temperatures in region 1 and 3 during the seven seasons studied. The series a maximum, a minimum and a mean indicate the maximum, minimum and mean values of coordinate **a** observed on each of the sampling dates.

Table 3
Representative values of region 1. The column **a** maximum represents the mean of the values corresponding to region 1 of each campaign. The same applies to the columns **a** minimum and **a** mean. The value **a** maximum corresponds to the maximum of the column **a** maximum, the minimum with the minimum of the column **a** minimum, and the mean max, and mean min to the maximum and minimum of the column **a** mean.

Season	**a** maximum	**a** minimum	**a** mean
2003/04	−14.59	−15.84	−15.11
2005/06	−15.03	−16.03	−15.47
2006/07	−14.90	−15.89	−15.21
2007/08	−13.12	−14.24	−13.69
2008/09	−13.09	−15.12	−14.39
2009/10	−12.22	−14.75	−13.26
2010/11	−10.75	−14.66	−12.88
	a maximum	−10.75	
	a mean maximum	−12.88	
	a mean minimum	−15.47	
	a minimum	−16.03	

3.3.1. Region 1

In region 1 the degreening process has not yet begun. Fig. 6 shows the range of values measured (for temperatures higher than 11 °C). For each year, the average of the maximum, minimum and mean values of **a** are given in Table 3. The values representing this region are taken as the mean of the previous measurements of the seven seasons. In region 1, the values vary between -13.04 and 15.09, with 14.08 being the most probable value.

3.3.2. Region 2

The estimate of the regression (3) should be made in accordance with the optimisation program (5)–(8). The results of the estimates of coefficients A_0 and A_1 for all the seasons and the average are shown in Table 4. The term shift is taken to be 15.94 (maximum temperature of region 2, which in this case minimises the Bisserier function for the seven seasons as a whole). Fig. 7 shows the results for the 2003/04 season.

To estimate coordinate **a** the mean of the coefficients was taken $A_0 = ([-17.17, 13.97], [-19.10, -12.71])$ and $A_1 = ([-1.49, -1.26], [-1.63, -1.18])$. Fig. 7 shows the estimate for the 2003/04 season, where the lines S−(estimated) and S+(estimated) are the minimum and maximum values that coordinate **a** can take, and K−(estimated) and K+(estimated) are the limits calculated for the central values. The aim of the estimate is that the series S−(estimated) and S+(estimated) include all the values of the estimate and that K−(estimated) and K+(estimated) include

Table 4
Summary of the estimates for the seven seasons. The coefficients A_0 and A_1 for the seven seasons and their average are shown. Also shown are the corresponding centre (M) and radii (R) according to Fig. 7.

	A_0				A_1			
	$S(A_0)^-$	$K(A_0)^-$	$K(A_0)^+$	$S(A_0)^+$	$S(A_1)^-$	$K(A_1)^-$	$K(A_1)^+$	$S(A_1)^+$
2003/04	−21.57	−20.63	−15.97	−15.57	−1.84	−1.69	−1.69	−1.69
2005/06	−17.10	−16.58	−15.38	−15.06	−0.63	−0.53	−0.35	−0.30
2006/07	−16.22	−15.99	−15.43	−15.17	−1.64	−1.50	−0.14	−0.01
2007/08	−16.81	−16.81	−16.10	−14.60	−1.50	−1.49	−1.42	−1.02
2008/09	−3.85	−0.54	4.34	4.89	−1.34	−1.34	−1.34	−1.34
2009/10	−27.92	−24.22	−18.40	−18.40	−2.68	−2.12	−2.12	−2.12
2010/11	−23.65	−18.51	−14.19	−8.16	−1.75	−1.75	−1.75	−1.75
Average	−18.16	−16.18	−13.02	−11.72	−1.63	−1.49	−1.26	−1.18
	$M(SA_0)$	−14.94			$M(SA_1)$	−1.40		
	$R(SA_0)$	3.22			$R(S_{A1})$	0.22		
	$M(KA_0)$	−14.60			$M(KA_1)$	−1.37		
	$R(KA_0)$	1.58			$R(KA_1)$	0.11		

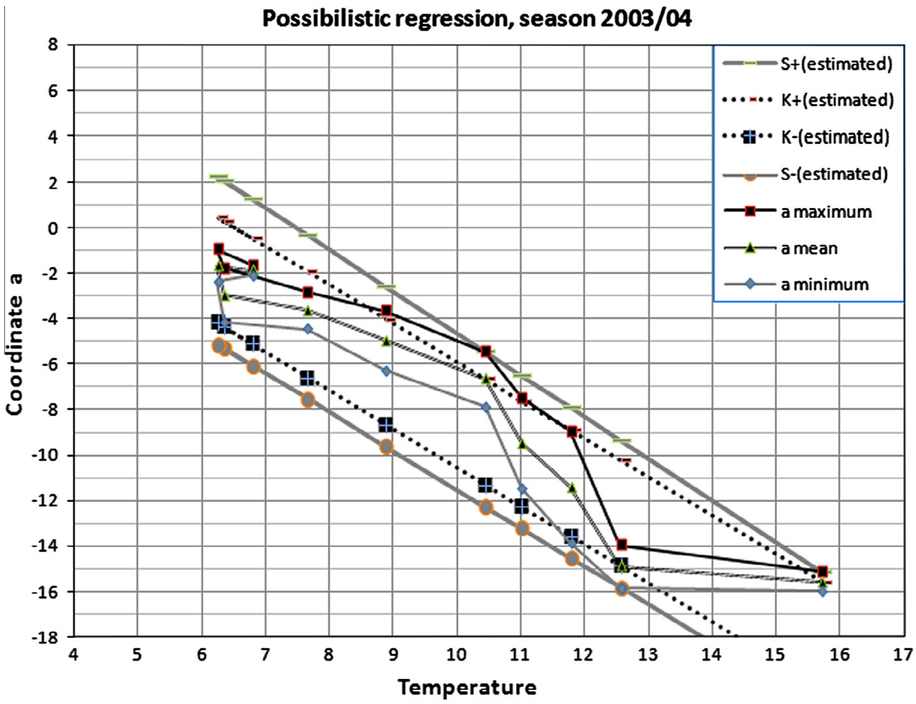

Fig. 7. Possibilistic regression, season 2003/04, between colorimetric coordinate **a** and mean minimum temperature for the 21 days preceding sampling for region 2. The series **a** maximum, **a** minimum and **a** mean indicate the maximum, minimum and mean values of coordinate **a** observed on each of the sampling dates. In turn, the series S−(estimated) and S+(estimated) correspond to the minimum and maximum values that coordinate a can reach for each temperature, and the series K−(estimated) and K+(estimated) include the mean values of the coordinate.

the central values. Of all the possibilities, that with the smallest area is taken. These results can be seen in Fig. 7 for the 2003/04 season, but also hold for the other seasons (not shown). The mean values and the results for a temperature of 10 °C (as an example) are shown in Fig. 8.

3.3.3. Region 3

Fig. 6 (for temperatures lower than 8 °C) depicts the values of the coordinate **a** in region 3, below temperatures of approximately 7 °C. Degreening can be considered close to its end and no tendency can be discerned. Following the same procedure as in region 1 gives Table 5. In short, the coordinate can be considered to vary between -7.76 and 5.61, although the mean values only vary between −6.51 and 1.31.

Most of the points, representative of coordinate **a,** with maxima, minima and means of all the measurements of the sampling day, are situated between 3 and −4, although some observations are between 6 and −8. Moreover, it can be seen that the variability is greater since the colorimetric coordinate **a** sometimes takes maximum values well above 0 and there are other minimum values that hardly exceed −8.

3.3.4. Final estimate

Fitting of the observations of coordinate **a** by diffuse mathematics would be the equivalent of making three estimates for each region and their weighting as a function of the membership function to the same, in accordance with Table 5. This gives the following results:

Region 1: coordinate **a** takes the TrFN ([−15.47, −12.88], [−16.03, −10.75]), a value we shall denote V_1.
Region 2: the linear regression is estimated according to expression (4). The parameters estimated are: A_0 = ([−17.17, 13.97], [−19.10, −12.71]) and, A_1 = ([− 1.49, −1.26], [−1.63, −1.18]), a value we shall denote as $V_2(T)$, that is, a temperature-dependent value.
Region 3: coordinate **a** takes TrFN ([−6.51, 1.31], [−7.76, 5.61]), denoted as V_3.

To obtain the final estimate, the value obtained for each region (V_1, $V_2(T)$ and V_3) is multiplied by the membership function of the temperature for the same region (μ_1, μ_2 and μ_3), in agreement with expressions (13)–(15). As an example, Table 6 shows the results of the membership functions for several temperatures.

First, an estimate is made for each season. For example, for 2003/04, generic estimates of regions 1 and 3 have been made and, as estimated parameters of region 2, the mean estimated temperatures have been taken: A_0 = ([−20.63, −15.97], [−21, 57, −15.57]) and A_1 = ([−1.69, −1.69], [−1.84, −1.69]). The estimate obtained is shown in Fig. 9. The TrFN estimated for each of the

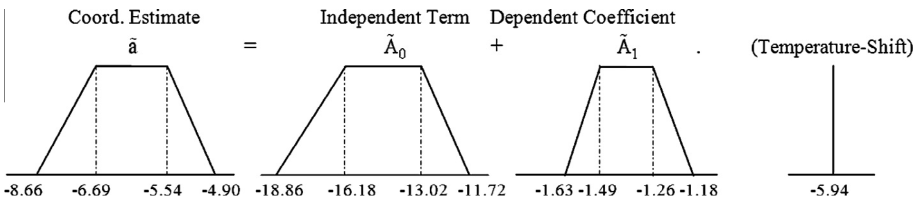

Fig. 8. Estimate of the colorimetric coordinate **a** for a temperature of 10 °C. The independent term $\tilde{A}_0$ and the coefficient of the independent term $\tilde{A}_1$ are fuzzy numbers. As a consequence, the colorimetric coordinate a is also a fuzzy number that can take values of between −8.66 and −4.90, although the mean values should be between −6.69 and −5.54.

Table 5
Values representative of region 3. To obtain column a maximum, the mean values corresponding to region 3 were obtained for each campaign, the same being applicable to the columns a minimum and a mean. The maximum value corresponds to the maximum of column a maximum, the minimum of column a minimum and the mean Max and min to the maximum and minimum of column a mean, respectively.

Season	**a** maximum	**a** minimum	**a** mean
2003	−1.71	−3.27	−2,44
2005	−5.69	−7.76	−6,51
2006	–	–	–
2007	0.57	−2.62	−0,59
2008	1.20	−0.91	0,97
2009	1.09	−0.45	0,44
2010	5.61	−2.89	1,31
	a maximum	5.61	
	a mean maximum	1.31	
	a mean minimum	−6.51	
	a minimum	−7.76	

Table 6
Obtaining the membership function for each temperature according to expressions (13)–(15) for each temperature.

Temperature	Region 1 μ_1	Region 2 μ_2	Region 3 μ_3
3	0.00	0.00	1.00
5	0.00	0.16	0.84
7	0.00	0.78	0.22
9	0.00	1.00	0.00
11	0.00	1.00	0.00
13	0.34	0.66	0.00
15	0.79	0.21	0.00
17	1.00	0.00	0.00

three regions are ([−15.47, −12.88], [−16.03, −10.75]) for region 1, ([−12.84, −10.53], [−14.33, −9.16]) for region 2, based on the previous estimations of A_0 and A_1 and following the expressions of (4), and ([−6.51, 1.31], [−7.76, 5.61]) for region 3. The final fitting is obtained by weighting the above TrFN with the membership functions according to expressions (13)–(15). The result is shown in Fig. 9.

In this way the three regions are integrated in one sole fit, which permits all the observed values of the colorimetric coordinate to be included (region delimited between S−(Estimated) and S+(Estimated)), and also permits another region that delimits the mean points of each observation to be fixed (region between K−(Estimated) and K+(estimated). If desired, a crisp estimation can be obtained by defuzzification.

Such estimates were made for each of the years studied, all the observations, every year, being delimited by the series S−(Estimated) and S+(Estimated). The mean values of the parameters estimated each year were then taken to provide an estimate of the seven seasons as a whole. The results can be seen in the row "average" of Table 4.

4. Conclusions

The aim of the present work has been to analyse the relation between the colorimetric coordinate **a** and temperature in lemon (variety Eureka) by fuzzy methodology. This relation is not functional because it is altered by several variables, including humidity, solar radiation, luminosity, wind, etc. For each data-recording session, while the mean temperature is a certain fact, the measurements of the coordinate **a** showed substantial variability despite the fact that they were made with an instrument of great accuracy.

A regression analysis which studies the relation between the average value of coordinate **a** and temperature is not sufficient since it does not take into account the variability of the variable. Moreover, the aim of this type of study cannot be to obtain one isolated estimate but rather a range of possible values that reflects reality.

The method used combines two elements: on the one hand a possibilistic regression by means of trapezoidal fuzzy numbers, the estimate of which will provide a range of values that **a** could attain for a given mean temperature. The introduction of the term

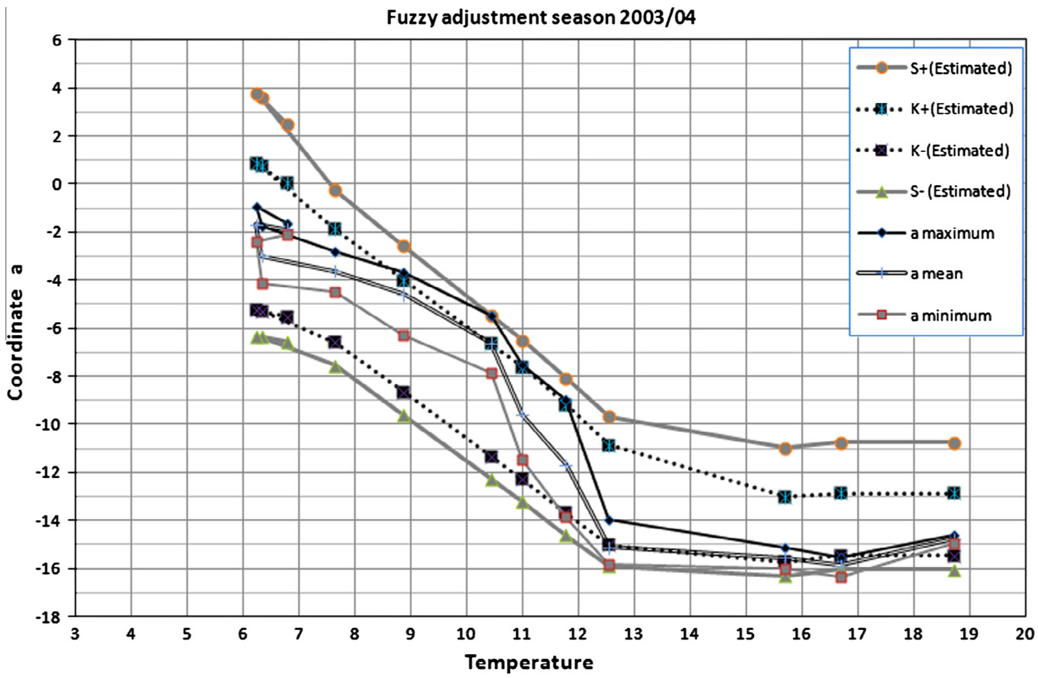

Fig. 9. Final fuzzy adjustment (season 2003/04). The series **a** maximum, **a** minimum and **a** mean indicate the maximum, minimum and mean values of coordinate **a** observed on each of the sampling dates. In turn, the series S−(estimated) and S+(estimated) correspond to the minimum and maximum estimated for each temperature, and the series K−(estimated) and K+(estimated)are the estimated series that include the mean values of each observation.

shift enables the amplitude of the dependent variable, **a**, to be treated suitably. That is, if in a given year, the amplitude of the colorimetric coordinate **a** varies with respect to temperature, the use of the term shift permits the result of the estimate to be fitted to the evolution of the amplitude.

On the other hand, the use of rules of the type *if*...... *then* provides greater accuracy to the estimate because the degreening process only occurs between given temperatures. Until these temperatures fall below 11.5–16 °C, degreening cannot be considered to have begun and the temperature will not influence the coordinate **a**. Once the degreening has begun, it will continue until the temperature reaches 4.4–7.7 °C, a point at which it will be considered to have finished. The final value reached by the coordinate will depend on, amongst other factors, the rate at which the temperatures fall and the starting values. A combination of *if*... *then* rules and the possibilistic regression improved the fitting of coordinate **a**.

The final result shows the mean range that coordinate **a** can take for each temperature and also the values between which the mean value can vary. These results will be of great use if the data are available, since it will be possible to predict for each cultivation area, each with its own climate, the temperatures below which, and the date from which, harvesting can be started - essential knowledge for all growers.

This study will help us in future research lines to look further into the possible existence of new variables that will permit a better explanation of degreening in this and other varieties of lemon such as Fino, Lisbon and Vera, not to mention other citrus species such as orange, mandarin and grapefruit.

Acknowledgements

The authors thank Philip Thomas for checking the English of the manuscript. This work was funded by the Murcian Institute of Agriculture and Food Research and Development and FEDER funds (FEDER-IMIDA POI-07-030).

References

Artés, F., Marín, J.G., Martínez, J.A., Tudela, J.A., García Lidón, A., 1997. Desverdización de nuevas variedades de limón y pomelo. Phytoma 90, 130–135.

Artés, F., Marín, J.G., Porras, I., Martínez, J.A., 1999. Evolución de la calidad del limón, pomelo y naranja durante la desverdización. Todo Citrus. 2ª Trimestre, pp. 5–14.

Bisserier, R.Boukezzoula., Galichet, S., 2010. Linear fuzzy regression using trapezoidal fuzzy intervals. J. Uncertain Syst. 4 (1), 59–72.

Brotons, J.M., Terceño, A., 2010. A risk premium in the Spanish market: an empirical study. Econ. Comp. Economic Cybern. Studies Res. 44 (1), 81–99.

Casas, A., Mallent, D., 1988a. El color de los frutos cítricos. I. Generalidades. II. Factores que influyen en el color. Influencia de la especie, de la variedad y de la temperatura. Rev. Agroquim. Tecnol. Alimentos 28 (2), 184–202.

Casas, A., Mallent, D., 1988b. El color de los frutos cítricos. II. Factores que influyen en el color (continuación). Influencia de la fertilización, del portainjerto y otros. Rev. Agroquim. Tecnol. Alimentos 28 (3), 344–356.

Duru, N., Dökmen, F., Mücella Canbayc, M., Kurtulus, C., 2010. Soil productivity analysis based on a fuzzy logic system. J. Sci. Food Agric. 90, 2220–2227.

Eaks, I.L., 1977. Physiology of degreening. Summary and discussion of related topics. P. Int. Soc. Citricult. 1, 223–226.

García Lidón, A., Del Río, J.A., Porras, I, Fuster, M.D., Ortuño, A., 2003. El limón y sus componentes bioactivos. Consejería de Agricultura, Agua y Medio Ambiente. Serie Técnica No. 25.

Gil-Aluja, J., 1999. Elementos para una teoría de la decisión en la incertidumbre. Milladoiro, España.

Grierson, W., Cohen, E., Kitagawa, H., 1986. Degreening. In: Wardowsky, W.F., Nagy, S., Grierson, W. (Eds.), Fresh Citrus Fruits. AVI Publishing Co, Wesport, CT, pp. 253–274.

Gross, J., 1977. Carotenoid pigments in Citrus. In: Nagy, S. et al. (Eds.), Citrus Science and Technology, vol. I. Avi Publ. Co. Inc., Wesport, Conn., pp. 302–354.

Haisman, D.R., Clarke, M.W., 1975. The interfacial factor in the heat-induced conversion of chlorophyll to pheophytin in green leaves. J. Sci. Food Agric. 26, 1111–1126.

Hou, P., Zhang, J., Zhanga, X., 2009. Fuzzy comprehensive evaluation for selecting mini watermelon cultivars. J. Sci. Food Agric. 90, 938–942.

Hunter, R.S., 1967. Development of the Citrus colorimeter. Food Technol. 21, 100–105.

Janssen, J.A.E.B., Krol, M.S., Schielen, R.M.J., Hoekstra, A.Y., de Kok, J.L., 2010. Assessment of uncertainties in expert knowledge, illustrated in fuzzy rule-based models. Ecol. Model. 221, 1245–1251.

John-Karuppiah, K.J., Burns, J.K., 2010. Degreening behavior in 'Fallglo' and 'Lee x Orlando' is correlated with differential expression of ethylene signaling and biosynthesis genes. Postharvest Biol. Technol. 58 (3), 185–193.

Kato, M., Ikoma, Y., Matsumoto, H., Sugiura, M., Hyodo, H., Yano, M., 2004. Accumulation of carotenoids and expression of carotenoid biosynthetic genes during maturation in citrus fruit. Plant Physiol. 134 (2), 824–837.

Kidsome, U., Edelenbos, M., Nørbæk, R., Christensen, L.P., 2002. Colour stability in vegetables. In: MacDougall, Douglas B. (Ed.), Colour in Food. Improving quality, vol. 8. Woodhead Publishing Limited, Cambridge England, pp. 179–232.

Kim, K.J., Moskowitz, H., Koksalan, M., 1996. Fuzzy versus statistical linear regression. Eur. J. Oper. Res. 92, 417–434.

Klir, B., Yuan, B., 1995. Fuzzy Sets and Fuzzy Logic. Prentice Hall.

Lee, H.S., Coates, G.A., 2003. Effect of thermal pasteurization on Valencia juice colr and pigments. Lebensm. –Wiss. U. Technol. 36, 153–156.

MacDougall, D.B., 2002. Colour measurement of food: principles and practice. In: MacDougall, Douglas B. (Ed.), Colour in Food. Improving quality. Woodhead Publishing Limited, Cambridge, England.

Manera, F.J., Brotons, J.M., Conesa, A., Porras, I., 2012a. Relationship between air temperature and degreening of lemon (*Citrus lemon* L. Burm. f.) peel color during maturation. Aust. J. Crop Sci. 6 (6), 1051–1058.

Manera, F.J., Brotons, J.M., Conesa, A., Porras, I., 2012b. Influence of temperature on the beginning of degreening in lemon peel. Sci. Hortic. Amsterdam. 145, 34–38.

Manera, F.J., Brotons, J.M., Conesa, A., Porras, I., 2013. Relation between temperature and the beginning of peel color change in grapefruit (Citrus paradisi Macf.). Scientia Hortic. Amsterdam. 160, 292–299.

Mazloumzadeh, S.M., Shamsi, M., Nezamabadi-pour, H., 2010. Fuzzy logic to classify date palm trees based on some physical properties related to precision agriculture. Precis Agric. 11 (3), 258–273.

Meléndez Martínez, A.J., Vicario, I.M., Heredia, F.J., 2007. Review: analysis of carotenoids in orange juice. J. Food Comp. Anal. 20 (7), 638–649.

Meléndez Martínez, A.J., Escudero-Gilete, M.L., Vicario, I.M., Heredia, F.J., 2010a. Effect of increased acidity on the carotenoids pattern and colour of orange juice. Eur. Food Res. Technol. 230, 527–532.

Meléndez Martínez, A.J., Escudero-Gilete, M.L., Vicario, I.M., Heredia, F.J., 2010b. Study of the influence of carotenoide structure and individual carotenoids in the qualitative and quantitative attributes of orange juice colour. Food Res. Int. 43, 1289–1296.

Navarro, J.M., Pérez-Pérez, J.G., Romero, P., Botía, P., 2010. Analysis of the changes in quality in mandarin fruit, produced by deficit irrigation treatments. Food Chem. 119, 1591–1596.

Petracek, P.D., Montalvo, L., 1997. The degreening of 'Fallglo' tangerine. J. Am. Soc. Hortic. Sci. 122 (4), 547–552.

Porat, R., 2008. Degreening of citrus fruit. Tree Forest. Sci. Biotechnol. 2, 71–76.

Reuther, W., 1973. Climate and citrus behavior. The Citrus Industry, vol. III. Univ. of California Press. Division of Agricultural Sciences, pp. 280–337.

Richardson, G.R., Cowan, A.K., 1995. Abscisic-acid content of Citrus flavedo in relation to color development. J. Hortic. Sci. 70 (5), 769–773.

Saunt, J., 1990. Citrus Varieties of the World. Sinclair Int. Ltd., ISBN 1-872960-00-6.

Schmidt, J., Almond, P.C., Basher, L., Carrick, S., Hewitt, A.E., Lynn, I.H., Webb, T.H., 2005. Modelling loess landscapes for the South Island, New Zealand, based on expert knowledge New Zealand. J. Geol. Geophys. 48, 117–133.

Sinclair, W.B., 1984. The Biochemistry and Physiology of the Lemon and Other Citrus Fruits. Univ. of California. Division of Agriculture and Natural Resources. Publication No. 3306. Oakland, CA.

Soni, S.L., Randhawa, G.S., 1969. Changes in pigments and ash contents of lemon peel during growth. Indian J. Hortic. 26 (1–2), 20–26.

Spiegel-Roy, P., Goldschmidt, E.E., 1996. Biologyof Citrus. Cambridge University Press.

Stearns, C.J., Young, G.T., 1942. The relation of climatic conditions to color development in citrus fruit. P. Fl. St. Hortic. Soc. 56, 39–61.

Stewart, I., 1980. Color as related to citrus quality. In: Citrus nutrition and quality. In: Nagy, S., Attaway, J.A. (Eds.), American Chemical Society, Washington, DC. Symp. Ser. 143.

Tanaka, H., Ishibuchi, H., 1991. Identification of possibilistic linear systems by quadratic membership functions of fuzzy parameters. Fuzzy Set. Syst. 41, 145–160.

Tanaka, H., Uejima, S., Asai, K., 1982. Linear regression analysis with fuzzy model, IEEE, Systems, Trans. Systems Man Cybernet. SMC-2, 903–907.

Tanaka, H., Hayashi, I., Watada, J., 1989. Possibilistic linear regression analysis for fuzzy data. Eur. J. Oper. Res. 40, 389–396.

Terceno-Gomez, A., Brotons-Martinez, J.M., Trigueros-Pina, J.A., 2009. Assessment of water needs in Spain. Ing. Hidraul. Mex. 24 (4), 7–22.

Tietel, Z., Weiss, B., Lewinsohn, E., Fallick, E., Porat, R., 2010. Improving taste and peel color of early-season Satsuma mandarins by combining high-temperature conditioning and degreening treatments. Postharvest Biol. Technol. 57 (1), 1–5.

Ting, S.V., Attaway, J.A., 1971. Citrus fruit. In: Hulme, A.C. (Ed.), The Biochemisstry of fruits and their Products, vol. 2. Academic Press, London, pp. 107–169.

Tremblay, N., Bouroubi, M.Y., Panneton, B., Guillaume, S., Vigneault, P., Bélec, C., 2010. Development and validation of fuzzy logic inference to determine optimum rates of N for corn on the basis of field and crop features. Precis. Agr. 11, 621–635.

Walker, W.E., Harremoës, P., Rotmans, J., Van der Sluis, J.P., Van Asselt, M.B.A., Janssen, P., Krayer von Krauss, M.P., 2003. Defining uncertainty a conceptual basis for uncertainty management in model-based decision support. Integr. Assess. 4, 5–17.
Yokoyama, H., Vandercook, C.E., 1967. Citrus carotenoids. I. Comparison of carotenoids of mature-green and yellow lemons. J. Food Sci. 32, 42–48.
Zadeh, L.A., 2005. Towards a generalized theory of uncertainty (GTU), an outline. Inform. Sci. 72, 1–40.
Zhou, J.Y., Sun, C.D., Zhang, L.L., Dai, X., Xu, C.J., Chen, K.S., 2010. Preferential accumulation of orange-colored carotenoids in Ponkan (*Citrus reticulata*) fruit peel following postharvest application of ethylene or ethephon. Sci. Hortic. Amsterdam. 126 (2), 229–235.
Zimmermann, H.J., 2000. An application-oriented view of modeling uncertainty. Eur. J. Oper. Res. 122, 190–198.