Phenological growth stages of tree tomato (*Solanum betaceum* Cav.), an emerging fruit crop, according to the basic and extended BBCH scales

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ABSTRACT

The tree tomato (*Solanum betaceum* Cav.) is a small tree native to the Andean region cultivated for its juicy fruits, which are having an increasing demand. Tree tomato is morphologically and phenologically different from other *Solanum* crops and tools for the phenological description of the developmental stages are needed for the enhancement of this emerging crop. We developed a basic and an extended numerical BBCH (Biologische Bundesanstalt, Bundessortenamnt, Chemische Industrie) scales which allow the precise identification of the phenological stages of tree tomato. Eight principal stages are described for germination, leaf development, formation of side shoots, stem elongation, inflorescence emergence, flowering, development of fruit, and ripening of fruit and seed. The basic (two-digit) scale is sufficiently precise for germination, stem elongation, and ripening of fruit and seed. However, for leaf development, formation of side shoots, inflorescence emergence, flowering, and development of fruit the extended (three-digit) scale is considered necessary for an adequate description. The description of the phenological stages is combined with illustrations for clarification. The tree tomato BBCH scale has been validated by characterizing 24 accessions of different varietal groups for traits of agronomic interest and evaluating the differences observed among accessions at specific BBCH developmental stages. The basic and extended BBCH scales represent a useful tool for the description and identification of phenological scales of tree tomato. These scales will be useful for the enhancement of this emerging fruit crop.

Keywords: Descriptors, developmental stages, fruit crop, phenological scale, Solanaceae, scale validation, varietal characterization

1. Introduction

Tree tomato (*Solanum betaceum* Cav., Solanaceae), also known as tamarillo, is an emerging exotic fruit crop native to the Andean region and cultivated in South America, as well as in other tropical and subtropical areas, like New Zealand, Australia, and India (Bohs, 1989; Carrillo-Perdomo et al., 2015; Samuels, 2015). The tree tomato fruits are fleshy and can be consumed in juices (its most common use), as a fresh fruit, cooked or processed in different ways (Bohs, 1989; Prohens and Nuez, 2000). Tree tomato fruits have a high content in ascorbic acid, provitamin A, carotenoids, and vitamin $B_{6,}$ as well as a high antioxidant activity (Vasco et al., 2009; Acosta-Quezada et al., 2015; Espin et al., 2016), which is stimulating its demand in both local and overseas fruit markets (Carrillo-Perdomo et al., 2015).

The tree tomato plant is a small tree which, in commercial plantations, has a height of 2 to 4 m. The trees start bearing within 12-18 months of planting reaching a production peak at 3-4 years, which is maintained until the plant has 6-8 years; however, if the plant is well managed, it can live and produce until it reaches 8-12 years (Rotundo et al., 1981; Nacional Research Council, 1989; Prohens & Nuez, 2000). The stem is typically divided in three (trifurcate) or two (bifurcate) main branches at a height of 1.1 to 1.8 m. The leaves are large (20-30 cm in length and 15-25 cm in width), simple, unlobed, with an ovate blade and evergreen. Stem leaves (produced at the younger stages of the plant) are considerably larger than the crown leaves (Acosta-Quezada et al., 2011). The inflorescence is branched (scorpioid cyme) with 10-50 flowers (Bohs, 1994). The flower is hermaphrodite and the anther morphology is very particular of the tree tomato and its wild relatives, which belong to *Solanum* section *Pachyphylla* (Bohs, 2007), presenting a dorsally gibbous anther connective that is joined to the two anther thecae. The tree tomato is diploid (2n = 24) and self-compatible (Pringle and Murray, 1991; Bohs, 1994). The fruit is ellipsoidal or ovoid, obtuse or acute at the apex, glabrous, yellow to orange, red, or purple, on occasion with darker longitudinal stripes (Acosta-Quezada et al., 2011; Bohs, 1994). Five cultivar groups, according to the fruit color and shape, are recognized (Acosta-Quezada et al., 2011, 2012): orange, orange pointed, purple, red, and red conical. Seeds are densely pubescent, and each fruit can present from a few (<10) to many (>350) seeds. Characterization with standardized morphological descriptors (Bioversity International et al., 2013) revealed large diversity within each cultivar group for descriptors related with plant height, size and shape leaf, inflorescence length, number of flowers, fruit size and weight, number of fruits/plant, and seeds per fruit (Acosta-Quezada et al., 2011). Despite the availability of these morphological descriptors, no internationally standardized tools exist in tree tomato for precisely determining the phenological stage, which is of great relevance for agronomic and botanical studies (Schwartz, 2013).

The “Biologische Bundesantalt, Bundessortenamt, and Chemische Industrie” (BBCH) numerical scale is a system for a uniform coding of phenologically similar growth stages of plants (Lancashire et al., 1991, Hack et al., 1992; Meier, 2001). The basic BBCH scale consists of a primary and a secondary scale, each of which is subdivided into 10 (0-9) clearly recognizable and distinguishable developmental phases. The primary scale defines the principal stages so that the entire developmental cycle of the plants is covered; the secondary scale is a subsequent division of the principal stages into 10 secondary development stages. An extended scale, which can provide a more detailed description can be established by including 10 mesostages (0-9), which are incorporated between the primary and secondary stages, resulting in a three-digit scale that provides a more detailed description (Meier, 2001).

The basic and extended BBCH scale have been successfully used in many crops, including some solanaceous crops native to the Andean region, like the economically important potato (*Solanum tuberosum* L.) and tomato (*Solanum lycopersicum* L.) (Feller et al., 1995; Hack et al., 1993; Meier et al., 2009), as well as emerging crops of this same region like pepino (*Solanum muricatum* Aiton) and cape gooseberry (*Physalis peruviana* L.) (Herraiz et al., 2015; Ramírez et al., 2013). However, up to now the BBCH scale has not been applied to the tree tomato, which presents some important differences with respect to these Solanaceous crops, like having a tree structure and a much longer period of development and cultivation (8-12 years). The purpose of this work is to establish a standardized BBCH phenological scale for tree tomato, and to validate it for evaluating differences in a set of accessions of this emerging fruit crop.

2. Material and methods

2.1. Plant material, cultivation and climatic conditions

Phenological observations were conducted by the authors since the 1990s in plants cultivated in the Andean region under commercial conditions and in experimental plots, as well as in experimental fields in Valencia (Spain). In particular, a detailed observation was conducted in a tree tomato morphological diversity trial initiated in 2007 in Ecuador. Data were obtained from a collection of 24 accessions of cultivated tree tomato belonging to five cultivar groups: orange, orange pointed, purple, red, and red conical originating in six countries (Acosta-Quezada et al., 2011). This trial was located at the UTPL farm (4º0’1.59’’S and 79º10’48.46’’W) in Loja, Ecuador at 2.160 m of altitude. This area corresponds to the low dry montane forest (bs-MB) formation (Holdridge, 1967), with 15.4 °C mean annual temperature and mean annual rainfall of 780 mm; the soil of the plot is clay loam. Plants were propagated from seed and the planting distance used was 2 x 2 m.

2.2. Tree tomato BBCH scale characteristics

A basic and an extended BBCH phenological scale specific to tree tomato were established according to the BBCH guidelines (Meier, 2001). The complete growth cycle of tree tomato has been subdivided into eight clearly recognizable principal growth stages, including germination (stage 0), stem and crown leaf development (stages 1a and 1b, respectively), formation of side shoots (stage 2), stem elongation (stage 3), inflorescence emergence (stage 5), flowering (stage 6), development of fruit and seed (stage 7), and ripening of fruit (stage 8). The development of harvestable vegetative plant parts or vegetatively propagated organs/booting (stage 4) is not applicable to tree tomato. The BBCH stage 9 was not considered as tree tomato is an evergreen that has no rest period and plantations are removed before plant senescence is evident. Given the particularities of the different development of stem and crown leaves of this species (Acosta-Quezada et al., 2011; Bioversity International et al., 2013), the tree tomato stage 1 (leaf development), has been subdivided depending on the type of leaves in consideration (stem vs. crown leaves) using the letters ‘a’ and ‘b’, respectively (e.g. 11a: first true leaf on stem fully unfolded, and 11b: first true leaf on crown fully unfolded).

The eight principal stages were subdivided into secondary stages ordered from 0 to 9, which can represent an ordinal number or a percentage (1 = 10%, 2 = 20%, etc.). These secondary stages describe specific time points or shorts intervals of development within each principal stage and are used as plant development stages that are precisely indicated, in contrast to the principal growth stages, which are longer developmental steps. The combination between the principal stage number and the secondary stage number results in the basic two digit BBCH scale (Meier, 2001). When the secondary stages are not well-defined with enough precision with the two digit scale, a mesostage from 0 to 9, is included between the principal and the secondary stage to create an additional subdivision generating the extended three-digit BBCH scale (Meier, 2001). For principal stages where the mesostage is not applicable and the extended BBCH scale is used, a 0 is used for the mesostage. The principal growth stages do need necessarily proceed in the strict numerical order of the digits defining the different stages of the basic or extended BBCH, but may also proceed in parallel. If two or more development stages take place in parallel, this can be indicated by using a diagonal stroke to indicate the different stages taking place simultaneously (e.g. 21/51) (Meier, 2001).

2.3. Validation of the tree tomato BBCH scale

The utility of the BBCH scale for the description and detection of differences among agronomically important traits at different precisely defined stages according to the BBCH scale were validated in 24 accessions from five cultivar groups using the Bioversity International et al. (2013) morphological and agronomical characterization descriptors. Traits evaluated included stem length (cm; stage 39 or 309), fruits per plant (stage 89 or 809), fruit length (cm, stage 81 or 801), fruit width (cm, stage 81 or 801) and fruit weight (g, stage 81 or 801), and fruit ripening (stage 85 or 805). For stem length, fruits per plant and fruit ripening after transplant 15 replicates (each plant was considered as a replicate) were considered, while for fruit length, width and weight 75 replicates (each corresponding to an individual fruit from a bulk of fruits harvested from the 15 individual plants evaluated) were measured. For each accession, the average and standard error (SE) were calculated for each trait.

3. Results and discussion

Most economically important *Solanum* crops, like potato, tomato and eggplant (*Solanum melongena* L.) are herbaceous and grown as annual crops. Other minor crops, like pepino, scarlet eggplant (*Solanum aethiopicum* L.) and gboma eggplant (*S. macrocarpon* L.) are also cultivated as annuals (Plazas et al., 2014; Herraiz et al., 2015). Tree tomato, however, is small tree that in the agricultural practice is grown as a fruit tree crop in plantations that normally last for eight to twelve years (Rotundo et al., 1981; Nacional Research Council, 1989; Prohens and Nuez, 2000). In consequence, there are many differences in the plant structure and phenology between tree tomato and other *Solanum* species for which BBCH scales already exist (Feller et al., 1995; Hack et al., 1993; Meier et al., 2009; Herraiz et al., 2015). Therefore, the development of a BBCH scale for tree tomato, rather than adapting the BBCH scale of other *Solanum* crops, was needed.

Although the basic two-digit BBCH scale allows precisely defining most phenological states of tree tomato and other crops (Meier, 2001), for principal developmental stages 2 (formation of side shoots), 5 (inflorescence emergence), 6 (flowering), and 7 (development of fruit) we considered that the basic scale may present some limitations, as it does not allow a precise definition of the phenological stage when more than nine side shoots, inflorescences, flowers or infructescences have been developed. Therefore, we developed an extended three-digit BBCH scale which includes mesostages in order to provide a better description of the aforementioned phenological stages. For the rest of developmental stages the basic and extended BBCH scales are synonymous.

3.1. Principal growth stage 0: germination

The germination principal stage incorporates secondary stages from dry seeds to cotyledons emergence (Table 1). Although tree tomato can be propagated vegetatively, the most common and routine propagation system is by seeds (Prohens and Nuez, 2000). Seeds are flattened and reniform in outline, densely pubescent (including residues of broken cellular walls), and the color is of different brown hues (Bohs, 1994). The seed has a size of 0.3-0.4 cm in length and 0.2-0.3 cm in width (Acosta-Quezada et al., 2011). The germination stage begins with the dry seeds (stage 00 or 000) (Fig. 1) and continues with the complete seed imbibition takes place in the 3rd or 4th day (stage 03 or 003), the radicle emergence from the seed (Fig. 1; stage 05 or 005), the hypocotyl with cotyledons breaking through seed coat (stage 07 or 007) and ends with the emergence of cotyledons through soil surface (Fig. 1; stage 09 or 009). In fresh tree tomato seeds with high vigour all germination stages this developmental stage is usually completed in 14 to 28 days depending on the temperature and the type of germination substrate.

3.2. Principal growth stage 1: leaf development

During the first six to eight months after transplanting the tree tomato plant undergoes a significant vegetative development, in particular a rapid growth of the stem and the development of very large stem leaves. Subsequently, and during the first year there is a stem bi- or (more generally) tri-furcation, either spontaneous or artificially induced by excising the main apex, followed by the development of abundant crown leaves, which are much smaller than stem leaves (Richardson and Patterson, 1993; Clark and Richardson, 2002).

For the principal stage 1 the number of fully developed leaves in the stem or crown determines the phenological stage (Table 2). Leaf development begins when the cotyledons are completely unfolded (stage 10 or 100). The next stages of stem leaves continue with unfolding of the first true leaf on main stem (stage 11a or 101a) and finish when at least nine (stage 19a; basic scale) or all leaves of the main stem (stage 1XYa, where X represents the tens and Y the number of units of the number of leaves of the stem, respectively; extended scale) have fully unfolded. Given that the number of stem leaves is usually around 30-50, this stage can be described using only two to five mesostages in the extended BBCH scale. After the stem leaves have developed and the crown branches have formed, the development of crown leaves begins. This stage begins when the first true leaf on the crown is fully unfolded (stage 11b or 101b) and ends when at least nine (stage 19b; two digit scale) or ninety-nine (stage 109b) crown leaves have been unfolded (Fig. 1).

3.3. Principal growth stage 2: formation of side shoots

This growth stage concerns the formation of side shoots derived from apical buds of the main stem, and which form the crown. This principal growth stage is characterized by a development of two to three primary apical side shoots in the shape of a jorquette, and the respective secondary, tertiary and higher order apical side shoots (Bohs, 1994) (Table 3). Stage 2 begins with the first primary apical side shoot (stage 21 or 201) and occurs simultaneously with stage 5 (Fig. 1), specifically with the first inflorescence visible (see below; stage 51 or 501), and continues with the of subsequent primary side shoots and with the formation of secondary, tertiary and higher order shoots. The first inflorescence is located very close to the branch fork or jorquette and marks the commencement of a differentiating event, which includes a vegetative period characterized by the presence of crown leaves, the beginning of flowering in general and subsequent fructification. The first primary apical side shoots are typically visible 6 to 8 months after transplant (Fig. 1).

3.4. Principal growth stage 3: stem elongation

As mentioned in section 3.2, the tree tomato has a fast growth during the first six to eight months and there is a significant vegetative growth regarding stem length and development of stem leaves. According to Richardson and Patterson (1993) this active development is characteristic from young plants of this species. Young stems are succulent and green, while older stems have smooth, light-colored bark with small lenticels (Bohs, 1994). The internode length usually ranges between 3 and 6 cm (Acosta-Quezada et al., 2011).

Stage 3 begins when the stem presents around three nodes, roughly equivalent to 10% of final stem length (stage 31 or 301) (Fig. 1), and ends when the elongation of the main stem has been completed, generally when the stem develops around 30 nodes (Table 4). For the tree tomato plant, the time required to reach a determined stem length or number of nodes depends on the cultivar group, of the type of cultivation techniques (e.g. pruned), as well on the environmental conditions (Richardson and Patterson, 1993; Prohens and Nuez, 2000).

3.5. Principal growth stage 5: inflorescence emergence

The inflorescence in tree tomato is branched (scorpioid cyme), and each adult plant develops between 15 and 60 inflorescences, each one typically with 10 to 50 flowers arranged in a double series along the axis (Bohs, 1994, Lewis and Considine, 1999a; Acosta-Quezada et al., 2011). The first inflorescence is located very close to the main stem bi- or tri-furcation point, so that the first flower bud visible from this first inflorescence marks the beginning of this differentiation event (stage 51 or 501) (Table 5 and Fig. 1). The number of inflorescences defines the phenological stage code, ending when at least nine (stage 59; basic scale) or all inflorescences (stage 5XY, where X represents the tens and Y the number of units of the number of inflorescences, respectively; extended scale) have fully unfolded. Given that normally less than 100 inflorescences appear in one plant during one year or season (Lewis and Considine, 1999a; Acosta-Quezada et al., 2011) the extended scale can give a precise definition of the inflorescence emergence state. Depending on the climatic conditions flowering can be continuous throughout the year in climates with few seasonal variations or be concentrated in spring (e.g., in Mediterranean climates) (*Calabrese et al.,* 1995; Lewis and Considine, 1999a;).

3.6. Principal growth stage 6: flowering

The flower in tree tomato is pentamer, with the calyx having a radius 0.3-0.5 cm, lobes having 0.1-0.2 cm in length and 0.2-0.3 cm in width. Corolla is pinkish white, stellate, with a radius of 2.0-2.6 cm, petals are narrowly triangular, of 1.0-1.3 cm long, 0.4-0.5 cm wide and acute apex (Bohs, 1994; Acosta-Quezada et al., 2011). The plant is self-compatible and in all probability largely autogamous (Pringle and Murray, 1991); however honey bees and bumble bees visit the flowers and may contribute to cross pollination (Pringle and Murray, 1991; Bohs, 1994).

The principal stage 6 is determined by the opening of the first flower of each inflorescence (Table 6); in this respect, this stage begins with the opening of the first flower in the first inflorescence (stage 61 or 601) (Fig. 1) and continues with the opening of the first flower of subsequent inflorescences (Table 6). As flower opening occurs approximately after the first flower bud is visible stage 6XY takes place five to eight days after stage 5XY.

3.7. Principal growth stage 7: development of fruit

Tree tomato fruit is a fleshy berry with ellipsoidal or ovoid shape having two locules; the development of fruit is accompanied by a color change from green (with or without darker stripes) to yellow, orange, red or purple (Pringle and Murray 1991; Bohs, 1994). As mentioned above, the tree tomato plant develops between 15 and 60 inflorescences, of which between 7 and 30 become infructescences and each one usually produces two to four fruits; although some small fruited cultivars have a much higher number of fruits (up to 15-20 per infructescence) (Acosta-Quezada et al., 2011). The development of fruit (stage 7) begins when the first fruit of the first infructescence, this last equivalent to first inflorescence, reaches the typical size (stage 71 or 701). The time required for reaching the final size after fruit set is variable and depends on the cultivar and climatic conditions, but typically lasts four to five months after anthesis (Heatherbell et al., 1982; Pringle and Murray, 1991).

3.8. Principal growth stage 8: ripening of fruit and seed

According to various authors (Morton, 1982; Bohs, 1994; Prohens and Nuez, 2000; Vasco et al., 2009; Acosta-Quezada et al., 2011) the ripe fruit of most common cultivars and local varieties usually has a size between 4 and 8 cm in length, 3.5 and 6 cm in diameter and a weight between 30-160g. The exocarp (skin) is smooth and glabrous, yellow, orange, red or purple (depending on the variety); usually has dark longitudinal stripes. The mesocarp (pulp) has a mildly acid and sweet taste, and has quite jelly-like flesh around the seeds (yellow, orange or purple according the genotype). The seeds are physiologically developed when the berry show the characteristic ripe colour. Pringle and Murray (1991) indicated that parthenocarpy has not been found in *S. betaceum*, but varieties with fruits with very few seeds exist (Acosta-Quezada et al., 2011).

The fruit requires several months to mature after pollination (Pringle and Murray, 1991; Lewis and Considine, 1999b). Once it has reached final size, the fruit can remain unripe over 3 months on the plant (Heatherbell et al., 1982). In the BBCH scale the ripening of fruit is determined taking into account the percentage of fruits that show the typical ripe colour according the variety, namely yellow, orange, red or purple (Table 8). This stage 8 begins when the 10% of fruits are fully ripe (stage 81 or 801, Fig. 1) and finishes when all fruits are ripe (stage 89 or 809). The stage 81 or 801 typically takes place after 4 to 7 months after the opening of the first flower (stage 61 or 601) and after one to three months after reaching the final size (stage 71 or 701).

3.9. Validation of BBCH scale in tree tomato

The evaluation of some characters of interest for production and marketing through specific BBCH developmental stages allows a precise characterization and differentiation of tree tomato cultivars. Large differences have been found among a set of 24 accessions (Acosta-Quezada et al., 2011) for all traits evaluated at determined basic BBCH scale stages of development (Table 9). Stem length (measured at stage 39) has presented many differences among accessions, from 116 to 163 cm (Table 9). Plant architecture traits, such as stem length, are of interest in the establishment and management of crop plantations (Roos et al., 2005; Turnbull, 2005); and therefore the differences detected may be relevant for selection and breedings. The number of fruits per plant are an indicator of how prolific is each plant material; in this regard, the evaluation of the number of fruits per plant at growth stage 89 allowed detecting significant differences among accessions and even cultivar groups. In this respect, the red conical group had a higher number of fruits per infructescence and per plant than the rest of cultivar groups (Table 9). Many significant differences have been found respect to fruit length, width and weight, measured in the first fruit of the first infructescence that reached the typical size and shape (stage 81) in the materials evaluated (Table 9). Interestingly, all accessions of the Red group had very large fruits, while those of the Red conical were the smaller ones. The fruit size and shape traits have been found to present heritability and highly discriminating among tree tomato accessions (Acosta-Quezada et al., 2011; Bioversity International et al., 2013). Evaluation at this stage has been very useful to identify some accessions, in particular A-21 and A-25 (purple group), A-20 (orange pointed), and A-18 (red), which had the largest and heaviest fruits (Table 9). These accessions may be of interest for international markets, which favour large fruits and diversification in the form of different cultivar groups. Regarding earliness, evaluated as time elapsed from transplant to ripening of about 50% of the fruits (stage 85), again considerable and significant differences have been found (Table 9). The most important difference was found between the orange accession A16 which it is the earliest (365 days) and the red accession A18, which was the latest (545 days).

The phenological characterization at specific stages is relevant for the characterization of varieties and genetic resources of specific crops (Fiorani and Schurr, 2013). The results obtained in the present work reveal that BBCH scales represent useful tools to characterize and describe the different phenological stages of tree tomato, as well as to study the tree tomato diversity.

4. Conclusions

The specific phenological stages of tree tomato according to the BBCH scale have been established for the first time. The specific basic and extended tree tomato BBCH scales allow the description of vegetative and reproductive stages of this crop in different environmental conditions as well as comparing different plant materials evaluated at the same developmental stage. They are also useful for an adequate general orchard management, including different irrigation and fertilizer needs at different developmental stages, for the prevention and control of pests and diseases, as well as for timely planning of harvesting. The specific BBCH scales represent a powerful standardized tool to researchers, agronomists, breeders and germplasm curators, which together with others standard tools like the descriptors for tree tomato published by Bioversity International *et al*. (2013) will contribute to an efficient management, enhancement and breeding of this emerging fruit crop.

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Table 1

Description of the phenological stages of tree tomato principal growth stage 0 (germination) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
00	000	Dry seeds
01	001	Beginning of seed imbibition
03	003	Seed imbibition complete
05	005	Radicle emerged from seed
07	007	Hypocotyl with cotyledons breaking through seed coat
09	009	Emergence: cotyledons break through soil surface

Table 2

Description of the phenological stages of tree tomato principal growth stage 1 (leaf development) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
10	100	Cotyledons completely unfolded
Stem leaf		
11a	101a	1st true leaf on stem fully unfolded
12a	102a	2nd leaf on stem unfolded
13a	103a	3rd leaf on stem unfolded
1.a	10.a	Stages continuous till…
19a	109a	9 or more leaves on stem unfolded (basic scale); 9th leaf on stem unfolded (extended scale)
-	110a	10th leaf on main stem unfolded
-	11.a	Stages continuous till…
-	1XYa	XYth leaf on the main stem unfolded
Crown leaf		
11b	101b	1st true leaf on crown fully unfolded
12b	102b	2nd leaf on crown unfolded
13b	103b	3rd leaf on crown unfolded
1.b	10.b	Stages continuous till…
19b	109b	9 or more leaves on the crown unfolded (basic scale); 9th leaf on crown unfolded (extended scale)
-	110b	10th leaf on crown unfolded
-	11.b	Stages continuous till…
-	1XYb	XYth leaf on crown unfolded

Table 3

Description of the phenological stages of tree tomato principal growth stage 2 (formation of side shoots) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
21	201	1st primary apical side shoot visible
22	202	2nd primary apical side shoot visible
23	203	3rd primary apical side shoot visible
-	221	1st secondary apical side shoot visible
-	22.	Stages continuous till…
-	231.	1st tertiary apical side shoot visible
-	23.	Stages continuous till…
-	2XY	Yth Xth order apical side shoot visible

Table 4

Description of the phenological stages of tree tomato principal growth stage 3 (stem elongation) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
31	301	Stem about 10% of final length
32	302	Stem 20% of final length
33	303	Stem 30% of final length
3.	30.	Stages continuous till…
39	309	Maximum stem length (diameter) reached

Table 5

Description of the phenological stages of tree tomato principal growth stage 5 (inflorescence emergence) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
51	501	1st inflorescence visible
52	502	2nd inflorescence visible
53	503	3rd inflorescence visible
5.	50.	Stages continuous till…
59	509	9 or more inflorescences visible (basic scale); 9th inflorescences visible (extended scale)
-	510	10th inflorescence visible (first flower bud visible)
-	51.	Stages continuous till…
-	5XY	XYth inflorescence visible

Table 6

Description of the phenological stages of tree tomato principal growth stage 6 (flowering) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
61	601	1st inflorescence with first flower open
62	602	2nd inflorescence with first flower open
63	603	3rd inflorescence with first flower open
6.	60.	Stages continuous till…
69	609	9 or more inflorescences with first flower open (basic scale); 9th inflorescence with first flower open (extended scale)
-	610	10th inflorescence with first flower open
-	61.	Stages continuous till…
-	6XY	XYth inflorescence with first flower open

Table 7

Description of the phenological stages of tree tomato principal growth stage 7 (development of fruit) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
71	701	1st infructescence with first fruit having reached final size
72	702	2nd infructescence with first fruit having reached final size
73	703	3rd infructescence with first fruit having reached final size
7.	70.	Stages continuous till
79	709	9 or more infructescences with first fruit having reached final size (basic scale); 9th infructescence with first fruit having reached final size (extended scale)
-	710	10th infructescence with first fruit having reached final size
-	71.	Stages continuous till…
-	7XY	XYth infructescence with first flower open

Table 8

Description of the phenological stages of tree tomato principal growth stage 8 (ripening of fruit and seed) according to the basic (two-digit) and extended (three-digit) BBCH scale.

Two-digit code	Three-digit code	Description
81	801	10% of fruits show typical fully ripe color
82	802	20% of fruits show typical fully ripe color
83	803	30% of fruits show typical fully ripe color
84	804	40% of fruits show typical fully ripe color
85	805	50% of fruits show typical fully ripe color
86	806	60% of fruits show typical fully ripe color
87	807	70% of fruits show typical fully ripe color
88	808	80% of fruits show typical fully ripe color
89	809	Fully ripe: all fruits have typical fully ripe color

Table 9

Means±standard errors (SE) for six traits of agronomic interest measured at specific BBCH scale phenological stages (indicated between square brackets using the basic BBCH scale) in 24 tree tomato (*S. betaceum*) accessions from five cultivar groups. The number of observations on which each mean is based (n) is indicated. Details on the origin of each accession can be consulted in Acosta-Quezada et al. (2011).

Cultivar groups/ accession	Stem length (cm) [39]	Fruits per plant [89]	Fruit length (cm) [81]	Fruit width (cm) [81]	Fruit weight (g) [81]	Fruit ripening after transplant (d) [85]
n	15	15	75	75	75	15
Orange						
A16	128±4.9	38.2±4.4	6.02±0.08	5.00±0.08	83.5±2.2	365±5.7
A22	133±4.9	31.8±3.8	6.75±0.09	5.08±0.03	98.2±2.1	381±4.2
A29	163±3.7	38.4±2.7	6.13±0.08	5.44±0.05	96.4±1.5	590±4.1
Orange pointed						
A17	128±3.4	41.0±5.4	6.74±0.14	4.70±0.09	78.4±1.9	435±7.4
A19	145±3.9	31.8±4.6	6.53±0.07	4.90±0.04	86.3±1.9	438±5.2
A20	148±4.6	20.5±2.1	7.49±0.07	5.88±0.06	139.2±2.3	520±8.8
A23	138±3.3	43.3±4.3	6.21±0.04	4.65±0.03	75.7±1.0	463±7.5
A31	140±2.9	30.7±3.9	5.92±0.18	4.80±0.15	81.3±2.8	500±7.1
A32	129±3.9	41.2±5.2	6.03±0.12	4.39±0.09	63.2±1.4	459±7.0
A33	120±4.5	42.5±5.7	6.18±0.19	4.26±0.13	61.0±2.4	417±5.4
A34	127±4.2	60.7±6.7	6.21±0.05	4.27±0.04	61.4±1.7	401±6.4
A35	137±2.9	55.6±6.0	6.03±0.05	4.06±0.03	54.2±1.0	405±4.0
A36	116±3.2	38.4±4.6	5.50±0.03	4.04±0.03	50.7±0.7	456±6.5
Purple						

A21	138±3.3	20.8±1.9	7.92±0.19	5.97±0.15	154.2±4.8	470±4.8
A25	131±5.7	28.0±2.8	7.03±0.05	5.74±0.04	132.4±1.8	404±3.4
A30	160±5.5	40.9±4.2	6.33±0.04	5.17±0.03	96.8±1.4	373±4.8
A37	151±3.7	54.1±4.6	6.06±0.12	4.68±0.09	75.8±1.2	392±6.0
A39	136±3.7	32.8±3.9	6.48±0.07	5.13±0.05	100.2±2.4	442±5.2
A40	130±1.8	31.3±3.9	5.56±0.06	4.69±0.08	93.5±2.7	462±8.2
Red						
A18	143±3.8	26.9±2.5	7.56±0.18	5.61±0.13	130.5±3.4	545±7.8
A24	130±2.5	22.2±3.1	7.62±0.07	5.51±0.04	123.4±2.4	495±5.5
A26	140±2.9	23.1±1.1	7.58±0.07	5.64±0.04	131.6±2.1	463±7.0
A27	135±2.8	18.3±1.1	7.36±0.05	5.49±0.04	125.5±1.7	494±5.4
Red conical						
A41	146±1.9	160.0±1.6	3.98±0.04	3.74±0.04	30.5±0.8	483±9.8

Fig. 1. Important phenological stages of tree tomato (*Solanum betaceum* Cav.) according to the BBCH scale. Two-digit and three-digit (between brackets) scale codes are indicated. Tables 1-8 show the respective description of each of the phenological stage codes.