J. Agr. Sci. Tech. (2017) Vol. 19: 669-680

A Fuzzy Approach for Relating a Pomegranate Maturity Index with to Solar Net Radiation

J. M. Brotons[1*], P. Legua[1], P. Melgarejo[2], F. J. Manera[3], F. Hernández[2], and J. J. Martínez[2]

ABSTRACT

Pomegranate fruit maturity status is commonly assessed based on external (skin) colour, juice colour and acidity of juice. Some researchers have studied the correlation between the parameters of the skin colour and acidity, total soluble solids, citric acid and anthocyanins. This study describes the relationship existing between solar radiation and a colorimetric maturity index in the pomegranate varietal group "Mollar de Elche". We propose a fuzzy methodology. The aim of this kind of study is to obtain on estimation a range of possible values that reflects reality. Using this methodology four phases were obtained, in which there is no relationship between radiation and the colorimetric Maturity Index (MIc) in phases 1 and 4, but there is such a relationship in phases 2 and 3. Fuzzy math demonstrates the positive relationship between radiation and *MIc*, confirming that fuzzy regression is appropriate for making estimations that reflect reality among variables showing a weak relationship. There is a high degree of uncertainty in the relationship between the colorimetric maturity index and the incident radiation. The individual values of radiation do not correspond to one sole value of *MIc*, but to a wide range of the same, due to several factors, such as fruit orientation, luminosity, etc. Fuzzy math reveals the positive relationship between net radiation and MIc in phases 2 and 3. All this shows that the fuzzy regression may be appropriate for making estimations reflect reality when the variables show a weak relationship.

Keywords: Colour, Fuzzy, Maturity index, Net radiation, *Punica grantum*.

INTRODUCTION

The importance of pomegranate (*Punica granatum* L.) has increased very significantly in recent times, especially during the last decade, partly due to the fact that many studies have confirmed the excellent organoleptic and nutritional properties of this fruit (Al-Said *et al.,* 2009; He *et al.,* 2010; Ozgen *et al.,* 2008; Shwartz *et al.,* 2009; Martínez *et al.,* 2012). Moreover, the traditional importance of pomegranate fruit as a medicinal plant is currently the subject of renewed research because of its anti-carcinogenic, anti-microbial and anti-viral properties (Al-Maiman and Ahnad, 2002; Bell and Hawthorne, 2008; Kotwal, 2007; Reddy *et al.,* 2007; Legua *et al.,* 2012; Zhao *et al*., 2014).

Although our knowledge on the potential importance of pomegranate in human nutrition has increased in recent years, very few papers have been published on the relationship between the external colour of

[1] Department of Economic and Financial Studies, Universitas Miguel Hernández. Avda. de la Universidad, s/n, 03202. Elche. (Alicante) Spain.
* Corresponding author; e-mail: jm.brotons@umh.es
[2] Department of Plant Science and Microbiology, Universitas Miguel Hernandez, Ctra Beniel 3.2, 03312 Orihuela (Alicante), Spain.
[3] Department of Physics and Computer Architecture, Universitas Miguel Hernandez, Ctra Beniel 3.2, 03312 Orihuela (Alicante), Spain.

the fruit maturity indices and climatic factors (Manera *et al.,* 2012a; Manera *et al.,* 2013; Brotons *et al.,* 2013).

Pomegranate acceptability on the part of consumers and processors depends basically on a combination of several quality attributes, which include rind colour, sugar content, acidity, flavour, etc. (Al-Said *et al.,* 2009). Some researchers have studied the correlation between rind colour parameters (L*, a*, b*, C* and h_{ab}*) and acidity, total soluble solids, citric acid and anthocyanin content (Dafny-Yalin *et al.,* 2010). Manera *et al.* (2012a) studied the correlation between pomegranate rind colour parameters and air temperature, and Manera *et al.* (2012b) studied the relationship between air temperature and the de-greening of lemon peel colour during maturation. Brotons *et al.* (2013) has described the relationship between air temperature and the loss of greenness in lemon rind and the appearance of the typical yellow colour in lemon varieties. The above authors proposed a fuzzy methodology combining two elements: (a) possibilistic regression by means of trapezoidal fuzzy numbers that provides a range of values which the variable in question could attain for a given mean temperature, and (b) the use of rules of the type *if. . . then*, which improve the accuracy of the estimation. It should be mentioned that the aim of this kind of study is not to obtain one isolated estimation but rather a range of possible values that reflect reality. In order to get an introduction to this methodology, several publications can be followed, as Ross (2010) or DuBois (1997).

All this underlines the enormous interest and potential of colorimetry and the maturity index as two agricultural tools. Although temperature is an important factor that influences maturation, it is not the only one and other factors such as solar net radiation intervene.

In our case, fuzzy methodology allows us to introduce this uncertainty into a model. In the first place, it enables crisp estimations through de-fuzzification of the results, while bearing in mind the uncertainty; secondly, it permits the range in which the value of the maturity index can vary for each net radiation to be obtained. In this way, an initial range is provided that indicates all the possible values that the maturity index might show, while the second range (included in the first) indicates the values that the maturity index is most likely to reach.

In this work, we use fuzzy methodology to explain the correlation between the colorimetric Maturity Index (MIc) and incident solar net radiation.

MATERIALS AND METHODS

Plant Material

The cultivar was selected according to four main criteria: sweetness, soft-seeds, large fruit size and high yield. The commercial variety “ME14” was selected from the “Mollar de Elche” varietal group, which is one of the most highly valued groups worldwide because of its outstanding flavour and high antioxidant capacity (Calín-Sánchez *et al.,* 2011). Furthermore, it is the most widely grown varietal group in Spain. The selected plant material belongs to the main pomegranate gene bank of the EU, located at the experimental field station of Miguel Hernández University in the province of Alicante, Spain (02º 03´ 50´´ E, 38º 03´ 50´´ N, and 25 m asl).

The orchard was established in 1992. Pomegranate trees were trained to the vase-shaped system and planted at a spacing of 4×3 m. They were drip irrigated, and standard cultural practices were performed (pruning, thinning, fertilisation and pest control treatments).

Determination of Fruit Colour and Colorimetric Maturity Index

Colour measurements were made using a spectrophotometer Minolta C-300 Chroma Meter (Minolta Corp., Osaka, Japan) coupled to a Minolta DP-301 data processor.

Colour was assessed according to the Commission Internationale de l'Éclairage (CIE) and expressed as L^*, a^*, b^* colour values. The coordinates L^*, a^* and b^* indicate the lightness of the colour ($L^*= 0$ and $L^*= 100$ represent black and white, respectively), its position between green and red (negative and positive a^* values indicate greenness and redness, respectively) and between blue and yellow (negative and positive b^* values tend towards blueness and yellowness, respectively).

The colorimetric Maturity Index ($MIc= L^*.a^*.b^{*-1}$) was determined, as indicated by Manera *et al*. (2013), for four years (between 2007 and 2010) in fruits grown in the open air.

The temperatures data and net radiation were collected from a weather station in the same experimental orchard. Net Radiation (Rn) is the difference between the incoming and outgoing radiation at long and short wavelengths. It is the balance between the energy absorbed, reflected and emitted by the earth's surface (Rb). Rn is the radiation that remains in the crop and is calculated by deducting from Rs the reflected radiation (which depends on the albedo) and the losses of long wave length radiation (Rb) which depend on the temperature, cloud cover and humidity level. *Rn* is normally positive during the day and negative during the night (Allen *et al.,* 1998). $Rn= (1-\alpha)\times(Rs- Rb)$, where *Rs*= Incident solar radiation.

Modeling Procedures

Trapezoidal Fuzzy Number (TrFN) can be defined by its support and its kernel bounds $A=(K_A,R_A)=\left(S_A^-,\left[K_A^-,K_A^+\right],S_A^+\right)$, where support: $S_A=\left[S_A^-,S_A^+\right]$, kernel: $K_A=\left[K_A^-,K_A^+\right]$ (see Figure 1). This means that number A can vary from S_A^- to S_A^+, being the most possible values of the range between K_A^- and K_A^+. The trapezoidal fuzzy regression proposed by Bisserier *et al.* (2010) will be used. 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.

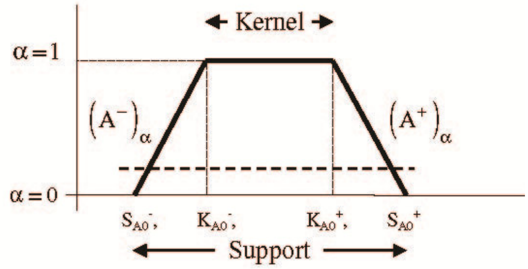

Figure 1. Fuzzy trapezoidal number.

In order to analyse the evolution of the *MIc* versus net radiation, we are going to consider several phases:

Phase 1. High net radiation levels, where *MIc* is not related with net radiation;

Phase 2. Lower levels of net radiation where there is a negative relation between net radiation and *MIc*. We estimated the regression proposed by Bisserier *et al.* (2010) 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,

$$Y(x)=A_0\oplus A_1(x-\text{shift}) \quad (1)$$

Where the parameters A_0 and A_1 are trapezoidal fuzzy coefficients, and when the model has an increasing radius, $\text{shift}=x_{min}$ will be taken, while $\text{shift}=x_{max}$ will be taken if the model has a decreasing radius.

Phase 3. Lower levels of net radiation where there is a negative relation between net radiation and *MIc*, but with a different slope.

Phase 4. The lowest level of net radiation, where there is no relation between net radiation and *MIc* and the fruit is mature and has taken on its characteristic colour.

Having made these calculations, the membership functions to each of the four

[DOR: 20.1001.1.16807073.2017.19.3.14.3]

phases (μ_1, …, μ_4) must be obtained for each net radiation value, in accordance with Bisserier *et al.* (2010). The extremes of the aggregated *TrFN* $(A,[B,C],D)$ can be obtained by multiplying these membership functions by the corresponding values,

$$A = a_1\mu_1(x^*) + a_2\mu_2(x^*) + a_3\mu_3(x^*) + a_4\mu_4(x^*) \quad (2)$$

Where, a_1, …, a_4 are the estimates for phases 1 to 4. The values of B, C and D are obtained in a similar way.

Moreover, the estimation made by means of fuzzy mathematics shows the range of values for the estimation (S- and S+), and the most probable values (K- and K+). If a crisp value z is wanted, de-fuzzification permits such an estimation, which is shown as the central line and obtained from expression.

$$z = \frac{\int \mu(x)\cdot x \cdot dx}{\int \mu(x)\cdot dx} \quad (3)$$

RESULTS AND DISCUSSION

Figure 2 shows the relation between the colorimetric Maturity Index (MIc) and the daily accumulated net radiation (the mean of 14 days, thus avoiding daily variations in this parameter). As can be seen, on the dates that the colour measurements were made there was a substantial difference between the minimum and maximum values for *MIc*, a difference that widened as the fruit reached the end of the ripening stage.

It can be seen that, for the four years that the study lasted, the *MIc* was unaffected by variations in net radiation above 20-21 MJ m^{-2} d^{-1}, while the slope representing *MIc* increased as the net radiation fell below this level (Figure 2). The fruit took on its characteristic colour (maximum MIc) when net radiation had reached suitably low levels, although in some cases it even began to fall as time progressed.

An analysis based on mean values is not always the most suitable because it overlooks the dispersion that occurs in a

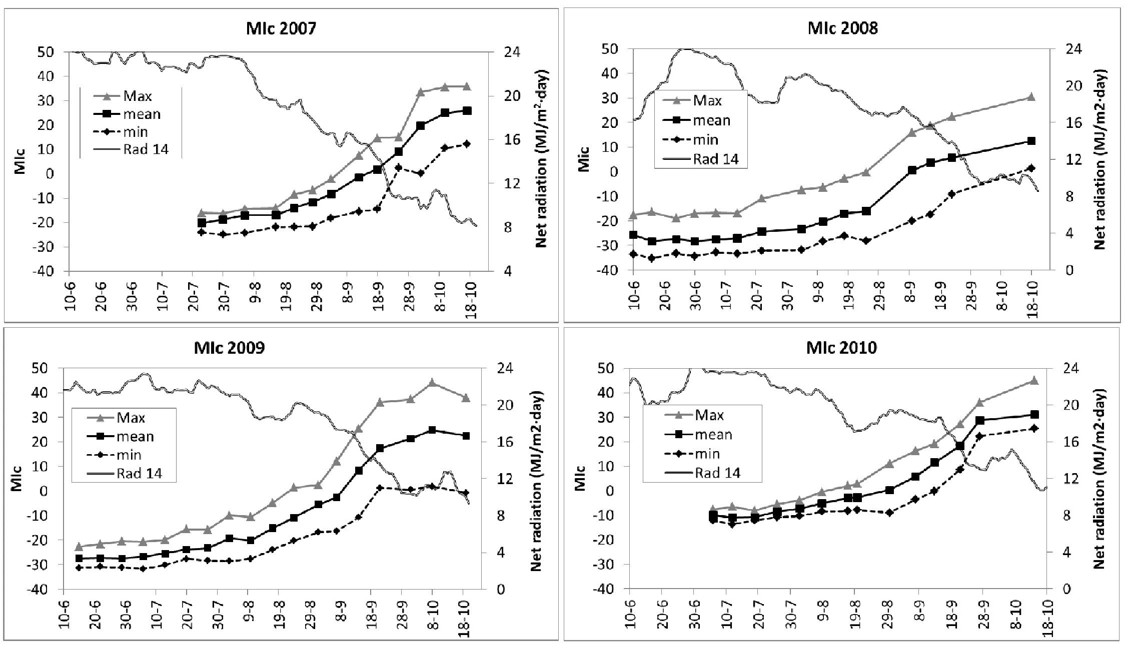

Figure 2. Evolution of net Radiation (Rad 14), taken as 14 day mean, and Maturity Index (MIc) (maximum, mean and minimum values).

series of *MIc* values. This is why we propose using possibilistic regression, as described by Tanaka *et al*. (1982, 1989), using non-linear functions followed by quadratic membership (Tanaka and Ishibuchi, 1991). The tendency of the interval spread was incorporated by Bisserier *et al*. (2010), who introduced the term "shift".

It should be remembered that fuzzy regression arises from probability theory, and its application is especially useful when the relation between variables is vague and imprecise, or cannot be defined exactly. In this case, a given net radiation value does not correspond to a sole value of *MIc* but to a wide range of the same. As mentioned by Kim (1996), fuzzy regression is especially suitable when the phases under study are imprecisely delimited, as in the case in hand.

As the delimitation of the different phases in *MIc* evolution is very difficult, we shall use a fuzzy expert system composed of a knowledge base, an inference engine and a data base, which describes the inference rules, links the data from the data base to the rules and as a result, provides an outcome value. The rules in the fuzzy knowledge base are generally of the shape "*if x, then y*", with *x* and *y* fuzzy sets.

Phases analysed

Figure 3 depicts the evolution of *MIc* versus net radiation. Starting from relatively high net radiation values of around 24 MJ m^{-2} $d^{-1}$and *MIc* values of between -20 and -30, the maturity index increases as the net radiation falls to below 15 MJ m^{-2} d^{-1} , although the maximum values increase slightly, the minimum values grow steadily. In order to improve the *MIc* estimations as a function of net radiation, two phases are distinguished in the lower part of the slope for further analysis.

Based on Figure 3 and the evolution for the other years studied, it is practically impossible to delimit different phases, so that we made a partition of the net radiation space, as can be seen in Figure 4, which shows the four phases studied and the "level of belonging" of the net radiation to each phase. Accordingly, we denominate: (i) Phase 1, with high net radiation levels of above 20–22 MJ m^{-2} d^{-1} and where *MIc* is not related with net radiation; (ii) Phase 2, where net radiation varies between 22 and 14 MJ m^{-2} d^{-1} and there is a negative relation between net radiation and MIc; (iii) Phase 3, where net radiation varies between 20 and 11 MJ m^{-2} d^{-1} and there is a negative relation

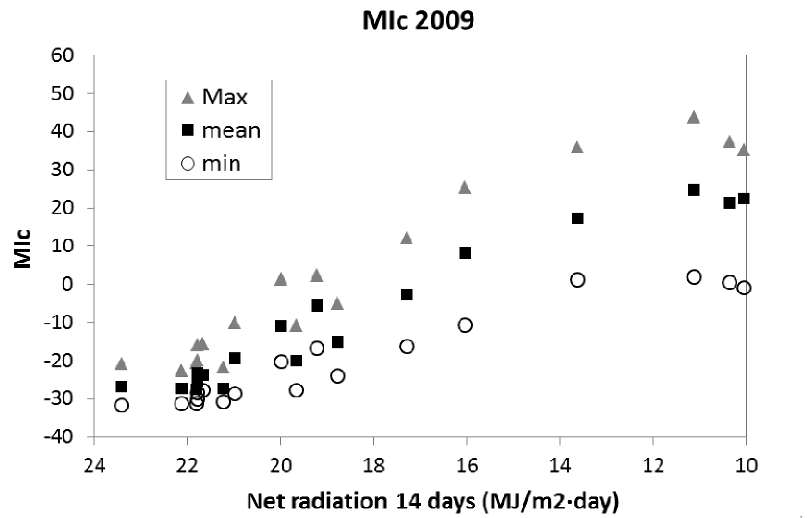

Figure 3. Relation between pomegranate Maturity Index (MIc) and radiation (24 day mean) for 2009.

[DOR: 20.1001.1.16807073.2017.19.3.14.3]

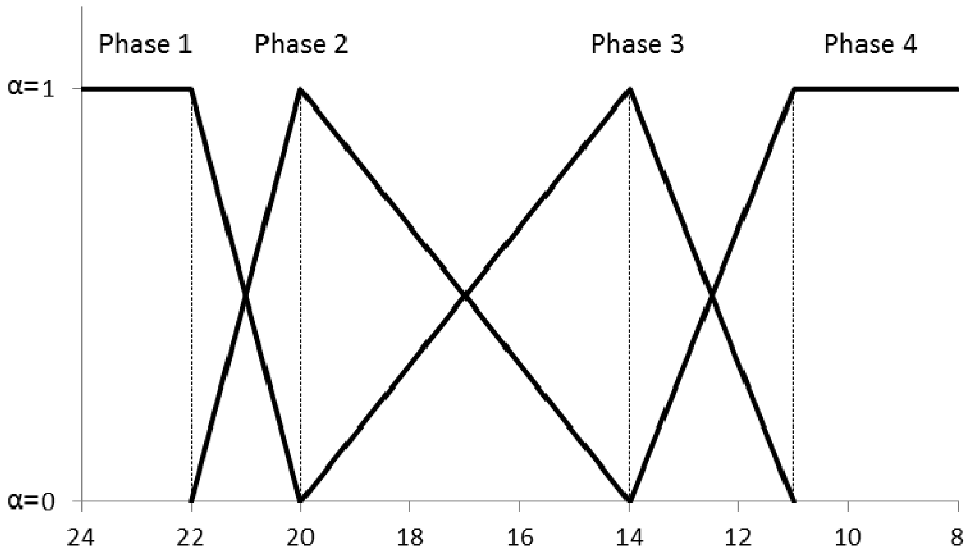

Figure 4. Representation of the membership functions of regions 1, 2, 3 and 4 as a function of the radiation (14 day mean). α indicates the "level of belonging" of a given temperature to each of the regions indicated.

between net radiation and *MIc*, but with a different slope, and (iv) Phase 4, where net radiation falls below 11-14 MJ m^{-2} d^{-1}, there is no relation between net radiation and *MIc* and the fruit is mature and has taken on its characteristic colour.

As can be seen in Figure 4, the different phases cannot be differentiated exactly since, for example, if we take a net radiation of 21.5 it is seen to belong to phase 1 with a membership function of 0.75 and to phase 2 with membership function of 0.25. The net radiation membership functions of the different phases are shown below.

Net radiation membership function, phase 1.

$$\mu_1(x)=\begin{cases}1 & x>22\\ \frac{x}{2}-10 & 22<x<20\\ 0 & 20>x\end{cases} \quad (4)$$

Net radiation membership function, phase 2.

$$\mu_2(x)=\begin{cases}11-\frac{x}{2} & 22<x<20\\ \frac{x-14}{6} & 20<x<14\\ 0 & \text{otherwise}\end{cases} \quad (5)$$

Net radiation membership function, phase 3.

$$\mu_3(x)=\begin{cases}\frac{20-x}{6} & 20<x<14\\ \frac{x-11}{3} & 14<x<11\\ 0 & \text{otherwise}\end{cases} \quad (6)$$

Net radiation membership function, phase 4.

$$\mu_4(x)=\begin{cases}1 & x<11\\ \frac{14-x}{3} & 11<x<14\\ 0 & x>14\end{cases} \quad (7)$$

Estimation of Colorimetric Maturity Index (MIc)

Phases 1 and 4

There is no relation between net radiation and *MIc* during these phases. For each year we take the minimum, mean and maximum *MIc* for net radiation levels above 20 MJ/m^2·day in phase 1 and below 14 MJ m^{-2} d^{-1} in phase 4 (Figure 5). In this way, the

[DOR: 20.1001.1.16807073.2017.19.3.14.3]

four year aggregation in phase 1 enabled us to obtain the Trapezoidal Fuzzy Number (TrFN) $(-34.36,[-28.24,-5.09],-0.44)$, where -34.36 is the minimum value of the four years for this phase, -0.44 is the maximum value for the same and -28.24 and -5.09 are the values between, the mean of which each data taking point lies. The *TrFN* for phase 4 can be obtained similarly $(-0.81,[9.18,28.66],44.01)$.

Phases 2 and 3

The values obtained for each growing season and the mean value are shown in Table 1. It can be firmly stated that the coefficients estimated for phase 2 correspond to the fuzzy numbers $A_0=(-11.75,[-2.93,13.27],24.59)$ and $A_1=((-4.15,[-4.15,-4.15],-3.92))$; while for phase 3 the fuzzy numbers are, $A_0=(-7.10,[3.53,20.07],31.75)$ and $A_1=((-3.88,[-3.88,-3.88],-3.78))$.

Figure 6 shows the estimation for the 2009 season, where the lines S-(estimated) and S+(estimated) are the minimum and maximum values that MIc takes for each date which the colour was measured, and K-(estimated) and K+(estimated) are the limits calculated for the mean *MIc* values for each date.

Final Estimation

In the above section, four estimations, one for each phase, were made. For phase 1 the *TrFN* was estimated: $A_0^1=(-34.36,[-28.24,-5.09],-0.44)$; for phase 2 the coefficients of the fuzzy regression, $A_0^2=(-11.75,[-2.93,13.27],24.59)$ and $A_1^2=((-4.15,[-4.15,-4.15],-3.92))$, were obtained; for phase 3 the coefficients $A_0^3=(-7.10,[3.53,20.07],31.75)$ and $A_1^3=((-3.88,[-3.88,-3.88],-3.78))$ were obtained and finally, for phase 4 the *TrFN* was $A_0^4=(-0.81,[9.18,28.66],44.01)$.

The extremes of the aggregated *TrFN* $(A,[B,C],D)$ can be obtained according to expression(2). The estimation for 2007-2010 can be followed in Figure 7.

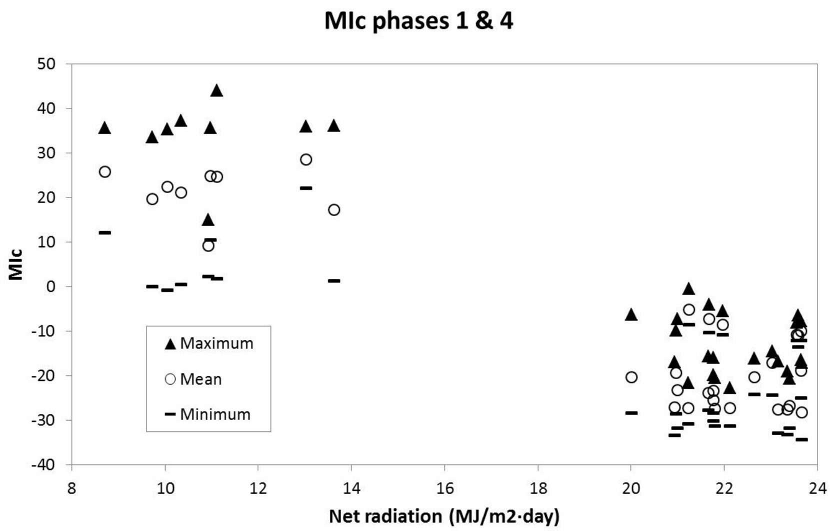

Figure 5. *MIc* and radiation (14 day mean) for phase 1 (high radiation) and 4 (low radiation) during the four seasons studied. The series maximum, minimum and mean indicate the maximum, minimum and mean values of *MIc* observed on each of the sampling dates.

Table 1. Summary of the estimations for the four growing seasons. The coefficients A_0 and A_1 for the four growing seasons and their average are shown. Also shown are the corresponding centre (M) and Radii (R).

		A_0				A_1			
	Year	S_{A0}^-	K_{A0}^-	K_{A0}^+	S_{A0}^+	S_{A1}^-	K_{A1}^-	K_{A1}^+	S_{A1}^+
Phase 2	7	-14.62	-2.42	2.50	14.66	-2.73	-2.73	-2.73	-2.73
	8	-26.42	-19.15	9.05	24.55	-3.01	-3.01	-3.01	-3.01
	9	-10.76	-0.16	11.97	25.43	-5.51	-5.51	-5.51	-5.51
	10	4.79	9.99	29.56	33.74	-5.32	-5.32	-5.32	-4.43
	Average	-11.75	-2.93	13.27	24.59	-4.15	-4.15	-4.15	-3.92
Phase 3	7	-14.62	0.09	3.84	14.66	-3.65	-3.65	-3.65	-3.65
	8	-26.42	-19.15	9.05	23.60	-3.01	-3.01	-3.01	-2.68
	9	1.86	17.20	29.84	47.07	-4.37	-4.37	-4.37	-4.37
	10	10.77	15.98	37.57	41.66	-4.47	-4.47	-4.47	-4.43
	Average	-7.10	3.53	20.07	31.75	-3.88	-3.88	-3.88	-3.78

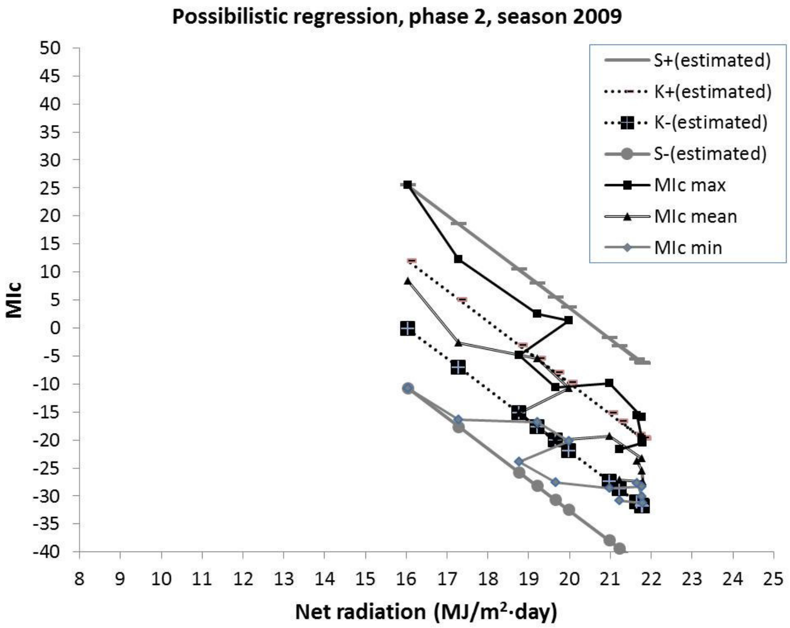

Figure 6. Possibilistic regression for 2009 season between colorimetric *MIc* and radiation (14 day average). The series S-(estimated) and S+(estimated) correspond to the minimum and maximum values that *MIc* reaches for each radiation level, and the series K-(estimated) and K+(estimated) include the mean values of *MIc*.

These estimations were made for the different years, giving the corresponding *TrFN* of the coefficients of the estimations. In order to avoid great dispersion of the data, the mean values were used (Figure 8). The result shows that, despite the wide dispersion of data, there was a positive relation between net radiation and *MIc*.

CONCLUSIONS

There is a high degree of uncertainty in the relationship between the colorimetric maturity index and the incident net radiation. The individual values of net radiation do not correspond to one sole value of *MIc*, but to a

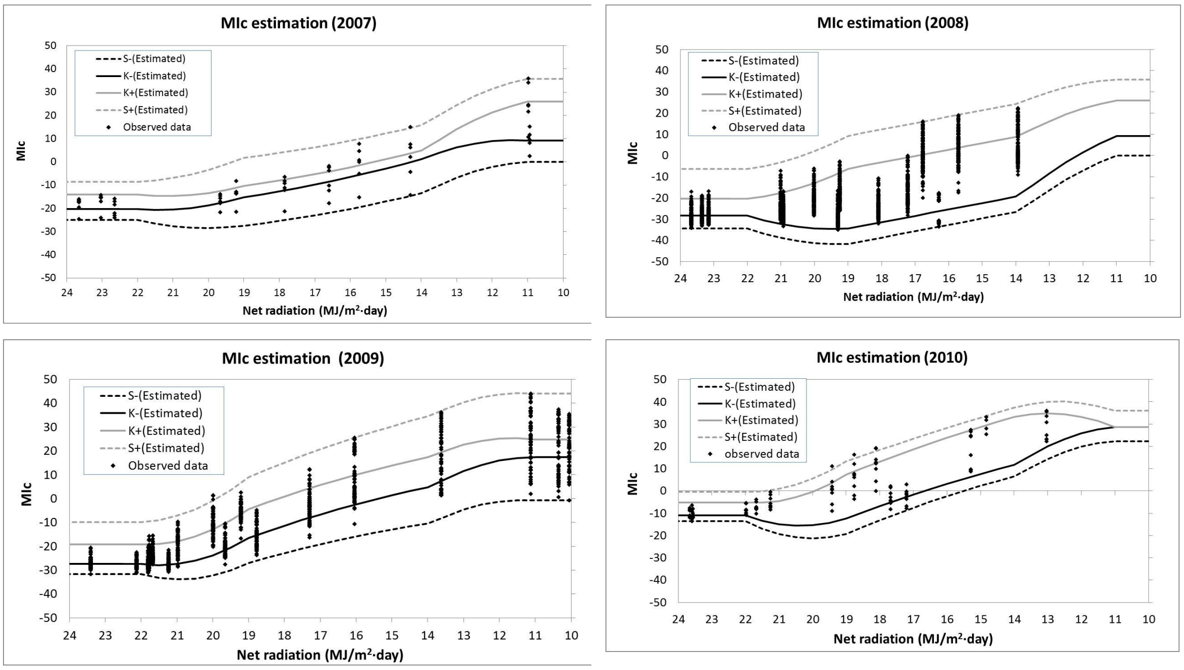

Figure 7. Final estimation for the four seasons. The points indicate the values observed, and S- and S+ are the limits which must contain all the values. The series K- and K+ include the mean values for each data taking point.

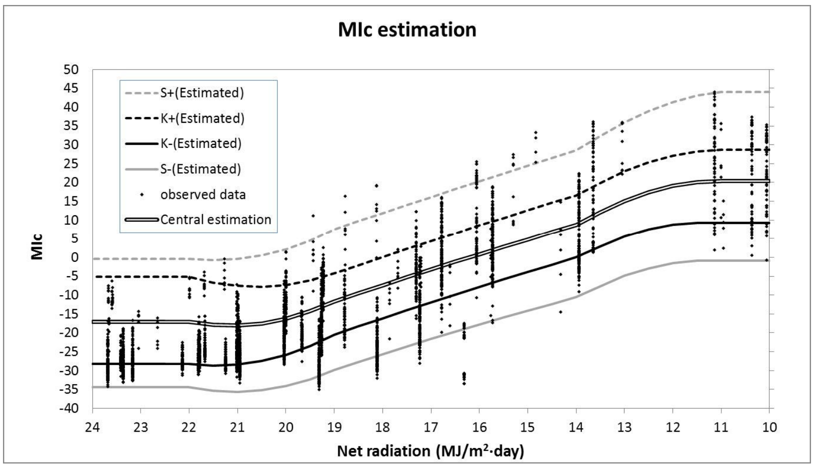

Figure 8. Summary of the estimation for the four years studied. The points indicate the values observed, and S- and S+ are the limits which must contain all the values (occasionally a value will lie outside the limits, since these are mean values for 4 years). The series K- and K+ include the mean values for each observation. The central estimation series was obtained by defuzzification of the values corresponding to the estimation carried out, in agreement with expression (7).

wide range of the same, due to several factors, such as fruit orientation, luminosity, etc.

Using this methodology we obtained four phases, in which there was no relationship between net radiation and *MIc* in Phases 1 and 4, but there was in Phases 2 and 3. In other words, Fuzzy maths reveals the positive relationship between net radiation and *MIc* in phases 2 and 3. All this shows that the Fuzzy regression may be appropriate for making estimations reflect reality when the variables show a weak relationship.

This method will be of great use if the net radiation data necessary for each variety are available since it will be possible to predict, for a given latitude, the most likely date from which the fruit will be ready for harvest. Both growers and distributors should benefit from this knowledge.

ACKNOWLEDGEMENTS

The authors thank Philip Thomas for checking the English writing of the manuscript. The authors are grateful to the Project on Genetic Resources, Preservation of Endangered Species: pomegranate and quince, Ref. RFP2012-00009-00-00.

REFERENCES

1. Al-Maiman, S. A. and Ahnad, S. A. 2002. Changes in Physical and Chemical Properties during Pomegranate (*Punica granatum* L.) Fruit Maturation. *Food Chem*., **76:** 437-441.
2. Al-Said, F. A., Opara, L. U. and Al-Yahyai, R. A. 2009. Physico-Chemical and Textural Quality Attributes of Pomegranate Cultivars (*Punica granatum* L.) Grown in the Sultanate of Oman. *J. Food Eng*., **90:** 129-134.
3. Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. 1998. *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements.* Paper 56, FAO Irrigation and Drainage.
4. Bell, C. and Hawthorne, S. 2008. Ellagic Acid Pomegranate and Prostate Cancer: A Mini Review. *J. Pharm. Pharmacol*., **60:** 139-144.
5. Bisserier, A., Boukezzoula, R. and Galichet, S. 2010. Linear Fuzzy Regression Using Trapezoidal Fuzzy Intervals. *J. Uncertain Syst*., **4(1):** 59–72.
6. Brotons, J. M., Manera, J., Conesa, A. and Porras I. 2013. A Fuzzy Approach to the Loss of Green Colour in Lemon (*Citrus lemon* L. Burm. f.) Rind during Ripening. *Comput. Electron. Agr*., **98:** 222–232.
7. Calín-Sánchez, A., Martínez, J. J., Vázquez-Araújo, L., Burló, F., Melgarejo, P. and Carbonell-Barrachina, A. A. 2011. Volatile Composition and Sensory Quality of Spanish Pomegranates (*Punica granatum* L.). *J. Sci. Food Agric*., **91:** 586–592.
8. Dafny-Yalin, M., Glazer, I., Bar-Ilan, I., Kerem, Z., Holland, D. and Amir, R. 2010. Colour, Sugars and Organic Acids Composition in Aril Juices and Peel Homogenates Prepared from Different Pomegranate Accessions. *J. Agric. Food Chem.,* **58:** 4342-4352.
9. Du Bois, D. 1997. *Fuzzy Sets and Systems: Theory and Applications.* Academic Press, Inc. Orlando, FL, USA.
10. He, L., Xu, H., Liu, X., He, W., Yuan, F., Hou, Z. and Gao, Y. 2010. Identification of Phenolic Compounds from Pomegranate (*Punica granatum* L.) Seed Residues and Investigation into Their Antioxidant Capacities by HPLC_ABTS+ Assay. *Food Res. Int*., **44(5):** 1161–1167
11. Kim, K. J., Moskowitz, H. and Koksalan, M. 1996. Fuzzy Versus Statistical Linear Regression. *Eur. J. Oper. Res*., **92:** 417–434.
12. Kotwal, G. J. 2007. Genetic Diversity-Independent Neutralization of Pandemic Viruses (e.g. HIV), Potentially Pandemic (e.g. H5N1 Strain of Influenza) and Carcinogenic (e.g. HBV and HCV) Viruses and Possible Agents of Bioterrorism (Variola) by Enveloped Virus Neutralizing Compounds (EVNCs). *Vaccine*, **26:** 3055-3058.
13. Legua, P., Melgarejo, P., Abdelmajid, H., Martínez, J. J., Martínez-Font R., Ilham, H., Habida, H. and Hernández, Fca. 2012. Total Phenols and Antioxidant Capacity in 10 Moroccan Pomegranate Varieties. *J. Food Sci*., **71:** 115-120.
14. Manera, F. J., Brotons, J. M., Conesa, A. and Porras, I. 2012b. Relationship between Air Temperature and Degreening of Lemon (*Citrus lemon* L. Burm. f.) Peel Colour during Maturation. *Aust. J. Crop Sci*., **6(6):** 1051-1058.
15. Manera, F. J., Legua P., Melgarejo P., Brotons, J. M., Hernández, F. and Martínez, J. J. 2013. Determination of a Colour Index for Fruit of Pomegranate Varietal Group "Mollar de Elche". *Sci. Hortic.,* **150:** 360–364
16. Manera, F. J., Legua P., Melgarejo P., Martínez R., Martínez J. J. and Hernández,

F. 2012a. Effect of Air Temperature on Rind Colour Development in Pomegranates. *Sci. Hortic.,* **134:** 245-247.
17. Martínez, J. J., Hernández, F.., Abdelmajid, H., Legua, P., Martínez, R., El Amine, A. and Melgarejo, P. 2012. Physico-Chemical Characterization of Six Pomegranate Cultivars from Morocco: Processing and Fresh Market Aptitudes. *Sci. Hortic.,* **140:** 100-106.
18. Ozgen, M., Durgaç, C., Serçe, S. and Kaya, C. 2008. Chemical and Antioxidant Properties of Pomegranate Cultivars Grown in the Mediterranean Region of Turkey. *Food Chem.*, **111:** 703-706.
19. Reddy, M. K., Gupta, S. K., Jacob, M. R., Khan, S. I. and Ferreira, D. 2007. Antioxidant, Antimalarial and Antimicrobial Activities of Tannin-Rich Fractions, Ellagitannins and Phenolic Acids from *Punica granatum* L. *Planta Med.*, **73:** 461-467.
20. Ross, T. 2010. *Fuzzy Logic, with Engineering Applications*. John Wiley and Sons, United Kingdom.
21. Shwartz, E., Glazer, I., Bar-Ya'akov, I., Matiyahu, I. and Bar-Ilan, I. 2009. Changes in Chemical Constituents during the mMaturation and Ripening of Two Commercially Important Pomegranate Accessions. *Food Chem.*, **115:** 965-973.
22. Tanaka, H., Hayashi, I. and Watada, J. 1989. Possibilistic Linear Regression Analysis for Fuzzy Data. *Eur. J. Oper. Res.* **40:** 389–396.
23. Tanaka, H. and Ishibuchi, H. 1991. Identification of Possibilistic Linear Systems by Quadratic Membership Functions of Fuzzy Parameters. *Fuzzy Set. Syst.*, **41:** 145–160.
24. Tanaka, H., Uejima, S. and Asai, K. 1982. Linear Regression Analysis with Fuzzy Model. *IEEE Syst.Trans. Syst. Man Cybernet,* **SMC-2***:* 903–907.
25. Zhao, X., Yuan, Z., Fang, Y., Yin, Y., Fena, L. 2014. Flavonols and Flavones Changes in Pomegranate (*Punica granatum* L.) Fruit Peel during Fruit Development. *J. Agr. Sci. Tech.,* **16:** 1649-1659.

یک روش فازی برای ارتباط دادن یک شاخص بلوغ انار با تابش خالص خورشیدی

ج. م. بروتونز، پ. لگوا، پ. ملگارجو، ف. ج. مانرا، ف. هرناندز، و ج. ج. مارتینز

چکیده

وضعیت بلوغ میوه انار براساس رنگ پوست خارجی و آب آن و اسیدیدته آن ارزیابی می شود. برخی از محققان ارتباط بین پارامترهای رنگ پوست و اسیدیته، مواد جامد محلول، اسید سیتریک، آنتوسیانین مطالعه کرده اند. این مطالعه به بررسی روابط موجود بین تابش خورشیدی و شاخص بلوغ رنگ سنجی در گروه رقم انار "Mollar de Elche " توصیف می کند. ما یک روش فازی پیشنهاد می کنیم. هدف از این نوع مطالعه بدست آوردن یک تخمین از طیف مقادیر ممکن است که منعکس کننده واقعیت باشد. با استفاده از این روش چهار مرحله به دست آمد، که در آن هیچ ارتباطی بین تابش و شاخص بلوغ رنگ (MIC) در مراحل ۱ و ۴ وجود نداشت، اما در فازهای ۲ و ۳ بود. روش فازی نشانگر رابطه مثبت بین تابش و MIC و تایید کننده مناسب بودن رگرسیون فازی برای ساخت تخمین های منعکس کننده واقعیت بین متغیرهایی است که رابطه بسیار ضعیف نشان می دهند. درجه بالایی از عدم اطمینان در رابطه بین شاخص بلوغ رنگ و تابش وجود دارد. ارزش فردی تابش

فقط به یک ارزش تنها MIC وابسته نیست، بلکه به یک طیف گسترده ای ، به علت فاکتورهای زیادی، مانند جهت گیری میوه، درخشندگی، و غیره وابسته است. ریاضی فازی رابطه مثبت بین تابش خالص MIC در فازهای ۲ و ۳ را نشان می دهد. همه این ها نشانگر مناسب بودن رگرسیون فازی برای ساخت تخمین های منعکس کننده واقعیت وقتی متغیرها رابطه ضعیف نشان میدهند می باشد.

[DOR: 20.1001.1.16807073.2017.19.3.14.3]