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Phenological growth stages of Gaúcho tomato based on the BBCH scale

Eliane Fonseca Cardoso[1], Allan Remor Lopes[2*], Marcelo Dotto[1], Kelli Pirola[3], Camila Moreno Giarola[4]

[1]University Center UNISEP, Dois Vizinhos, Brazil
[2]State University of Western Paraná, Cascavél, Brazil
[3]Federal Technological University of Paraná, Pato Branco, Brazil
[4]Paraná University, Umuarama, Brazil
*Corresponding author, e-mail: allanremorlopes@gmail.com

Abstract

The phenological growth stages of Gaúcho tomato were firstly described here using the BBCH scale. Based on this general scale, tomato gaúcho phenology showed 8 of 10 principal stages: germination, leaf development, formation of side shoots, inflorescence emergency, flowering, fruit development, maturity of fruit and senescence. A practical use of the scale is proposed, with particular reference to harvest time and management treatments. This scale aims to support farmers and researchers to efficiently plan management practices and experimental treatments.

Keywords: Phenology, BBCH growth stages, Morphology, *Lycopersicum esculentum*

Introduction

Tomato cultivation stands out an important economic and social activity, and its the second most produced vegetable in the world (Nasir et al., 2015; Stajcic et al., 2015). Tomato is an important edible plant cultivated in Brazil (Sari et al., 2017). In 2019, 58.166 hectares of tomato plants were cultivated in Brazil, resulting in a production of 4.075.890 tons of fruit (IBGE, 2019).

Tomato has numerous cultivars, with several particular characteristics, which are chosen according to the needs of the farmers. Gaúcho tomato, also known Caqui, has as its characteristic larger fruits, with greater consistency and more acid. However, its phenological description is stil unknown.

The study of periodic biological events such as budbreak, flushing, flowering and fruit development is called phenology. From na agronomic point of view, knowledge of crop phenology is crucial for timing proper management practices such as plant watering and fertilization, pest and weed control, among others (Martínez-Nicolás et al., 2016). Many efforts have been made to observe and document plant phenological phenomena (Zhao et al., 2019).

Despite the availability of these morphological descriptors, no internationally standardized tools exist in Gaúcho tomato for precisely determining the phenological stage, which is of great relevance for agronomic and botanical studies.

The BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) numerical scale, a system for uniform coding of growth stages, has been widely used for describing phenological stages of plants. The BBCH scale has been used to describe the phenological growth stages of numerous horticulturally important plant and tree species (Ramírez et al., 2013;

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Ramírez & Davenport, 2016; Acosta-Quezada et al., 2016; Fadón et al., 2015), and crops (Martínez-Núnez et al., 2019;). This scale is organized into 10 principal growth stages, which in turn are further subdivided into secondary growth stages. The scale describes plant development from germination to senescence.

However, up to now the BBCH scale has not been applied to the tomato Gaúcho. The purpose of this work is to establish a standardized BBCH phenological scale for Gaúcho tomato.

Material and Methods

Study area

The study area was located in Marmeleiro, state of Paraná, Brazil (26° 08' 56" S and 53° 1' 36" O, 654 m a.s.l.), the experiment was carried out from January 23, 2017 to June 8, 2017. The soil is classified as an Latossolo Roxo (EMBRAPA, 2018) and the climate in this site is Cfa, humid subtropical (Aparecido et al., 2016).

Firstly, the site was prepared, fertilizing the soil with 60 kg ha^{-1} N; 350 kg ha^{-1} P and 250 kg ha^{-1} K. After fertilization, four Gáucho tomato seeds were sown. The spacing used was 0.5 m between plants and 1 m between lines.

The first germinations started 5 days after the beginning of the experiment. After germination, the seedlings were thinned, leaving one plant per hole. From germination, observations and records of each stage of development of the plant began, which were recorded through photographs, and the observations were made every day.

After the end of its phenological development cycle, the photographs obtained through the observations were used, making a photographic memorial to characterize each stage of development and the codifications of the stages of germination, growth, flowering and fruiting.

After coding the main and secondary development phases, an illustrative development scale was set up, based on the photographic memorial. Thus, the photographs obtained through the observations served to illustrate some of the codes of the descriptive phenological scale, making it easier to understand, to verify how the crop is at that particular stage of its development.

In this study, eight of tem principal growth stages based on the existing BBCH scale were used to describing tomato Gaúcho, starting with germination (stage 0), leaf development (stage 1), formation of side shoots (stage 2), inflorescence emergency (stage 5), flowering (stage 6), fruit development (stage 7), maturity of fruit (stage 8) and senescence (stage 9). The main secondary growth stages were also described (Muhamed & Kurien, 2017).

Results

The phenological growth stages according to the BBCH scale for Gaúcho tomato are depicted in Table 1 and Figures 1-7 as follows:

Table 1. Phenological growth stages of tomato according to the BBCH scale.

BBCH code	Description	
Principal growth stage 0: Germination		
00	Dry seed	
01	Initiation of seed imbibition	
03	Seed imbibition completed	
05	Radícle emergence from seed	
07	Emergence of hypocotyl with cotyledons from the seed	(Fig. 1A)
09	Emergence of cotyledons through soil surface	(Fig. 1B)
Principal growth stage 1: Leaf development		
10	Cotyledons fully unfolded	(Fig. 2A)
11	First elliptic leaf visible	(Fig. 2B)
12	First pair of true leaves visible	(Fig. 2C)
14	Fourth pair of true leaves visible	(Fig. 2D)
19	Ninth pair of true leaves visible	
27	Side shoots above 70% formed	(Fig. 3A)
Principal growth stage 5: Inflorescence emergency		
51	First inflorence visible, visible closed flower bud	(Fig. 4A)
59	9 or more inflorescences visible	
Principal growth stage 6: Flowering		
60	First flowers open	(Fig. 5A)
61	Beginning of flowering, about 10% of flowers open	(Fig. 5B)
65	Full flowering, at least 50% of flowers open, first petals falling	
69	End of flowering	(Fig. 5C)
Principal growth stage 7: Fruit development		
70	Fruits at the main stem or branches visibles	(Fig. 6A)

Continue…

72	20% of final fruit size	(Fig. 6B)
77	70% of final fruit size	(Fig. 6C)
79	90% or final fruit size	(Fig. 6D)
Principal growth stage 8: Maturity of fruit		
81	10% of fruits show typical fully ripe color	(Fig. 7A)
82	20% of fruits show typical fully ripe color	
83	30% of fruits show typical fully ripe color	(Fig. 7B)
89	Fruit fully ripe for consumption	(Fig. 7C)
Principal growth stage 9: Senescence		
97	All leaves fallen	
99	Post harvest or storage treatments	

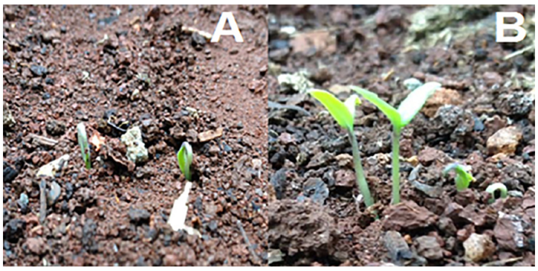

Figure 1. Principal growth stage 0: Germination according to the BBCH scale. (**A**) Stage 07, (**B**) Stage 09

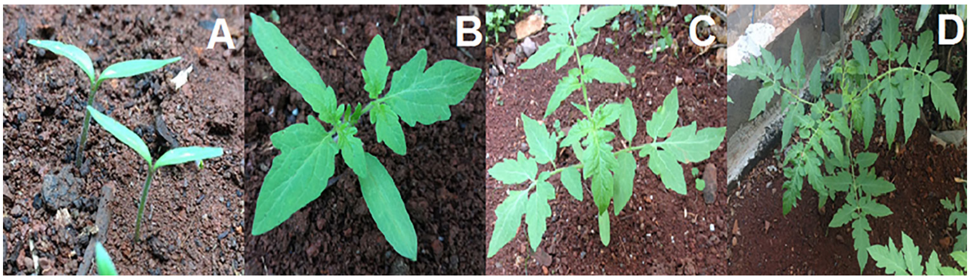

Figure 2. Principal growth stage 1: Leaf development according to the BBCH scale. (**A**) Stage 10, (**B**) Stage 11, (**C**) Stage 12, (**D**) Stage 14.

Figure 3. Principal growth stage 2: Formation of side shoots according to the BBCH scale. Stage 27.

Figure 4. Principal growth stage 5: Inflorescence emergency according to the BBCH scale. Stage 51

Figure 5. Principal growth stage 6: Flowering according to the BBCH scale. (**A**) Stage 60, (**B**) Stage 61, (**C**) Stage 69

Figure 6. Principal growth stage 7: Fruit development according to the BBCH scale. (**A**) Stage 70, (**B**) Stage 72, (**C**) Stage 77, (**D**) Stage 79

Figure 7. Principal growth stage 8: Maturity of fruit according to the BBCH scale. (**A**) Stage 81, (**B**) Stage 83, (**C**) Stage 89

Discussion

Germination

This stage is relevant in crop establishment as any environmental adversity (waterlogging or soil caking) could generate a low plant stand (Awadhwal & Thierstein, 1985; Setter & Waters, 2003). Thus, soil tillage should be done with extreme care.

The germination principal stage incorporates secondary stages from dry seeds to cotyledons emergence. Althrough 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 pubescente, and the color is of different brown hues (Bohs, 1994). The germination stage begins with the dry seeds (stage 0), and continues with the complete seed inbibition takes place in the 3rd or 4th day (stage 3), the radicle emergence from the seed (stage 5), the hypocotyl with cotyledons breaking through seed coat (stage 7, Figure 1A) and ends with the emergence of cotyledons through soil surface (stage 9, Figure 1B).

Leaf development

This stage begins when cotyledons are already full unfolded (stage 10, Figure 2A), and it is determined by the number of visible basal leaves. The number of leaves per plant determines the current principal growth stage (Table 1). The formation of the first pair of true leaves, that develop concomitantly, is coded as stage 11 (Figure 2B). These first 2 leaves have to be scored when longer than 1 cm. On the contrary, leaves of subsequent stages can be considered visible when longer than 2 cm (Martinelli et al., 2014).

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 caracterized 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 (Acosta-Quezada et al., 2016).

Flowering

The stage 6 is determined by the opening of the first flower of each inflorescence (Table 1). Stage 60 is reached when the first blooming flower on the head is visible outside the bracts (Figure 5A). In this respect, this stage begins with the opening of the first flower in the first inflorescence (stage 61, Figure 6A) and continues with the opening of the first flower of subsequente inflorescences (Table 1). Flowering involves a sequence of steps with profound changes, being highly influenced by environmental conditions, and plants have the ability to detect variations in the environment allowing the determination of the event to happen within favorable conditions (Schmidt et al., 2017).

Fruit development

Fruit development occurs as the first fruit begins to enlarge (Ramírez & Davenport, 2019). Gaúcho tomato fruit is a flesh berry with elipsoidal or ovoid shape having two locules, the development of fruit is accompanied by a color change from green to red (Pringle & Murray, 1991).

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 & Murray, 1991).

Maturity of fruit

The maturation stage of the fruit defines the moment of harvest, which is defined by the color. The change in the color of the tomato is due to chlorophyll and carotenoids. The green color of immature fruits is attributed to chlorophyll. At maximum size, an immediate color change follows, beginning of maturation, reflecting the degradation of chlorophyll, which remains in a small amount in the fruit's tissues (Medina & Medina, 1981; Zambon, 1984; Zambrano et al., 1995). The main components of caretoids in tomatoes are carotene (yellow) and lycopene (red), whose synthesis and decomposition are accentuated in the transition phase between fruit ripening and senescence (Zambon, 1984; Zambrano et al., 1995). In tomatoes there is intense chlorophyll degradation during ripening, with gradual synthesis of lycopene (Chitarra & Chitarra, 1990). The red color of the fruits is considered to be an accumulation of lycopene. The mature green stage (beginning of the color change) is considered the first visual symptom for the maturation index (Zambon, 1984). The tomato has round, globose or flat fruits and are typically plurilocular (Ferreira et al., 2004).

Senescence

The fenology of a fruit tree is studied so that the periodicity of its life-cycle can be determined and used in agronomical management. The BBCH scale can provide a more detailed and accurate description of the main phenological events than any of the other coding systems for tomato Gaúcho. When using the BBCH scale, tomato Gaúcho life-cycle can be divided into eight main growth stages: Germination, leaf development, formation of side shoots, inflorescence emergency, flowering, fruit development, maturity of fruit and senescence.

With the BBCH scale the absence of the principal growth stages 3 (shoot development) and 4 (development of harvestable vegetative plant parts). Shoot development proceeds in parallel with leaf developement before inflorescence and flower development (Muhamed & Kurien, 2018).

Tomato is almost always cultivated for its harvestable fruits, although rarely plants may be grown as ornamental. In consequence this main growth stage, which is included in the BBCH scale, is not applicable to the tomato. The absence of principal growth stage 4 has already been observed by Acosta-Quezada et al. (2016)

when studying the tomato tree.

Conclusions

Thus, a standardized phenological scale describing it cycle is mandatory. This study generated a standardized BBCH scale for this crop.

The number of principal stages obtained using the BBCH scale was eight. The tomato BBCH scale represents a standardized tool for researchers, agronomists and breeders.

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