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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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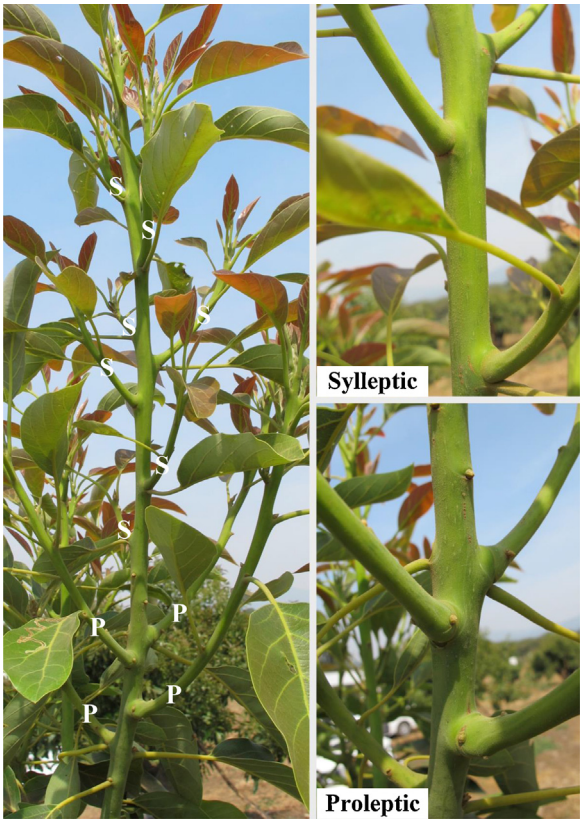

Fig. 1. Proleptic (P) and sylleptic (S) axillary shoot types on the primary growth axis of a 'Hass' avocado shoot. Bud scale scars from the resting bud can be seen at the base of proleptic shoots. Bud scales are absent from sylleptic shoots.

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

Table 1
Description of the phenological growth stages of avocado (*Persea americana* Mill.) according to the BBCH scale.

BBCH code	Description (mesostage 1)
Principal growth stage 0: vegetative bud development	
010	Vegetative buds dormant
011	Beginning of bud swell
013	End of bud swell
017	Beginning of bud break
019	End of bud break
Principal growth stage 1: primary leaf expansion	
110	First leaves separating
111	First leaf unfolded
112	More leaves unfolded. First leaf at 20% of its full size
113	More leaves unfolded. First leaf at 30% of its full size
11.	Stages continue until . . .
119	All leaves unfolded and fully expanded
Principal growth stage 2: axillary (sylleptic) shoot formation	
210	No sylleptic shoots visible
211	First sylleptic shoot visible
212	Two sylleptic shoots visible
213	Three sylleptic shoots visible
21.	Stages continue until . . .
219	Nine or more sylleptic shoots visible
Principal growth stage 3: primary shoot extension	
310	Beginning of shoot extension
311	10% of final shoot length
312	20% of final shoot length
31.	Stages continue until . . .
319	90% or more of final shoot length
Principal growth stage 5: reproductive development	
510	Reproductive buds dormant
511	Beginning of reproductive bud swell
512	End of reproductive bud swell
513	Reproductive bud break
515	Inflorescences 50% of final length
517	Inflorescences 70% of final length
519	End of inflorescence extension
Principal growth stage 6: flowering	
610	First flowers open
611	10% of flowers opened
612	20% of flowers opened
61.	Stages continue until . . .
619	90% or more of flowers opened
Principal growth stage 7: fruit development	
710	No ovary growth visible
711	Initial ovary growth
712	First fruitlet abscission
715	50% of final fruit size
71.	Stages continue until . . .
719	90% or more of final fruit size

when the fruit approaches its final size and is ready for commercial harvest (stage 719) (Table 1 and Fig. 3). The focus is generally on the development of the terminal bud, leaves, inflorescences, flowers and fruit on primary shoots. However, with avocados, axillary shoots formed by syllepsis are also important. Extension of these stage 2 sylleptic shoots is contemporaneous with extension of the stage 3 primary shoots. Avocado fruit do not ripen until after harvest, so the principal growth stage 8 "ripening or maturity of fruit/seed" is not included in our description.

3. Results and discussion

Under the environmental conditions of southern Spain, avocado shows two vegetative growth flushes, one in spring (mesostage 1) and one in summer (mesostage 2). Floral buds develop in the fall (autumn) and flowering takes place in spring, concomitant with the spring flush of shoot growth. The length of the flowering period is cultivar dependent and is also highly dependent on environmental conditions, mainly temperature (Sedgley and Annells, 1981).

3.1. Principal growth stage 0: vegetative bud development

3.1.1. First vegetative flush (mesostage 1)

In southern Spain, bud development preceding the first vegetative flush in spring normally occurs in February/March for 'Hass' avocado.

010 Vegetative buds dormant: vegetative buds are closed and covered by green-brown bud scales (Fig. 3).
011 Beginning of bud swell: bud scales begin to separate, buds visibly swollen.
013 End of bud swell: bud scales completely separated, lighter green sections of inner bud scales visible.
017 Beginning of bud break: bud scales partially folded back and first green leaf tips just visible.
019 End of bud break: leaf tips about 3 mm above bud scales, external bud scales shed (Fig. 3).

3.1.2. Second vegetative flush (mesostage 2)

In southern Spain, bud development preceding this second vegetative flush in late summer (August/September) normally occurs in July/August for 'Hass' avocado.

020 Vegetative buds dormant: vegetative buds are closed and covered by green-brown bud scales with no sign of growth.
021 Beginning of bud swell: bud scales begin to separate, buds visibly swollen.
023 End of bud swell: bud scales completely separate, lighter green sections of inner bud scales visible.
027 Beginning of bud break: bud scales partially folded back and first green leaf tips just visible.
029 End of bud break: leaf tips about 3 mm above bud scales, external bud scales shed.

Additional flushes: Under climatic conditions where additional flushes are observed, additional mesostages can be added.

3.2. Principal growth stage 1: primary leaf expansion

3.2.1. First vegetative flush (mesostage 1)

In southern Spain, most leaves on the first vegetative growth flush emerged during March and April for 'Hass' avocado. Growth phase 110–119 is achieved in approximately 30 days.

110 First leaves separating: leaves unfolding with leaf tips 10 mm above the bud scales (Fig. 3).
111 First leaf unfolded: primary axis of developing shoot visible.
115 More leaves unfolded: first leaf of the flush at 50% of its full size, leaf petioles extending (Fig. 3).
119 All leaves unfolded: all leaves fully expanded (Fig. 3).

3.2.2. Second vegetative flush (mesostage 2)

In southern Spain, most leaves on the second vegetative growth flush emerged during August/September for 'Hass' avocado. Growth phase 120–129 is achieved in approximately 30 days.

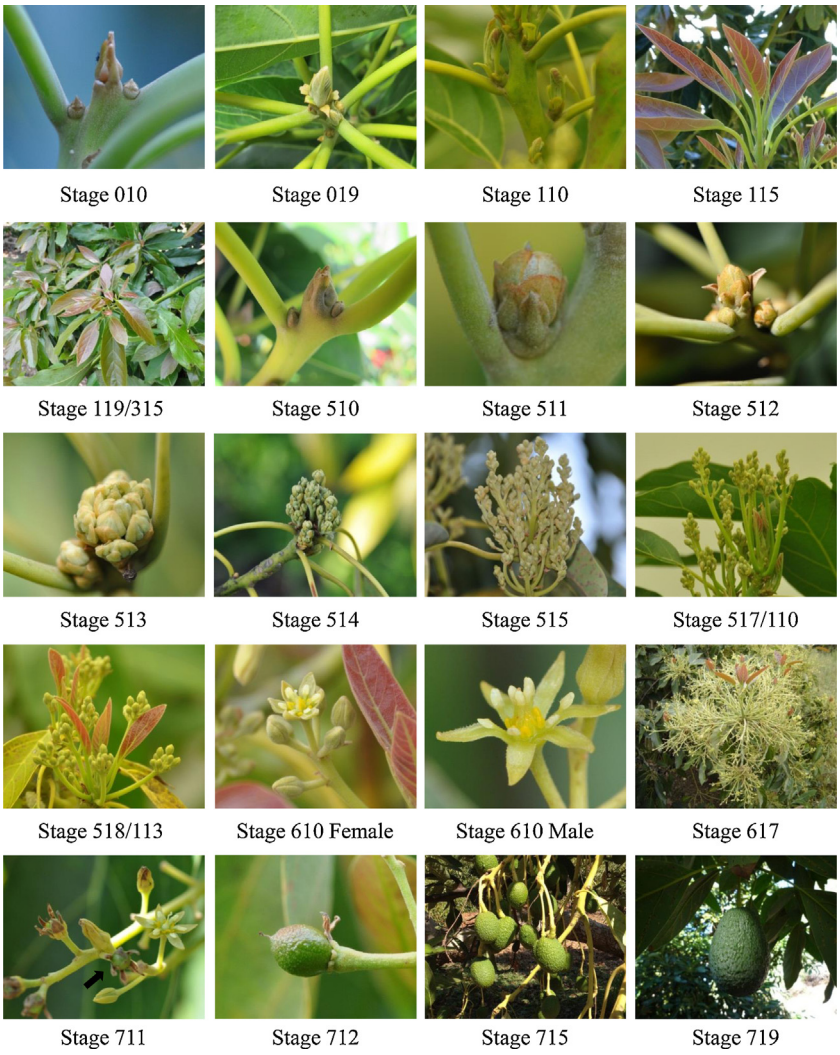

Fig. 3. Main phenological growth stages of 'Hass' avocado according to the extended BBCH scale.

120 First leaves separating: leaves unfolding with leaf tips 10 mm above the bud scales.
121 First leaf unfolded: primary axis of developing shoot visible.
125 More leaves unfolded: first leaf of the flush at 50% of its full size, leaf petioles extending.
129 All leaves unfolded: all leaves fully expanded.

Additional flushes: Under climatic conditions where additional vegetative flushes are observed, additional mesostages can be added.

3.3. Principal growth stage 2: axillary (sylleptic) shoot formation

Axillary (sylleptic) shoot growth develops at the same time as extension of the primary growth axis (stage 3).

3.3.1. First vegetative flush (mesostage 1)

210 No sylleptic shoots visible.
211 First sylleptic shoot is visible.
212 Two sylleptic shoots visible.
213 Three sylleptic shoots visible.
219 Nine or more sylleptic shoots visible.

3.3.2. Second vegetative flush (mesostage 2)

220 No sylleptic shoots visible.
221 First sylleptic shoot is visible.
222 Two sylleptic shoots visible.
223 Three sylleptic shoots visible.
229 Nine or more sylleptic shoots visible.

3.4. Principal growth stage 3: primary shoot extension

3.4.1. First vegetative flush (mesostage 1)

In southern Spain, the first vegetative flush normally takes place in spring (March/April) during inflorescence emergence (stage 5) and flowering (stage 6).

310 Beginning of shoot extension: axes of developing shoots visible.
311 10% of final shoot length: shoots 10% of final length, leaves unfolding.
315 50% of final shoot length: shoots 50% of final length, all leaves unfolded (Fig. 3).
319 Shoots more than 90% of final length: end of shoot extension (apical bud set).

3.4.2. Second vegetative flush (mesostage 2)

In southern Spain, the second vegetative flush normally takes place in late summer (August/September) during fruit development (stage 7).

320 Beginning of shoot extension: axes of developing shoots visible.
321 10% of final shoot length: shoots 10% of final length, leaves unfolding.
325 50% of final shoot length: shoots 50% of final length, all leaves unfolded.
329 Shoots more than 90% of final length: end of shoot extension (apical bud set).

Additional flushes: Under climatic conditions where additional flushes are observed, additional mesostages can be added.

3.5. Principal growth stage 5: reproductive development

In southern Spain, reproductive bud development occurs during autumn and winter (October/February) with bud break and inflorescence emergence occurring in spring (March/April). Reproductive buds become spherical during development as inflorescences develop within the buds whereas vegetative buds remain elongated. Vegetative bud break and shoot extension from the terminal bud on indeterminate inflorescences occurs during the later stages of inflorescence development (stage 517–519).

510 Reproductive buds dormant: buds covered with green-brown bud scales with no sign of growth (Fig. 3).
511 Beginning of reproductive bud swell: light brown scales begin to separate, buds visibly swollen (Fig. 3).
512 End of reproductive bud swell: bud scales completely separated, lighter green sections of inner bud scales visible (Fig. 3).
513 Reproductive bud break: bud scales folded back, inflorescences just visible in axils of bud scales (Fig. 3).
514 Compound inflorescence separated: individual inflorescences separated and beginning of inflorescence elongation (Fig. 3).
515 Inflorescences 50% of final length: secondary axes elongated, tertiary axes still covered by bracts, small closed flowers (Fig. 3).
517 Inflorescences 70% of final length: tertiary axes elongated, individual flowers separated, first visible expansion of leaves on indeterminate inflorescences (Fig. 3).
518 Inflorescences 80% of final length (Fig. 3).
519 End of inflorescence extension: secondary and tertiary axis fully developed, individual flower pedicels elongated, sepals closed, flowers differentiated and closed, shoot extension underway on indeterminate inflorescences.

Additional flowering periods: Under climatic conditions where there is more than one period of flowering, additional mesostages can be added.

3.6. Principal growth stage 6: flowering

In southern Spain, the first flowers in 'Hass' avocado opened at the end of March or early April and flowering continues for about one month. Stage 615 is achieved approximately 15 days after stage 611.

610 First flowers opened (Fig. 3).
611 10% of flowers opened.
615 50% of flowers opened; mid-bloom.
617 70% of flowers opened (Fig. 3).
619 90% or more of flowers opened: full bloom.

Additional flowering periods: Under climatic conditions where there is more than one period of flowering, additional mesostages can be added.

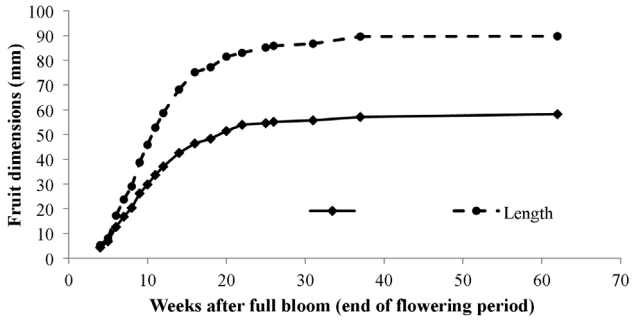

Fig. 4. Diameter and length of 'Hass' avocado fruit growing from the end of the flowering season (stage 712) until the time of commercial fruit harvest (stage 719) 62 weeks after flowering.

3.7. Principal growth stage 7: fruit development

Avocado fruit growth follows a sigmoidal pattern (Fig. 4). In southern Spain, for 'Hass', fruits are ready for commercial harvest (stage 719) between 31 and 37 weeks after the end of flowering. Two major periods of fruit drop can occur, in late spring (May/June) approximately 30 days after mid-bloom and in summer (July/August).

710 No ovary growth visible.
711 Initial ovary growth: following fertilization and fruit set (Fig. 3).
712 First fruitlet abscission: ovaries green and surrounded by dying sepals, diameter of retained fruit 5–10 mm (Fig. 3).
715 50% of final fruit size: second main period of fruit drop (Fig. 3).
717 70% of final fruit size.
719 90% or more of final fruit size: fruit ready for commercial harvest (Fig. 3).

Additional fruiting periods: Under climatic conditions where there is more than one period of flowering and fruiting, additional mesostages can be added.

In this work, the phenological stages in avocado have been described for the first time according to an extended BBCH scale. This BBCH-scale distinctly separates the different vegetative and reproductive flushes occurring in avocado. The description presented here will be useful not only to provide basic information on crop requirements, crop management and pest and disease control but also to facilitate exchange of scientific information among avocado experiments in different environmental conditions.

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