Physiological maturity in sunflower. Correspondence between the quantitative and the visual definition

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ABSTRACT

The identification of physiological maturity (PM) in sunflower (*Helianthus annuus* L.) by visual methods is highly subjective. In order to find an indirect method for objectively defining PM, this study was conducted to correlate, in two sunflower hybrids, Macón and MG60, quantitative color parameters in the receptacle (Hue and Chroma in the *HSB* color space and $L*$, $a*$ and $b*$ in the *CIE* color space) with physiological markers such as fruit dry weight (FDW) and fruit water content (FWC). Fruits from each cultivar were sampled at 2-day intervals from first anthesis until harvest maturity (HM). Fruit dry weight and color changes of the receptacle base, using digital images, were followed over time until HM. Fruits attained their maximum dry weight when the capitulum color turned from dark green to pale green in MG60 and when it turned from dark green to buttery-yellow in Macón. The color parameters L*, a*, b*, Hue and Chroma were tested against the fruit dry weight, and several good correlations were found, but from a crop management point of view the Hue (r_{MG60}= 0.876; $r_{\mathrm{Macón}}$= 0.794) appeared to be a valid color parameter to define visual PM.

Keywords: color correlation – color parameters – *Helianthus annuus* – physiological maturity – sunflower.

INTRODUCTION

Physiological maturity (PM; Schneiter and Miller, 1981), is an important reproductive stage of the sunflower crop. At PM fruit dry weight (FDW) has reached its maximum value with a water content (FWC; d.w.b.) of about 38% (Rondanini, 2007). In the decimal notation by Schneiter and Miller (1981), the most frequently used scale to define the developmental stages of sunflower, PM, also defined as phenostage R9, is externally observed when the phyllaries become brown and brittle and the receptacle base turns buttery yellow.

The time elapsed to attain PM varies according to genotypes and environmental conditions such as nitrogen and soil water availability, temperature and photoperiod (Connor and Hall, 1997). The same genotype can differ from between 7 and 10 days to reach PM in response to changes in the variables mentioned (Kaya et al., 2004). Therefore, although the scale by Schneiter and Miller (1981) is a useful tool to study many sunflower genotypes, it fails for others. In fact, in some "stay green" (SG) genotypes the base of the receptacle at PM is green or yellowish green; only the phyllaries can become slightly brown (Cukadar-Olmedo and Miller, 1997).

Changes in color of the sunflower receptacle when approaching PM are recorded at naked eye. This is why the method is highly subjective. The aim of this work was to determine the correspondence among chromaticity of the receptacle base, by analyzing digital images of the receptacle development from first anthesis (FA) until harvest maturity (HM), the phenostage scale developed by Schneiter and Miller (1981) and the evolution of FDW and FWC.

MATERIALS AND METHODS

Two short season sunflower hybrids: Macón (Syngenta, Argentina) and MG-60 (Dow-Agrosciences, Argentina) were used in the study. Plants were grown at the Chacra Experimental de Barrow (INTA-MAA, Tres Arroyos, Argentina; Lat. S. 38º20'; Long. W. 60º13') following conventional cultural practices.

Qualitative determination of phenological stages was made using the scale by Schneiter and Miller (1981). At FA (phenostage R5.1; Schneiter and Miller, 1981) twelve plants of each hybrid were selected and labeled. FDW and FWC (d.w.b.) were measured in 6 plants of each hybrid by taking samples of fruits from the capitulum's rim at 3-day intervals from FA to HM.

A biphasic fit of FDW vs. time (days from FA) was performed using the model: **y** = a+b.X (for X<c); **y** = b.c (for X>c), where **c** corresponds to the unknown break point of the two linear functions, this being the maximum grain weight of the fruit F(t), where PM is attained.

Simultaneously with fruit sampling, photographs of the receptacle base were taken from 8:00 a.m to 9:00 a.m. to the remaining 6 plants of each hybrid using a digital camera. A color reference scale was included in each image. Digital images were corrected for light intensity changes and analyzed to determine the parameters L^*, a^* and b^* within the CIE $L^*a^*b^*$ color space, (CIE, 1986, 2001), using Photoshop CS2 software (Adobe Systems Inc.; San José, CA, USA).

L^*, a^* and b^* values were furthermore converted into the *HSB* color space (Adobe Systems Inc., 2000; MacEvoy, 2005), defining the parameters Hue (the attribute of color by means of which it is perceived to be red, yellow, green, blue, etc. Pure white, black, and gray possess no Hue) and Chroma (also called "saturation" and indicating the amount by which a color differs from gray, white or black, from neutral to fully saturated color). The values run from 0%, which is no color saturation, to 100%, which is the fullest saturation of a given Hue, using the algorithms:

$$\text{Hue} = h^* = \tan^{-1}(b^*/a^*), \text{[when } a^*>0 \text{ y } b^*\geq 0\text{]; Hue} = h^* = 180 + \tan^{-1}(b^*/a^*) \text{ [when } a^*<0\text{]}$$
$$\text{Chroma} = C^* = [a^{*2} + b^{*2}]^{1/2}$$

RESULTS AND DISCUSSION

Maximum FDW significantly differed ($p<0.01$) between genotypes, with 0.043 g/fruit, 31 days after FA in MG60 (Fig. 1A) and 0.045 g/fruit, 28 days after FA in Macón (Fig. 1B). Maximum FDW for both hybrids was attained with a FWC of 38.6% in MG60 (Fig. 1A) and 39.2% in Macón (Fig. 1B). These values showed no significant differences ($P<0.05$). However, Macón showed a higher average FWC (Fig. 1B), possibly as a consequence of green mass retention at PM.

The magnitudes of the L^*a^* and b^* at the time of PM were: L^*: 68.3 (MG60) and 73.6 (Macón); a^*: -4.2 (MG60) and -6.2 (Macón); b^*: 48.4 (MG60) and 52.3 (Macón) (Fig 2. A and B, respectively).

The L^* magnitude showed important fluctuations (Fig. 2A-B) in response to variations in daily luminosity when digital images were taken. This probably masked the real magnitude of luminosity as maturity advanced (Shewfelt et al., 1988). However, it was observed that L^* magnitude decreases with capitulum maturity in response to opacity and darkening of the capitulum's tissue (Fig. 2 A-B).

A significant correlation between the FDW and colorimetric parameters a^* (0.752; 0.638), b^* (0.771; 0.670), Hue (0.876; 0.794) and Chroma (0.669; 0.593) for MG60 and Macón, respectively, were observed. Nevertheless, it was found that both Hue and Chroma were the best color parameters to be considered when working in a relationship between their changes with time of capitulum maturation and FDW.

In early developmental stages the presence of a high concentration of chlorophyll in the receptacle tissues is significantly related to the green color observed. So, as maturity advances, chlorophyll degradation, (Sexton and Woolhouse, 1985) and the predominance of xanthophylls and other carotenoid pigments (Sinecker et al., 2002) are the reason for the variation in color turning from green to yellow.

Magnitudes of a^* and b^* moved over time from minus a^* (green component; HunterLab., 2001) to plus a^* (yellow-red component; HunterLab., 2001) (Fig. 2A-B). The parameter b^* (yellow-blue component; HunterLab., 2001) always had positive values.

For both hybrids, results showed that the magnitude of b^* tends to increase up to the moment of the maximum value of FDW and then decreases (Fig 2 A-B) following the diminution of FWC, in response to plant senescence (Fig. 1A-B). The a^* value increases as capitulum maturity advances (Fig 2 A-B), allowing the b^* component (yellow) to stand out. Yellowing of the receptacle was characterized, as expected, by a constant increase in the value of a^* (less green) and a maximum magnitude of b^* (more yellow) (Fig. 2A-B).

Hue values decreased from 122.8 to 74.6 in MG60 (Fig. 1A) and from 115.4 to 71.1 in Macón (Fig. 1B). Chroma increased until 28 days after anthesis in MG60 (Fig. 1A) and in Macón (Fig. 1B), when both hybrids attained their maximum FDW. From that moment on Chroma magnitude started decreasing.

The maximum Chroma (maximum color saturation) in MG60 was attained 2 days before PM (Chroma=59; Fig. 1A); the Hue at that time was 98 showing a buttery yellow capitulum base and brown phyllaries. The maximum Chroma in Macón was attained at PM (Chroma=62; Fig. 1B) with a yellowish receptacle base and the phylllaries still green. Also, in this hybrid with a higher retention of green tissue, PM was attained 12 days before phenostage R9 was observed (Fig. 1B).

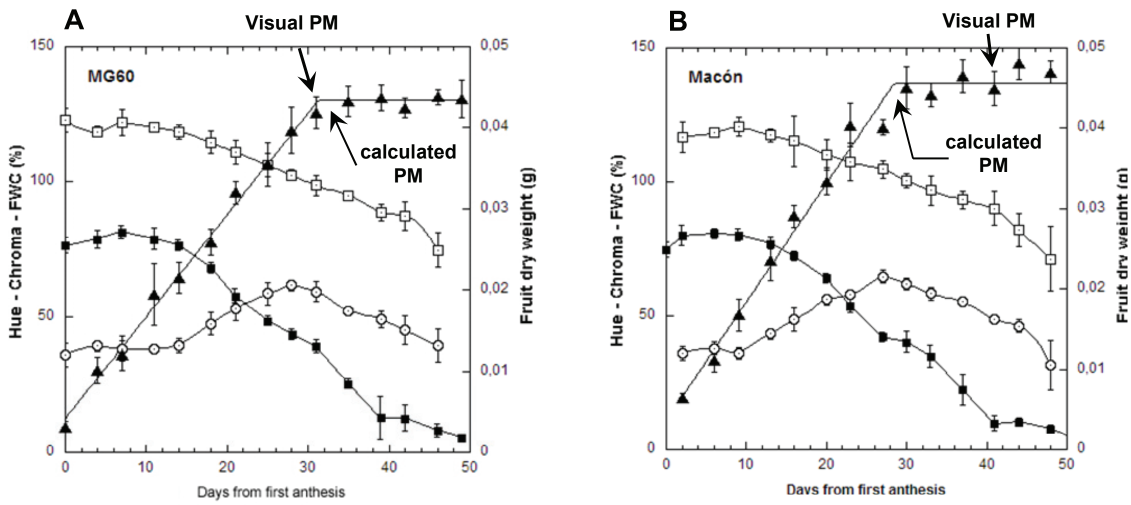

Figure 1: Evolution from first anthesis until harvest maturity of fruit dry weight (FDW), fruit water content (FWC) and the color parameters Hue Chroma in MG60 (A) and Macón (B). The visual PM (R9; Schneiter and Miller, 1981) and maximum FDW (calculated PM) in MG60 (A) was atta 31 days after anthesis. The maximum FDW in Macón (B) was attained 28 days after anthesis, while the visual PM was approximately 12 days l Then only in the genotype MG60 (B), the maximum FDW coupled the visual PM according to the morphological characteristics defined by Schn and Miller (1981). (□) Hue; (○): chroma; (▲): fruit dry weight (FDW); (■): Fruit water content (FWC). Vertical bars: ± 1SE.

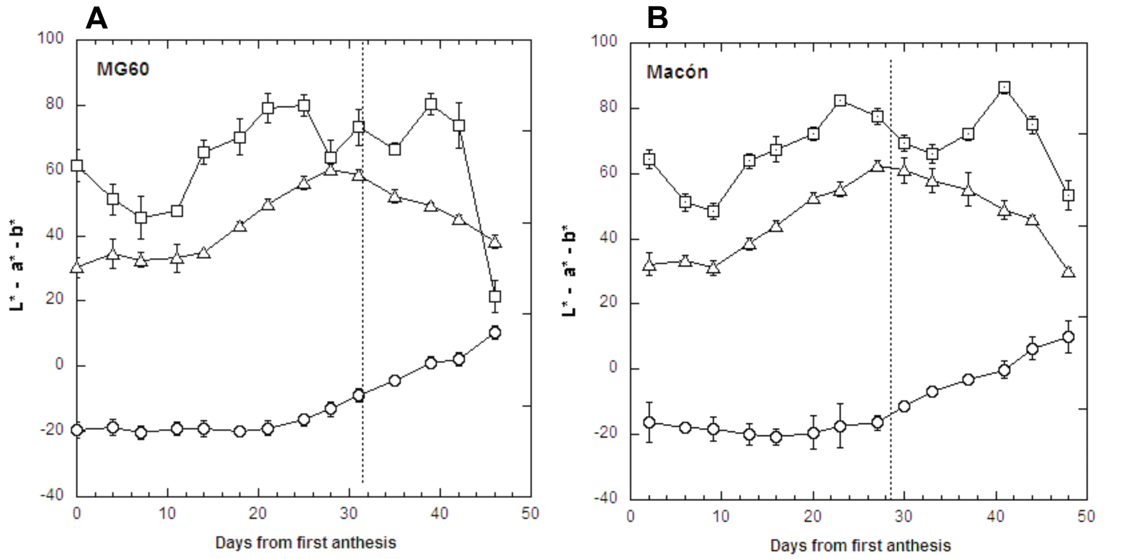

Fig. 2. Changes in the CIE $L^*a^*b^*$ parameters in the base of capitula of the sunflower hybrids MG60 (A) and Macón (B) from first anthesis until HM. The vertical dashed line indicates the time when the maximum FDW, and hence PM was attained. (□) L^*; (○): a^*; (△): b^*. Vertical bars: ± 1SD.

The hybrid MG60 attained visual PM (R9; Schneiter and Miller, 1981) 31 days after first anthesis (Fig. 1A) while Macón, attained visual PM 40 days after FA (Fig. 1B). In MG60 visual PM (Hue= 98) and measured PM were reached at the same time (Fig. 1A). In Macón the maximum FDW was attained 12 days earlier than visual PM (Fig. 1B) indicating that fruits reached their maximum dry weight when the receptacle base was still green with a Hue of 103.

The linear variations in Hue, between 10 and 40 days after FA in both hybrids (Fig. 1A-B), showed the direct relationship between the receptacle color change and the advance of fruit maturity. The Hue is then best associated with the attainment of the visual PM, corresponding to phenostage R9, this value being nearly similar for both hybrids: Hue Macón=103; Hue MG60=98 (Fig. 1A-B). Therefore, the Hue of the receptacle base could be a useful parameter to express differences or similitudes between sunflower genotypes in the attainment of PM.

This work demonstrates that visual scales, which are generally widely subjective, are not always appropriate for determining maturity stages of crop plants, particularly sunflower. The brown phyllaries as a qualitative concept of PM cannot be applied to all genotypes. Using quantitative color parameters in genotypes grouped by maturity length and/or green mass retention could be a more precise approach to determine the correspondence between the measured PMs and their visual morphological characteristics.

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