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Phenological growth stages of avocado (*Persea americana*) according to the BBCH scale

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ABSTRACT

Avocado (*Persea americana*) is an important evergreen fruit crop grown in several countries with tropical and subtropical climates. In this work, a precise standardized description of the different growth stages of this crop is proposed. The BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) code has been used to define the most important phenological growth stages from vegetative bud dormancy to fruit harvest. The code will be an important tool to assist the development and implementation of agronomic management protocols and to standardize observations made in different environments and/or under different experimental conditions in this crop.

1. Introduction

Avocado (*Persea americana* Mill.) is an evergreen fruit tree native to tropical and subtropical regions of Mexico, Guatemala and the Pacific Coast of Central America. Avocado belongs to the Lauraceae, in the order Laurales, a family with mostly woody species, comprising about 50 genera and 2500 species, which are distributed worldwide mainly in tropical and subtropical regions (APG III, 2009; Rohwer, 1993). Recent molecular phylogenetic analyses and previous morphological studies have placed the Laurales, together with the orders Canellales, Magnoliales and Piperales, in the early-divergent angiosperm clade magnoliid (APG III, 2009).

Archeological records suggest that avocado fruits were consumed in Mexico at least 10,000 years ago (Knight, 2002; Galindo-Tovar et al., 2008). *P. americana* consists of at least eight botanical varieties or subspecies of which three, also known as horticultural races, have agronomic interest: West Indian (*P. americana* var. *americana*), Guatemalan (*P. americana* var. *guatemalensis*) and Mexican (*P. americana* var. *drymifolia*) (Scora et al., 2002). From its center of origin, avocado cultivation has extended to different regions with tropical, subtropical and temperate climates. Total world production was more than 4 million tons in 2011, with 70% of this production coming from relatively few countries: Mexico, Chile, Dominican Republic, Indonesia, Colombia, Peru, USA and Kenya (FAOSTAT, 2013).

Avocados are large forest trees, often over 20 m tall. As with many evergreen tropical and subtropical trees, avocados exhibit rhythmic growth with two or more flushes of shoot growth per year, alternating with short periods of rest (Thorp and Sedgley, 1993; Thorp et al., 1994). Shoot growth is generally monopodial and axillary shoots can be proleptic (formed after a period of rest of their apical meristem) or sylleptic (formed without a rest period) (Fig. 1) with the relative proportions of the two being cultivar dependent. Bud scales form around the apical meristem during the period of rest; these bud scales and bud scale scars are visible at the base of proleptic shoots for several months after shoot extension. There are no bud scales at the base of sylleptic shoots as there has been no period of rest.

Floral shoots may contain one or more floral buds derived from terminal and/or subterminal buds on the parent shoot (Thorp et al., 1994). Floral buds are generally mixed buds with both reproductive and vegetative primordia. Each floral bud develops into a compound inflorescence or thyrse that can be determinate (ends in a flower) or indeterminate (ends in a vegetative bud) (Fig. 2). Each compound inflorescence contains approximately 80 flowers. The avocado flower is bisexual having both functional male and female organs although the functions are separated in time by synchronous protogynous dichogamy (Davenport, 1986). Each flower opens twice, the first functionally as a female flower which closes then re-opens the following day in the male stage. Heterodichogamy is

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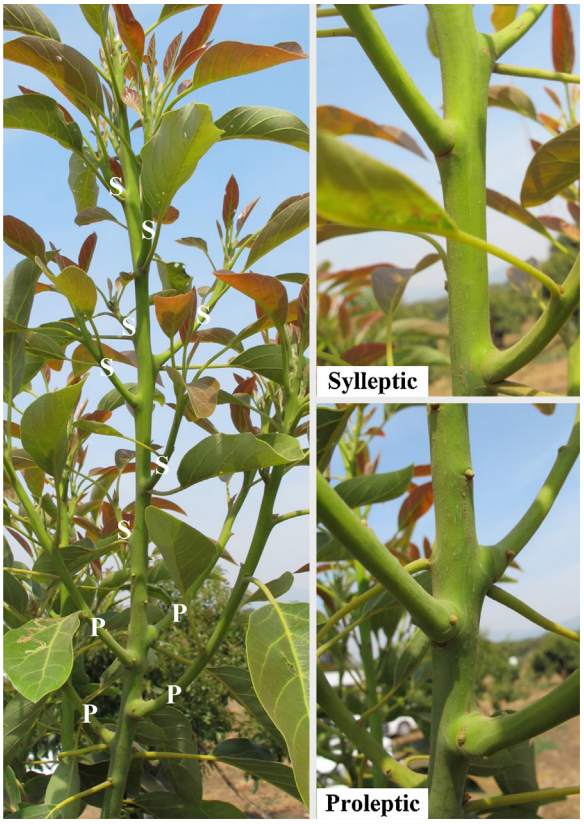

Fig. 1. Proleptic (P) and sylleptic (S) axillary shoot types on the primary growth axis of a 'Hass' avocado shoot. Bud scale scars from the resting bud can be seen at the base of proleptic shoots. Bud scales are absent from sylleptic shoots.

present in this species such that the different avocado cultivars are classified in two groups (A or B) according to their flowering behavior (Nirody, 1922). In type A cultivars, flowers usually open in the morning in the female stage, close at midday and reopen in the afternoon of the following day in the male stage. In type B cultivars, the flowers open in the afternoon in the female stage, close in the evening and reopen the following morning in the male stage (Stout, 1923). Fruit growth follows a sigmoidal pattern and can continue for more than 12 months depending on cultivar and climate.

Several descriptions of phenological growth stages in avocado have been proposed since the early works of Venning and Lincoln (1958) but a unified approach compatible with other crops is still lacking. Until the 1990s, most of the phenological stages of fruit crops were described based on the Fleckinger scale (Fleckinger, 1948), which includes only inflorescence and flower development. Bleiholder et al. (1989) introduced a two-digit decimal coding system for angiosperms, the BBCH scale (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) and, more recently, a revised scale specific to woody plants has been proposed (Finn et al., 2007). A history and background to the development and use of the BBCH scale has been prepared by Meier et al. (2009) with several examples presented in monograph form by Meier (2001). The general scale describes the entire developmental cycle of both herbaceous and woody plants. This method identifies the different stages of development with two digits; the first uses 10 principal growth stages (0–9) divided into 10 secondary (0–9) growth stages. For plants exhibiting rhythmic growth with more than one growth cycle per year, an extended three-digit BBCH scale is used with the middle digit describing the intermediate growth flushes or mesostages (1 to *n*) as used by Niemenak et al. (2010) for cacao and by Hernández Delgado et al. (2011) for mango. Principal growth stages that overlap, for example leaf expansion and shoot extension, are indicated by using a diagonal stroke (e.g. 119/315). When there is a group of trees at a range of growth stages, this range is indicated by a hyphen (e.g. 611–617).

Fig. 2. Indeterminate (A) and determinate (B) compound inflorescences from 'Hass' avocado.

Application of the extended BBCH scale provides a consistent description of the different phenological growth stages of a particular crop. It is an important tool to assist the development and implementation of agronomic management protocols and to standardize observations made in different environments and/or under different experimental conditions.

Previous workers have proposed various systems to describe phenological growth stages in avocado at both the macroscopic and microscopic levels, each with a different purpose in mind (Inoue and Takahashi, 1989, 1990; Thorp et al., 1994; Salazar-García et al., 1998; Buzgo et al., 2007). In this work, we propose to apply the extended BBCH scale system to describe the phenological growth stages of avocado and thus contribute to the standardization of phenology studies in this crop and the quantitative analysis of avocado tree growth cycles (Thorp et al., 1998).

2. Materials and methods

Data were collected from adult trees (25 years old) of *Persea americana* 'Hass' grafted on 'Topa-Topa' seedling rootstocks located at the IHSM la Mayora in Málaga (Spain) at latitude 36°45′N, longitude 4°4′W and altitude 35 m above sea level. Long-term climate data (50 year average) for this region show annual average mean temperatures of 18.5 °C, average maximum temperatures of 28.9 °C in the hottest month (August) and an average minimum temperature of 9.8 °C in the coolest month (January) with an average annual rainfall of 536 mm.

Measurement and observations of vegetative and reproductive development were carried out during two annual growing seasons (2010–2012). A total of 79 buds located in 15 different branches were marked and measurements were made once per week from November to January and twice per week from January to April. During the experimental period the average maximum and minimum temperatures were 19.3 °C and 9.9 °C, respectively. To estimate fruit growth, 200 recently set fruits were marked at the end of May and diameter and length were measured weekly with a digital Digi-Max slide caliper (Sigma–Aldrich Co., Germany) over two months and, later, every two weeks until the date of commercial harvest.

For avocado, the BBCH scale uses 7 of the 10 principal growth stages starting with vegetative bud dormancy (stage 0) and ending