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Phenological description for the initial development stage of five Brazilian native forest species according to BBCH scale

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Abstract

A specific phenological scale designated for each forest species facilitates the standardization of different phenophases encountered during the growth and development of seeds to seedlings. This study is the first to apply the Biologische Bundesanstalt, Bundessortenamt and Chemical Industry scale to describe the phenophases during the initial development of five important Brazilian forest species: *Bauhinia forficata* Link, *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Handroanthus chrysotrichus* (Mart. ex DC.) Mattos, *Handroanthus impetiginosus* (Mart. ex DC.) Mattos and *Tabebuia roseoalba* (Ridl.) Sandwith. Phenological data were collected from experiments conducted across multiple sowing dates between 2022 and 2024 at the Federal University of Itajubá, in Itajubá, Minas Gerais State, Brazil. Two phenophases (main growth stages) were identified and described, that is, stage 0 (germination) and development stage 1 (leaf development), along with 12 sub-stages. The species reached sub-stage 110 (10th visible leaf on the main stem), marking the end of initial development, within approximately 171 days (*H. chrysotrichus*), 184 days (*C. speciosa*) and 190 days (*H. impetiginosus*, *B. forficata* and *T. roseoalba*), with variations observed in the duration of the sub-stages (00-110) in all species. This study highlights the variations in the duration of sub-stages associated with the emergence and vegetative development phenophases across the five forest species studied. The binary codes assigned in this study can be used for multiple purposes, including the standardization and optimization of silvicultural techniques, as well as establishing comparative benchmarks for global warming studies, such as phenological cycle lengthening or shortening.

KEYWORDS
Bauhinia forficata, *Ceiba speciosa*, *Handroanthus* spp., leaf development, phenology, phenophases, *Tabebuia* spp.

1 | INTRODUCTION

Forest species exhibit varying growth rates, physiological and ecological requirements throughout their development stages. The seedling (the developing embryo after emerging from the seed) and the initial development (emergence of the first leaves) stages are particularly sensitive to environmental conditions and, thus, less tolerant of climatic variations and extremes (Fagundes et al., 2024b; Martins

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et al., 2024). For instance, high temperatures during post-germination stages can inhibit plant metabolic processes, including photosynthesis and carbon fixation, thereby reducing photosynthetic efficiency and affecting membrane stability, hormone levels and the production of primary and secondary metabolites (Baath et al., 2020). Such impacts may be exacerbated under future climates, particularly in regions where increasing air temperature, reduced humidity and heterogeneous precipitation patterns are projected (Dias et al., 2024). These conditions are projected in several parts of Brazil, which may further exacerbate evolutionary/adaptive pressures (Gray & Brady, 2016). In other words, amplified physiological and metabolic changes over time can lead to significant shifts in phenology.

Phenology (Greek *phaínō* = to appear, *logos* = knowledge) is the study of the timing of biological events in plants and their interactions with biotic and abiotic factors. By analyzing phenology and phenological patterns, researchers can gain a deeper understanding of species-specific developmental patterns and environmental demands. This understanding is vital for improving forest management practices, advancing seedling production technologies and developing strategies for the conservation and management of forest species (Adiga et al., 2019; Konan et al., 2023).

Over the past few decades, there has been a growing emphasis on observing and documenting plant phenological events, highlighting the need for a uniform standard to describe these events (Adiga et al., 2019). Typically, this description is based on a coding system of letters and numbers (or just numbers) that identify each stage (or sub-stage) of plant development, known as a phenological scale. In this context, the Biologische Bundesanstalt, Bundessortenamt and CHemical industry (BBCH) scale (Meier, 2018) is the most widely adopted and utilized worldwide.

The BBCH scale offers a simple and uniform coding system for identifying the developmental stages of both monocotyledonous and dicotyledonous plants (Meier, 2018). Its wide applicability extends beyond phenological descriptions to encompass various plant management practices in nurseries and fields. These include pest and disease control (B. G. Silva et al., 2023), weed control (Baccin & Moretti, 2024), pruning and thinning (Monteiro et al., 2021) and fertilizer application (Prysiazhniuk et al., 2022). By assigning specific numerical codes to each phenophase, the scale enables nursery managers to visually identify sub-stages in the field and plan the allocation of labour and inputs more accurately for those requiring greater care, such as stages with high thermal demand. This approach reduces waste and aligns management practices with the phases of vegetative development. As a result, it directly contributes to more efficient resource utilization and increased productivity during the initial stages of forest seedling production (Martins et al., 2024; Romero-Marcano et al., 2023).

Although the BBCH scale is mostly applied to annual crops and economically important ornamentals, it has also been adapted for perennial species (Finn et al., 2007). In recent years, studies focusing on forest species have increased, including those performed for *Anacardium occidentale* L. (Adiga et al., 2019), *Eugenia uniflora* L., *Psidium cattleianum* Afzel. ex Sabine, *Eugenia involucrata* DC., *Plinia cauliflora* (DC.) Berg, *Eugenia myrcianthes* (Nied.), *Myrcianthes pungens* (O. Berg.) D. Legrand, *Campomanesia xanthocarpa* (O. Berg.), *Campomanesia guazumifolia* (Cambess.) O. Berg. (Guollo et al., 2020), *Vitellaria paradoxa* subsp. *paradoxa* (Konan et al., 2023), *Prunus persica* (L.) Batsch (Verma et al., 2023), *Mangifera indica* L. (Hernández Delgado et al., 2011), *Moringa oleifera* Lam. (Singh et al., 2021), *Tamarindus indica* L. (Kishore et al., 2022) and *Tecoma stans* (L.) Juss. ex Kunth (Rana et al., 2023) considering development and reproductive growth stages. However, studies focusing on the phenological description of the initial development of forest species are still scarce, with the study by Martins et al. (2024) being the only one to date. Studies of this nature are crucial, especially given the growing demand for seedlings of native species to meet the goals of large-scale restoration programs (Fagundes et al., 2024a).

Brazil is home to a vast diversity of native forest species, currently estimated at approximately 7900 species (SNIF, 2019). Among these, five species of significant ecological, economic and environmental importance stand out: *Bauhinia forficata* Link, *Ceiba speciosa* (A. St.-Hil.) Ravenna, *Handroanthus chrysotrichus* (Mart. ex DC.) Mattos, *Handroanthus impetiginosus* (Mart. ex DC.) Mattos and *Tabebuia roseoalba* (Ridl.) Sandwith (Figure 1). These forest species occur naturally across various Brazilian biomes, including the Atlantic Forest, Cerrado and Caatinga, which are particularly vulnerable to biodiversity loss under anticipated future climates (Fagundes et al., 2024b).

Bauhinia forficata (Fabaceae; pata-de-vaca, bauínia, unha-de-vaca) is a pioneer to early secondary species, heliophilous, semi-deciduous and of moderate growth (~10 m in height) (Carvalho, 2003). Given its great medicinal potential, it is listed in RENISUS, the Portuguese acronym for the National List of Medicinal Plants of Interest to the Brazilian Unified Health System. Its leaves have well-documented hypoglycaemic, antioxidant, hepatoprotective and diuretic properties, with demonstrated efficacy in managing type II diabetes mellitus (Dimer et al., 2024). Its wood, with a density of 0.66 g cm^{-3}, is used for various timber and lumber purposes such as joinery, construction, carpentry and for making charcoal, firewood and cellulose (Carvalho, 2003).

Ceiba speciosa (Malvaceae; paineira, barriguda, árvore-de-paina) is a pioneer, heliophilous, deciduous species with quick to moderate growth (~30 m in height). Its light wood (0.22 to 0.34 g cm^{-3}) is widely used for making canoes, troughs, furniture linings, manufacturing model airplanes and crates, as well as for cellulose pulp production. The fruit is a dehiscent capsule that has seeds trapped inside a species of cotton called 'paina', which is used for filling cushions, blankets and pillows. Its leaves, flowers, bark and resin are traditionally used in folk medicine to treat hernias, liver conditions and burns (Roveri Neto & Paula, 2017).

H. chrysotrichus (Bignoniaceae; ipê-amarelo-cascudo, ipê-felpudo, pau-d'arco-amarelo), *H. impetiginosus* (Bignoniaceae; ipê-roxo-de-bola, ipê-roxo, pau-d'arco-roxo) and *T. roseoalba* (Bignoniaceae; ipê-branco, ipê-do-cerrado; piuxinga) are secondary, heliophilous, deciduous trees with slow to moderate growth (~30–35 m in height). They are valued for their ornamental potential due to their vibrant flowers and are frequently used in afforestation and landscaping projects

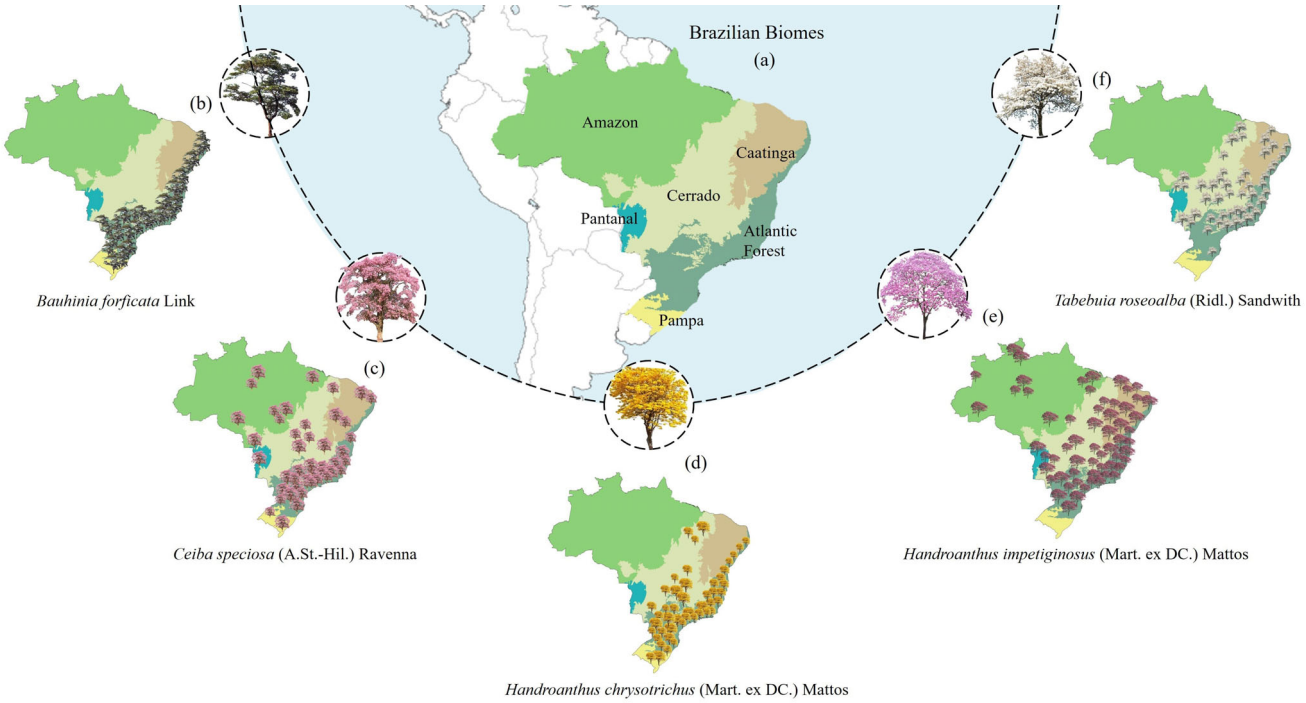


FIGURE 1 Brazilian biomes (IBGE, 2019) (a) and distribution of the five forest species in the respective biomes (data available at https://specieslink.net): *Bauhinia forficata* (b), *Ceiba speciosa* (c), *Handroanthus chrysotrichus* (d), *Handroanthus impetiginosus* (e) and *Tabebuia roseoalba* (f).

(Carvalho, 2003, 2006; Vieira et al., 2016). Ecologically, their flowers provide food for insects, birds and small mammals (P. A. Silva et al., 2021). These species are also recognized as unconventional food plants and are used in high-end restaurants, often in salads or as fried dishes (Kinupp & Lorenzi, 2021). These trees are recommended for the ecological restoration of degraded areas and are highly regarded in the timber industry, especially in construction, due to their desirable properties, such as high-density wood (0.58–1.08 g cm^{-3}) and durability (Carvalho, 2003, 2006).

Unfortunately, unsustainable logging, extraction and illegal trade led to significant population decline in *H. impetiginosus* and *T. roseoalba*. As a result, they are classified as near threatened species by the International Union for Conservation of Nature's Red List (IUCN, 2021) and included in appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2023), alongside other species of the genera *Handroanthus* Mattos and *Tabebuia* Gomes ex DC. This inclusion necessitates regulatory protection and additional measures, beyond those already implemented in forest management projects, aimed at reducing exploitation and illegal trade.

Given the critical ecological, economic and environmental importance of these species and the lack of phenological studies on their initial development stage, this study aimed to adapt the BBCH scale to describe the phenophases of initial development for *B. forficata*, *C. speciosa*, *H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba*. These phenological scales are expected to support more efficient silvicultural management practices by guiding nursery planning and interventions, as well as facilitating the monitoring of seedling developmental progress under varying weather and environmental conditions.

2 | MATERIALS AND METHODS

2.1 | Field experiment and data description

The phenological data used in this study included the dates of seed sowing, cotyledon emergence and leaf emergence, along with images and the occurrence dates of each stage/sub-stage of development. Leaves were counted weekly once they reached 1.0 cm in length (visible leaf) (Fagundes et al., 2024a; Martins et al., 2024), starting from the emergence date (EM) until the end of the initial development stage (*n*) for each forest species. All data were obtained from experiments conducted between June 2022 and February 2024. EM was defined as the date when the seeds germinated and became visible above ground (Table 1), while *n* was marked specifically by the appearance of the 10th leaf on the main stem. Both thresholds were determined in preliminary experiments to establish the minimum emergence rate for seed samples and the criteria for the end of the initial development. Additionally, morphological characteristics of each species were observed at each stage of development (or leaf emergence).

The field experiments were conducted in the experimental area of the Federal University of Itajubá, Itajubá, Minas Gerais State, Brazil. Itajubá is the natural occurrence site of the studied forest species and has a typical monsoon climate, with two well-defined seasons: dry

TABLE 1 Emergence rate (%), seed characteristics, storage duration and collection site of *Bauhinia forficata*, *Ceiba speciosa*, *Handroanthus chrysotrichus*, *Handroanthus impetiginosus* and *Tabebuia roseoalba* seeds used in this study and in preliminary experiment.

Sample	Emergence rate[a] (%)	Minimum value for EM[b] (%)	1000 seed weight[c] (g)	Storage duration[d] (days)	Collection site (municipality, state)
Bauhinia forficata					
A1	48.3	24.2	113.0	333	Santa Maria, Rio Grande do Sul State
A2	65.8	32.9		205	
Ceiba speciosa					
A1	60.0	30.0	94.9	1428	Rio das Pedras, São Paulo State
A2	71.7	35.9		256	Porto Feliz, São Paulo State
A3	94.2	47.1		353	Itajubá, Minas Gerais State
Handroanthus chrysotrichus					
A1	11.7	5.9	10.3	193	Santa Maria, Rio Grande do Sul State
A2	10.8	5.4		312	Itajubá, Minas Gerais State
Handroanthus impetiginosus					
A1	48.3	24.2	104.3	1002	Lavras, Minas Gerais State
A2	53.3	26.7		231	Seropédica, Rio de Janeiro State
A3	20.8	10.4		295	Itajubá, Minas Gerais State
Tabebuia roseoalba					
A1	70.8	35.4	13.4	204	Porto Feliz, São Paulo State
A2	20.8	10.4		270	Itajubá, Minas Gerais State

[a]Emergence rate was obtained in the preliminary experiment, defined as the stage when the radicle breaks through the substrate and the cotyledons emerge above the soil surface, visibly observable from any viewing angle (Biezus et al., 2017).
[b]Minimum emergence rate value used to define the emergence date (EM).
[c]Average weight of 1000 seeds (Felix et al., 2018; Lopes et al., 2007; Maeda & Matthes, 1984; Missio et al., 2021).
[d]Seed storage duration, counted from the date of collection to the date on which the preliminary experiments were conducted. The seeds were not subjected to any dormancy-breaking treatment.

autumn and winter (from April to September) and humid spring and summer (October to March) (Fagundes et al., 2024a) (Figures 1 and 2).

The seeds used in this study were sourced from various Brazilian locations, collected at different dispersal times and kindly provided by both Brazilian public institutions and private companies. Additionally, seeds collected in Itajubá were used. The use of seeds from multiple locations and different matrices (isolated and embedded) aimed to encompass a broad range of geographical gradients and genetic conditions, which are important for adapting the phenological scale. It is important to highlight that the seed collections of native forest species were disrupted during the Covid-19 pandemic, resulting in difficulties obtaining a diversity of available seed samples for seedling production and for conducting this study.

The experiments were conducted in a completely randomized design, with five forest species (*B. forficata*, *C. speciosa*, *H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba*), grown in 8-L white polyethylene pots (24.0 cm × 20.5 cm × 20.0 cm), on 14 sowing dates (SDs) installed at an interval of approximately 30 days, totalling 40 pots per SD. The use of multiple SDs ensures seed emergence and subsequent development under a wide range of weather conditions (Fagundes et al., 2024b) (Table 2).

The pots were filled with moderate type A horizon subsoil of a Rhodic Hapludox Oxisol (Santos et al., 2018), collected in Itajubá, Minas Gerais. The soil contained 18.2 g kg^{-1} organic matter, 0.66 mg dm^{-3} P and 15.3 mg dm^{-3} K. Approximately 30 days before each SD, acidity and fertility corrections were made following the Soil Fertility Commission of Minas Gerais (CFSEMG, 1999), Evaristo et al. (2020) and Freitas et al. (2017), by applying 1.96 g of calcium carbonate ($CaCO_3$) and 0.65 g of magnesium carbonate ($MgCO_3$) per pot. Between 60 and 120 days after sowing, top dressing was applied with 0.8 g of ammonium sulphate ($[NH_4]_2SO_4$), 1.2 g of potassium chloride (KCl) and 1.2 g of simple superphosphate (18% P, 16% Ca and 10% S) per pot. The plants were grown outdoors in pots under a 50% shade screen made of black high-density polyethylene mesh, suspended 3 m above ground level. Shading was designed to replicate standard operational conditions commonly used in Brazilian forest nurseries, thereby minimizing excessive solar radiation that could induce stress in developing seedlings. Water loss was quantified using a gravimetric method based on daily pot weighing (Abreu et al., 2022). Except on rainy days, daily irrigation was performed by replenishing water lost to evapotranspiration, ensuring optimal soil moisture and fertilization, following the container-grown plant method described by Fagundes et al. (2024a, 2024b).

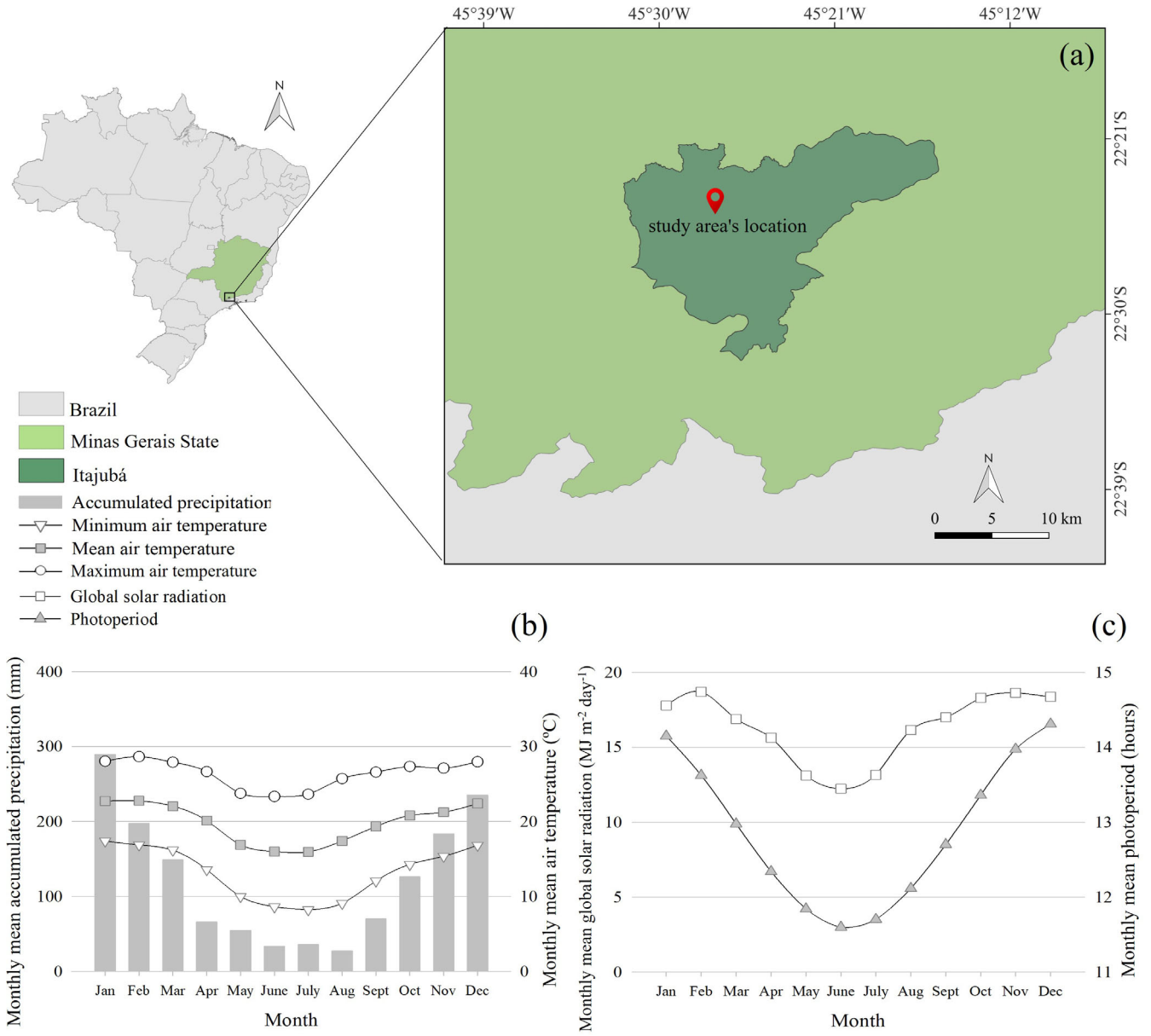


FIGURE 2 Study area location (a) and monthly climatological means for accumulated precipitation (mm month^{-1}), air temperature (minimum, mean and maximum, °C) (b), global solar radiation (MJ m^{-2} day^{-1}) and photoperiod (hours) (c) for Itajubá, Minas Gerais State, Brazil. The monthly means were calculated from 1985 to 2014 using high-resolution weather data (0.25° × 0.25° latitude/longitude) available at https://utexas.app.box.com/v/Xavier-etal-IJOC-DATA (Xavier et al., 2016).

2.2 | Adapting the BBCH scale for five native Brazilian forest species

In this study, the BBCH scale was adapted to describe the initial development stages of five native forest species (Table 3). The BBCH scale employs a two-digit code, with the first digit representing the main growth stage and the second digit indicating subsequent sub-stages (up to the 10th leaf).

Images were taken at each stage described in Table 3. To create the phenological scale adapted for the five species, these images were analysed alongside the occurrence (time and date) of each development stage and its corresponding BBCH code. The duration (in days) of each stage for each species was determined by averaging the duration of the pots across all SDs. The duration of each sub-stage was analysed using the one-way variance analysis test, followed by the least significant difference test (LSD). Both tests were used to detect whether the duration differed among the stages of each forest species. The hypotheses tested were: H0 = the sub-stage duration values do not differ among phenophases ($p \geq 0.05$) versus H1 = the sub-stage duration values differ among phenophases ($p < 0.05$).

TABLE 2 Sowing, emergence and end of initial development stage dates for forest species—*Bauhinia forficata*, *Ceiba speciosa*, *Handroanthus chrysotrichus*, *Handroanthus impetiginosus* and *Tabebuia roseoalba*—from experiments conducted in Itajubá, Minas Gerais, Brazil.

	Sowing date (SD) (month day, year)		Emergence date[a] (EM) (month day, year)	End date[b] (*n*) (month day, year)
B. forficata	SD1	June 14, 2022	July 8, 2022	December 2, 2022
	SD2	July 15, 2022	August 5, 2022	January 26, 2023
	SD3	August 16, 2022	September 2, 2022	February 22, 2023
	SD4	September 16, 2022	October 17, 2022	February 22, 2023
	SD5	October 17, 2022	November 1, 2022	March 31, 2023
	SD6	November 14, 2022	November 24, 2022	May 3, 2023
	SD7	December 16, 2022	December 26, 2022	May 26, 2023
	SD8	January 17, 2023	January 30, 2023	August 4, 2023
	SD9	February 15, 2023	February 27, 2023	September 8, 2023
	SD10	March 15, 2023	March 22, 2023	September 29, 2023
	SD11	April 17, 2023	May 5, 2023	November 17, 2023
	SD12	May 16, 2023	June 5, 2023	November 17, 2023
	SD13	June 19, 2023	July 7, 2023	January 5, 2024
	SD14	July 13, 2023	August 4, 2023	January 26, 2024
C. speciosa	SD1	June 14, 2022	June 29, 2022	December 2, 2022
	SD2	July 15, 2022	July 29, 2022	January 4, 2023
	SD3	August 16, 2022	September 2, 2022	January 12, 2023
	SD4	September 16, 2022	October 7, 2022	February 15, 2023
	SD5	October 17, 2022	October 27, 2022	March 15, 2023
	SD6	November 14, 2022	November 28, 2022	June 7, 2023
	SD7	December 16, 2022	December 23, 2022	June 30, 2023
	SD8	January 17, 2023	January 27, 2023	September 15, 2023
	SD9	February 15, 2023	February 22, 2023	September 1, 2023
	SD10	March 15, 2023	March 22, 2023	October 13, 2023
	SD11	April 17, 2023	April 28, 2023	November 17, 2023
	SD12	May 16, 2023	June 2, 2023	November 10, 2023
	SD13	June 19, 2023	July 7, 2023	December 15, 2023
	SD14	July 13, 2023	August 4, 2023	December 8, 2023
H. chrysotrichus	SD1	June 14, 2022	July 15, 2022	December 2, 2022
	SD2	July 15, 2022	August 22, 2022	December 21, 2022
	SD3	August 16, 2022	September 23, 2022	February 2, 2023
	SD4	September 16, 2022	October 21, 2022	February 8, 2023
	SD5	October 17, 2022	November 7, 2022	March 1, 2023
	SD6	November 14, 2022	December 5, 2022	April 12, 2023
	SD7	December 16, 2022	January 2, 2023	May 10, 2023
	SD8	January 17, 2023	February 6, 2023	August 4, 2023
	SD9	February 15, 2023	March 1, 2023	August 18, 2023
	SD10	March 15, 2023	April 12, 2023	September 1, 2023
	SD11	April 17, 2023	May 2, 2023	November 3, 2023
	SD12	May 16, 2023	June 7, 2023	November 10, 2023
	SD13	June 19, 2023	August 7, 2023	January 12, 2024
	SD14	July 13, 2023	August 14, 2023	December 1, 2023
H. impetiginosus	SD1	June 14, 2022	July 18, 2022	December 2, 2022
	SD2	July 15, 2022	August 1, 2022	January 19, 2023
	SD3	August 16, 2022	September 9, 2022	February 2, 2023

TABLE 2 (Continued)

	Sowing date (SD) (month day, year)		Emergence date[a] (EM) (month day, year)	End date[b] (*n*) (month day, year)
	SD4	September 16, 2022	October 10, 2022	March 1, 2023
	SD5	October 17, 2022	November 1, 2022	March 15, 2023
	SD6	November 14, 2022	November 28, 2022	June 2, 2023
	SD7	December 16, 2022	December 23, 2022	June 7, 2023
	SD8	January 17, 2023	February 1, 2023	August 18, 2023
	SD9	February 15, 2023	March 1, 2023	August 25, 2023
	SD10	March 15, 2023	March 31, 2023	September 15, 2023
	SD11	April 17, 2023	May 5, 2023	November 10, 2023
	SD12	May 16, 2023	June 23, 2023	November 17, 2023
	SD13	June 19, 2023	July 28, 2023	January 12, 2024
	SD14	July 13, 2023	August 18, 2023	January 12, 2024
T. roseoalba	SD1	June 14, 2022	July 12, 2022	December 2, 2022
	SD2	July 15, 2022	August 10, 2022	January 19, 2023
	SD3	August 16, 2022	September 16, 2022	February 15, 2023
	SD4	September 16, 2022	October 18, 2022	February 22, 2023
	SD5	October 17, 2022	November 7, 2022	March 22, 2023
	SD6	November 14, 2022	December 5, 2022	May 3, 2023
	SD7	December 16, 2022	December 28, 2022	May 26, 2023
	SD8	January 17, 2023	February 8, 2023	August 25, 2023
	SD9	February 15, 2023	March 1, 2023	September 8, 2023
	SD10	March 15, 2023	April 6, 2023	September 29, 2023
	SD11	April 17, 2023	May 10, 2023	November 10, 2023
	SD12	May 16, 2023	June 12, 2023	November 24, 2023
	SD13	June 19, 2023	August 4, 2023	January 19, 2024
	SD14	July 13, 2023	August 21, 2023	January 26, 2024

[a]The emergence date was taken when the seeds reached the minimum germination rate defined in preliminary experiments (see Table 1).
[b]The end date was taken when the plants emerged 10 leaves on the main stem.

3 | RESULTS

Based on phenological observations of the initial development of the five species (*B. forficata*, *C. speciosa*, *H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba*) in the field experiments, we identified and described the two principal stages and their respective sub-stages according to the BBCH scale. The plants developed under different weather conditions across different SDs (Figure 3).

Weather conditions varied during the experiments, influencing plant development among the SDs. Accumulated precipitation ranged from 124.8 to 1635.4 mm per SD, with an average air temperature of 20.6°C, ranging from 3.4°C (minimum absolute) to 38.1°C (maximum absolute). Global solar radiation ranged from 1.8 MJ m^{-2} day^{-1} (minimum) to 34.9 MJ m^{-2} day^{-1} (maximum) and the photoperiod ranged from 11.6 h (minimum) to 14.3 h (maximum). In general, the lowest average air temperature values occurred in SD9 and SD10 (~March to September) and the highest during SD13 and SD14 (October to January). The highest (lowest) accumulated precipitation occurred in SD5 and SD6 (October to March) (and SD9 and SD10, March to September), coinciding with the coldest (hottest) and rainiest (driest) months. These values align with the climatological means for precipitation, temperature and global solar radiation for Itajubá (Fagundes et al., 2024a, 2024b).

3.1 | Principal growth stage 0: Germination

All five species have orthodox seeds, that is, desiccation-tolerant and undergo maturation drying to achieve a moisture content of <15% before being dispersed by the mother plant (Missio et al., 2021; Ranganathan & Groot, 2023). These seeds exhibit a slow loss of vigour and can generally be stored for extended periods, ranging from 6 months to 2 years, under low temperature (<5°C) and humidity (<50%) conditions (Mayrinck et al., 2019). Furthermore, these seeds exhibit epigeal

TABLE 3 Codification and description adapted for the phenophases of five Brazilian native forest species (*Bauhinia forficata*, *Ceiba speciosa*, *Handroanthus chrysotrichus*, *Handroanthus impetiginosus* and *Tabebuia roseoalba*) during initial development stages.

Original code	Original description	Adapted code	Adapted description
Principal growth stage 0: germination			
0	Dry seed	00-09	Dry seed to emergence (cotyledons above the soil surface)
1	Beginning of seed imbibition		
3	Seed imbibition complete		
5	Radicles emerged from the seed		
7	Plumule emerged from seed (plumule apparent)		
8	Plumule growing toward the soil surface		
9	Emergence: emerges through the soil surface		
Principal development stage 1: leaf development			
10	Pair of visible cotyledons completely unfolded horizontally	10	Pair of visible cotyledons completely unfolded horizontally
11	First leaf unfolded	11	1st visible leaf on the main stem
12	Two leaves	12	2nd visible leaf on the main stem
13	Three leaves	13	3rd visible leaf on the main stem
14	Four leaves	14	4th visible leaf on the main stem
15	Five leaves	15	5th visible leaf on the main stem
16	Six leaves	16	6th visible leaf on the main stem
17	Seven leaves	17	7th visible leaf on the main stem
18	Eight leaves	18	8th visible leaf on the main stem
19	Nine or more leaves unfolded	19	9th visible leaf on the main stem
		110	10th visible leaf on the main stem

Note: Adapted from Cavalcante et al. (2020) and Martins et al. (2024). A visible leaf was considered as one with a leaf blade ≥1.0 cm long.

germination, where the hypocotyl elongates in an arch, breaking through the soil and lifting the cotyledons and enclosed plumule into the air (Nautiyal et al., 2023). This stage describes the germination period from dry seed (sub-stage 00, Figures 4a, 5a, 6a, 7a, 8a) to the emergence of the radicle and development of the cotyledons (sub-stage 09, Figures 4b, 5b,c, 6b, 7b, 8b and Table 4).

The five species differ in the duration of the germination stage, according to the LSD test (±9 days), ranging from ∼14 days (*C. speciosa*) to ∼27 days (*H. chrysotrichus*).

3.2 | Principal development stage 1: Leaf development

The principal development stage 1 (codes 09–110) marks the beginning of vegetative development. From code 09 onwards, the cotyledon pair becomes visible and unfolds horizontally. At this stage, photosynthetic activity begins, carried out by the green cotyledons (Buffon et al., 2022; Nautiyal et al., 2023) (Figures 4c, 5d, 6c, 7c, 8c). This stage is followed by the opening of the eophylls, that is, the first expanded leaf or the first pair of leaves with a green blade (codes 11 and 12). The duration of principal development stage 1 ranged from 144 days (*H. chrysotrichus*) to 173 days (*B. forficata*).

3.2.1 | *Bauhinia forficata*

In *B. forficata*, the eophylls are unifoliate with alternate phyllotaxis, that is, one leaf per node, arranged distichously (new leaf positioned 180° to the previous leaf). The eophylls do not differ morphologically from the metaphylls (adult leaves), displaying a bifid laminar organ, divided into two parts by an incision that does not exceed half the length of the laminar organ (Gonçalves & Lorenzi, 2011), resembling the shape of a cow's foot (Figure 4e–g).

As development progresses through subsequent sub-stages (codes 11–110), the leaves turn a dark green colour (Figure 4f,g). The main stem is tapered and flexible, with a slow diameter growth (according to experimental observations). Spines (stipules transformed into spines; Ye & Craene, 2024) were observed at the base of the petioles.

When the plants reach 10 leaves on the main stem (code 110), they have an average height of ∼22.4 cm (above the ground) but remain fragile with minimal support from the main stem. There is a difference in the duration of the development sub-stages (codes 00-09 to 110) for *B. forficata*. Sub-stage 09-11 (emergence—first visible leaf on the main stem) had the shortest duration (7 days), while the sub-stages 16 and 17 (6th and 7th visible leaves on the main stem) had the longest durations (31 and 24 days, respectively).

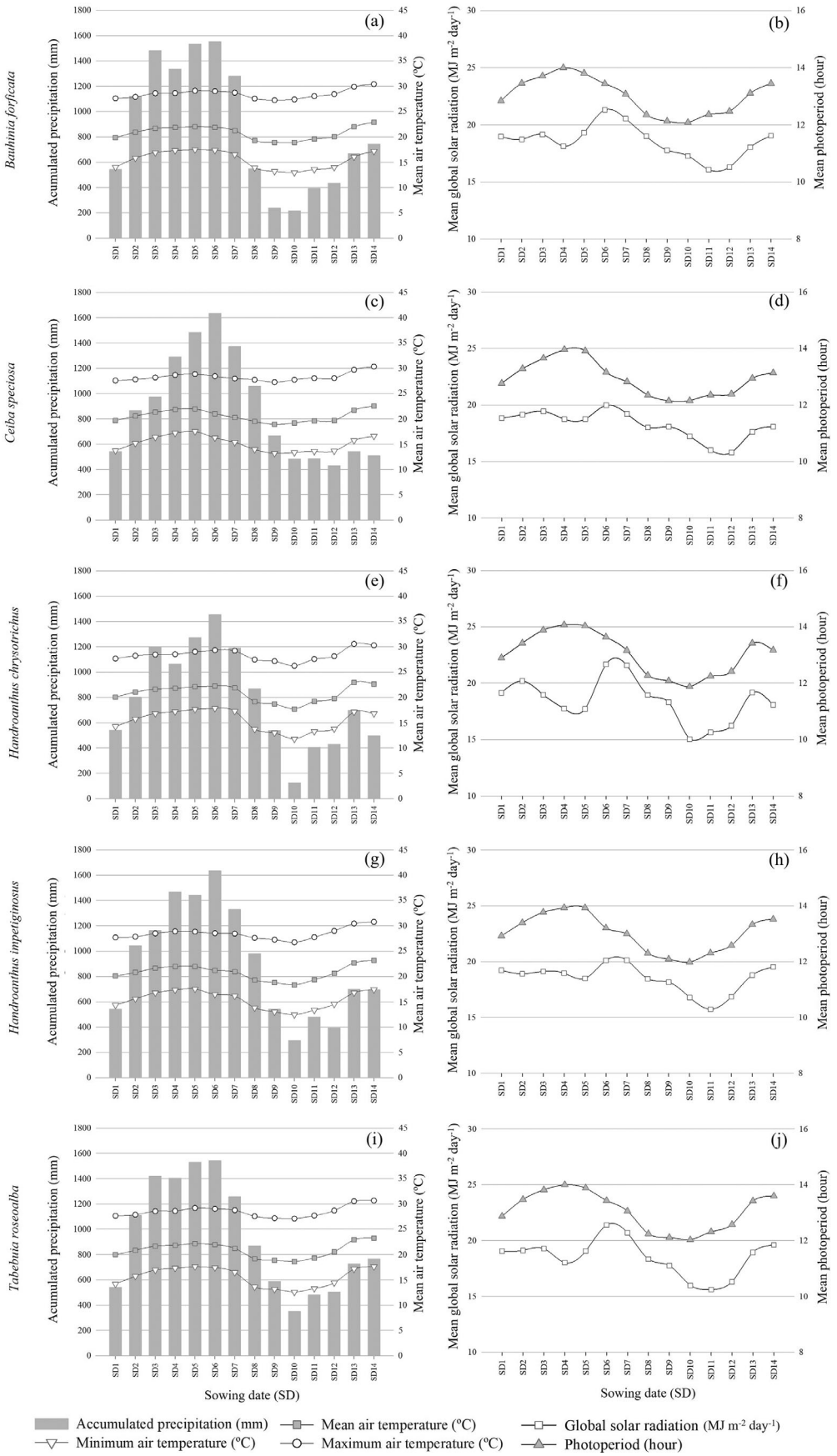


FIGURE 3 Variation in accumulated precipitation per sowing date (mm SD^{-1}), air temperature (°C, minimum, mean and maximum), global solar radiation (MJ m^{-2} day^{-1}) and mean photoperiod (hours) for each sowing date (SD) for five native forest species: (a, b) *Bauhinia forficata*, (c, d) *Ceiba speciosa*, (e, f) *Handroanthus chrysotrichus*, (g, h) *Handroanthus impetiginosus* and (i, j) *Tabebuia roseoalba* from experiments conducted in Itajubá, Minas Gerais, Brazil. The weather variables were taken using an automatic weather station located at the experimental area.

3.2.2 | *Ceiba speciosa*

C. speciosa has unifoliolate eophylls arranged in an alternating tristate pattern, that is, one leaf per node, arranged in three rows along the stem, with an angle of 120° between the leaves (Gonçalves & Lorenzi, 2011). The eophylls and metaphylls are digitate compound leaves, with a limb divided into independent leaflets, where the veins radiate from a single point at the base, resembling the palm of the hand (Carvalho, 2003), ranging from 3 to 7 leaflets (Figure 5e–g).

C. speciosa exhibits rapid development/growth compared to the other species studied, with a duration of ∼170 days from emergence (code 09) to the emergence of the 10th leaf (code 110). The base of the stem and main root thicken within the first few months (∼3 months after sowing). By approximately 150 days, the first prickles appear on the stem, which are hard, pointed epidermal structures without vascularization (Zhou et al., 2021) (Figure 5g). The plants reach 10 leaves in ∼184 days (code 110) with an average height of 31.0 cm.

There is a difference in the duration of the development sub-stages (00-09 to 110) for *C. speciosa*. The 09-11 sub-stage (emergence—first visible leaf on the main stem) had the shortest duration (10 days), while the sub-stages 14 and 15 (fourth and fifth visible leaves on the main stem) had the longest duration (25 and 23 days, respectively).

3.2.3 | *Handroanthus chrysotrichus*

In *H. chrysotrichus* the eophylls and metaphylls are arranged in opposite and decussate patterns, that is, two leaves emerge at a node and are positioned oppositely at a 90° angle to subsequent pairs (Gonçalves & Lorenzi, 2011) (Figure 6d–g). The first leaves are simple, with a hairy limb (trichomes) on both sides and serrated edges (Carvalho, 2006). The main stem and its branches are tapered and hairy. Compound leaves (digitate with three leaflets) were observed from the emergence of the fourth pair (seventh and eighth leaves). Juvenile individuals of this species characteristically exhibit digitate leaves with 3–5 leaflets (Frigieri et al., 2016). Generally, the plants reached 10 leaves (code 110) on the main stem at ∼171 days, with an average height of 10.6 cm and small leaves (∼5.0 cm) (Figure 6g).

The species shows differences in the duration among the development sub-stages (00-09 to 110). The 09-12 sub-stage (emergence—first pair of visible leaves on the main stem) was the shortest duration, lasting 13 days, while the 16 sub-stage (third pair of visible leaves on the main stem) was the longest, lasting 44 days.

3.2.4 | *Handroanthus impetiginosus*

H. impetiginosus displays opposite eophylls and metaphylls and a decussate leaf arrangement, similar to *H. chrysotrichus*. The stem is tapered, and the first leaves are simple with serrated edges (Carvalho, 2003). Compound leaves (digitate with three leaflets) emerge from the third and fourth pairs of leaves (Figure 7f,g). At later developmental stages, the plant produces digitate compound leaves with five leaflets (Vieira et al., 2016); however, this characteristic was not observed during this study period. The plants reach the end of the initial development (10th leaf) in ∼188 days (code 110) with an average height of 15.2 cm.

The species exhibits differences in the duration of the development sub-stages (00-09 to 110), with the 09-12 sub-stage (emergence—first pair of visible leaves on the main stem) having the shortest duration (14 days), while the 16 sub-stage (third pair of visible leaves on the main stem) had the longest duration (48 days).

3.2.5 | *Tabebuia roseoalba*

T. roseoalba also features a pair of opposite eophylls with a decussate leaf arrangement. The leaves are simple, with serrated edges and a tapered stem (Carvalho, 2003) (Figure 8), unlike juvenile individuals, which exhibit digitate compound leaves with 3 leaflets (Frigieri et al., 2016). The species does not have compound leaves at sub-stages 11–110. The plants reach the end of initial development (code 110) in ∼193 days, with an average height of ∼11.5 cm. There is also a difference in the duration of the development sub-stages (00-09 to 110), with the 09-12 sub-stage (emergence—first pair of visible leaves on the main stem) having the shortest duration (14 days), while the 16 sub-stage (third pair of visible leaves on the main stem) had the longest duration (57 days). This behaviour is similar among the three species of ipês studied (*H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba*).

4 | DISCUSSION

The BBCH scale provides a standardized, bi-numeric coding system that allows for the precise and comparable description of distinct phenophases across plant species. In this study, the phenophases of the five forest species were described using bi-digit codes, following the modified BBCH scale proposed by Cavalcante et al. (2020) and Martins et al. (2024).

The life cycle of a seed-propagated plant begins with the germination process, which is defined as the metabolic activation of the seed after hydration, culminating in embryonic development and the rupture or protrusion of the radicle through the seed coat (Buffon et al., 2022; Nautiyal et al., 2023). This stage starts when the seeds are still dry (code 00) and ends when the cotyledons emerge above the soil surface and become visible to the naked eye (code 09). The five species studied differed in the duration of the germination process, which can be attributed to the intrinsic characteristics of each species, such as their temperature and humidity requirements. Moreover, factors like seed quality can also influence the germination time for each species. Even when a seed lot exhibits high viability, as demonstrated by germination percentage, some individual seeds may still fail to germinate under favourable environmental conditions due to endogenous factors. Among these, embryo dormancy stands out, characterized by small and still-developing embryos that require

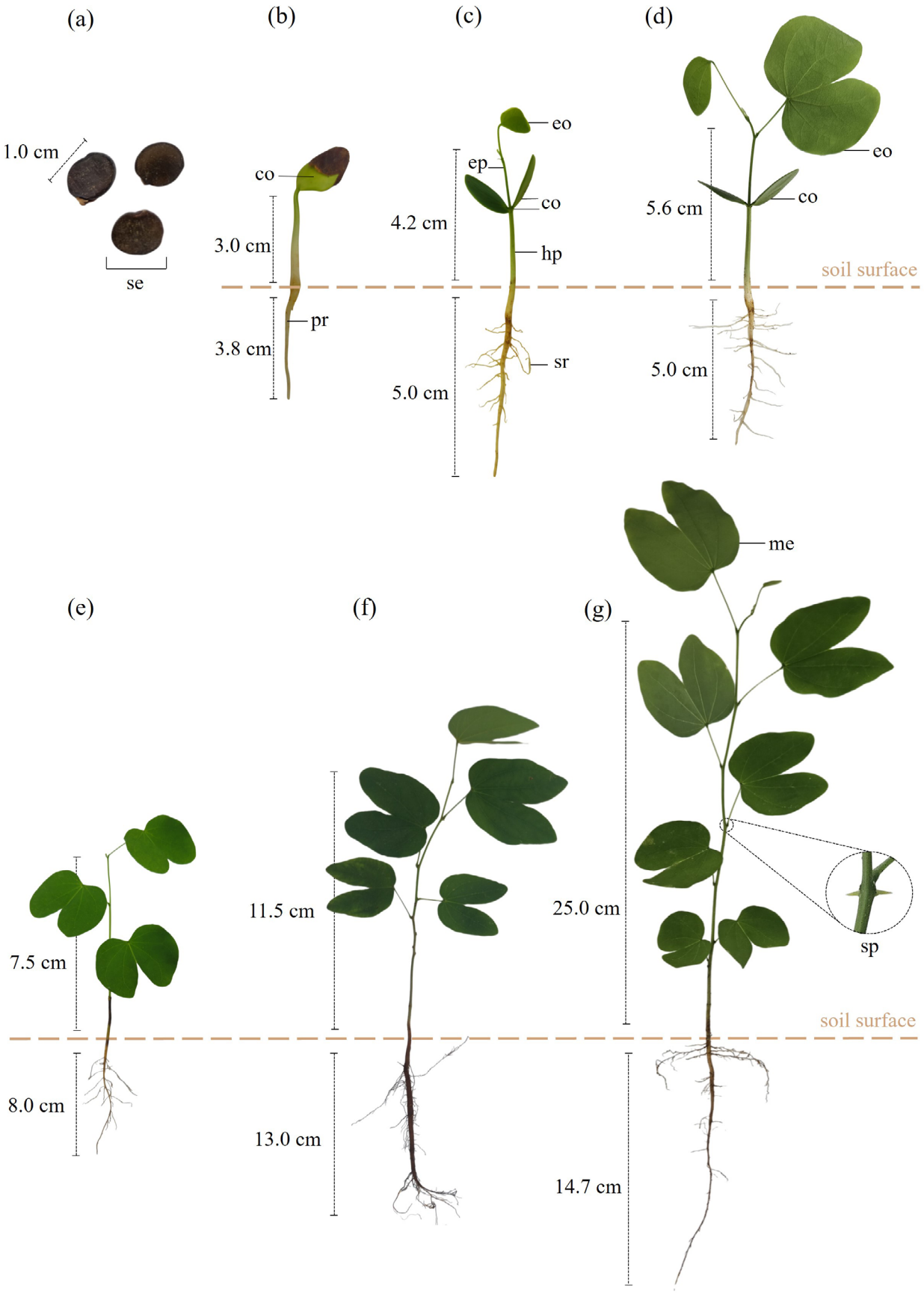


FIGURE 4 Morphology of the two main growth stages—germination and initial development of the forest species *Bauhinia forficata* (co, cotyledon; eo, eophyll; ep, epicotyl; hp, hypocotyl; me, metaphyll; pr, primary root; se, seed; sp, spines; sr, secondary root).

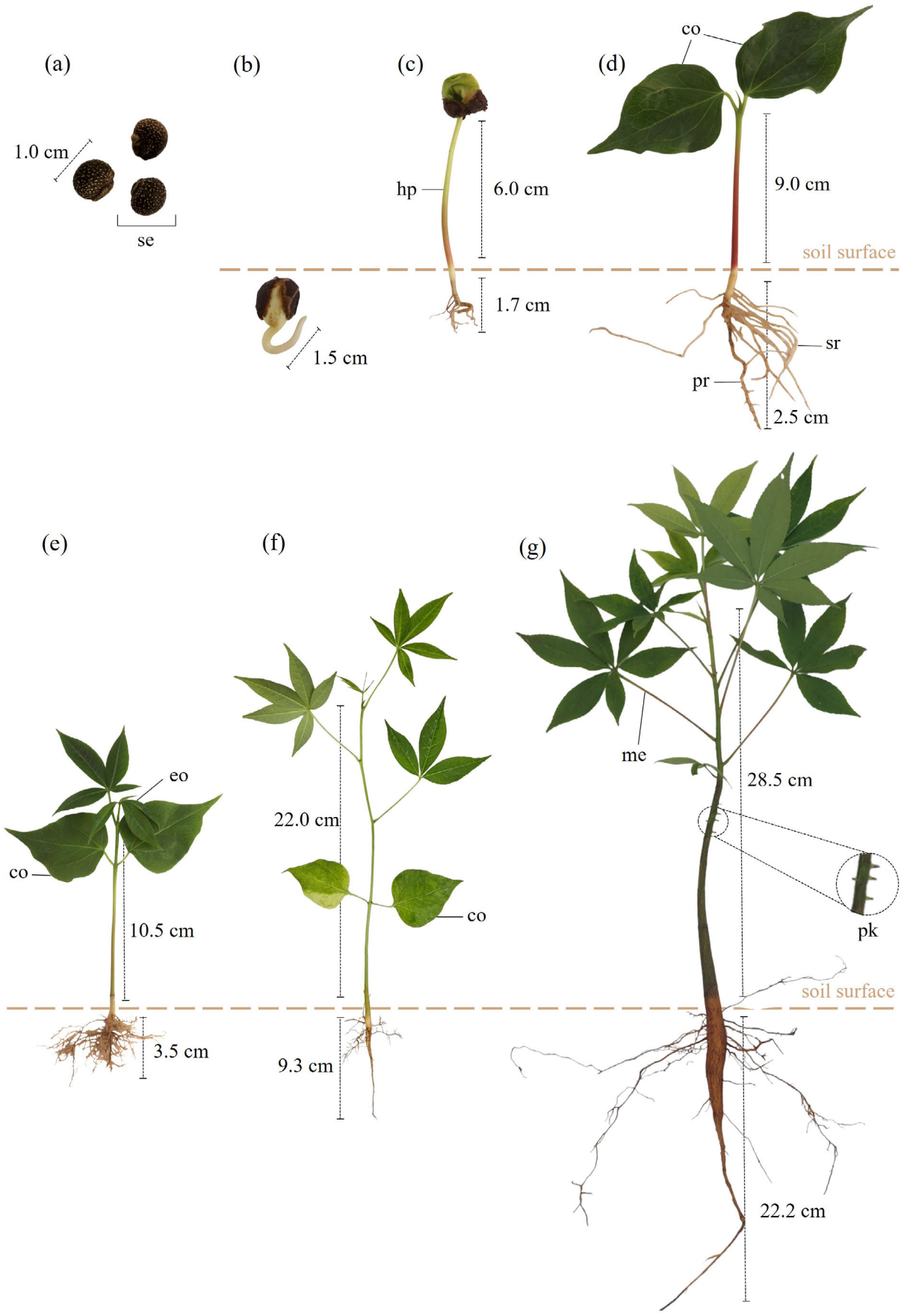


FIGURE 5 Morphology of the two main growth stages—germination and initial development of the forest species *Ceiba speciosa* (co, cotyledon; eo, eophyll; hp, hypocotyl; me, metaphyll; pk, prickles; pr, primary root; se, seed; sr, secondary root).

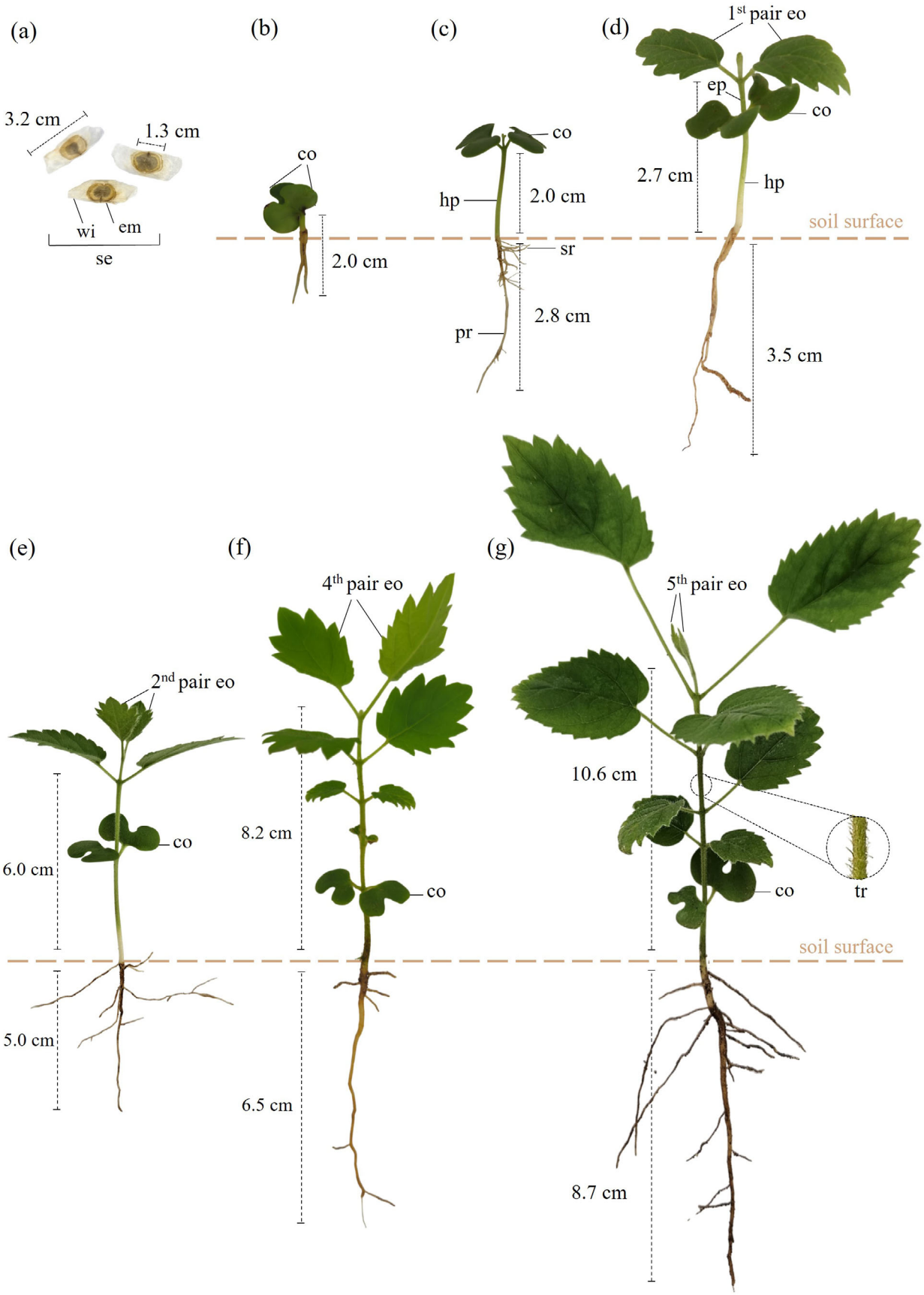


FIGURE 6 Morphology of the two main growth stages—germination and initial development of the forest species *Handroanthus chrysotrichus* (co, cotyledon; em, embryo; ep, epicotyl; hp, hypocotyl; pair eo, pair of eophylls; pr, primary root; se, seed; sr, secondary root; tr, trichomes; wi, wing).

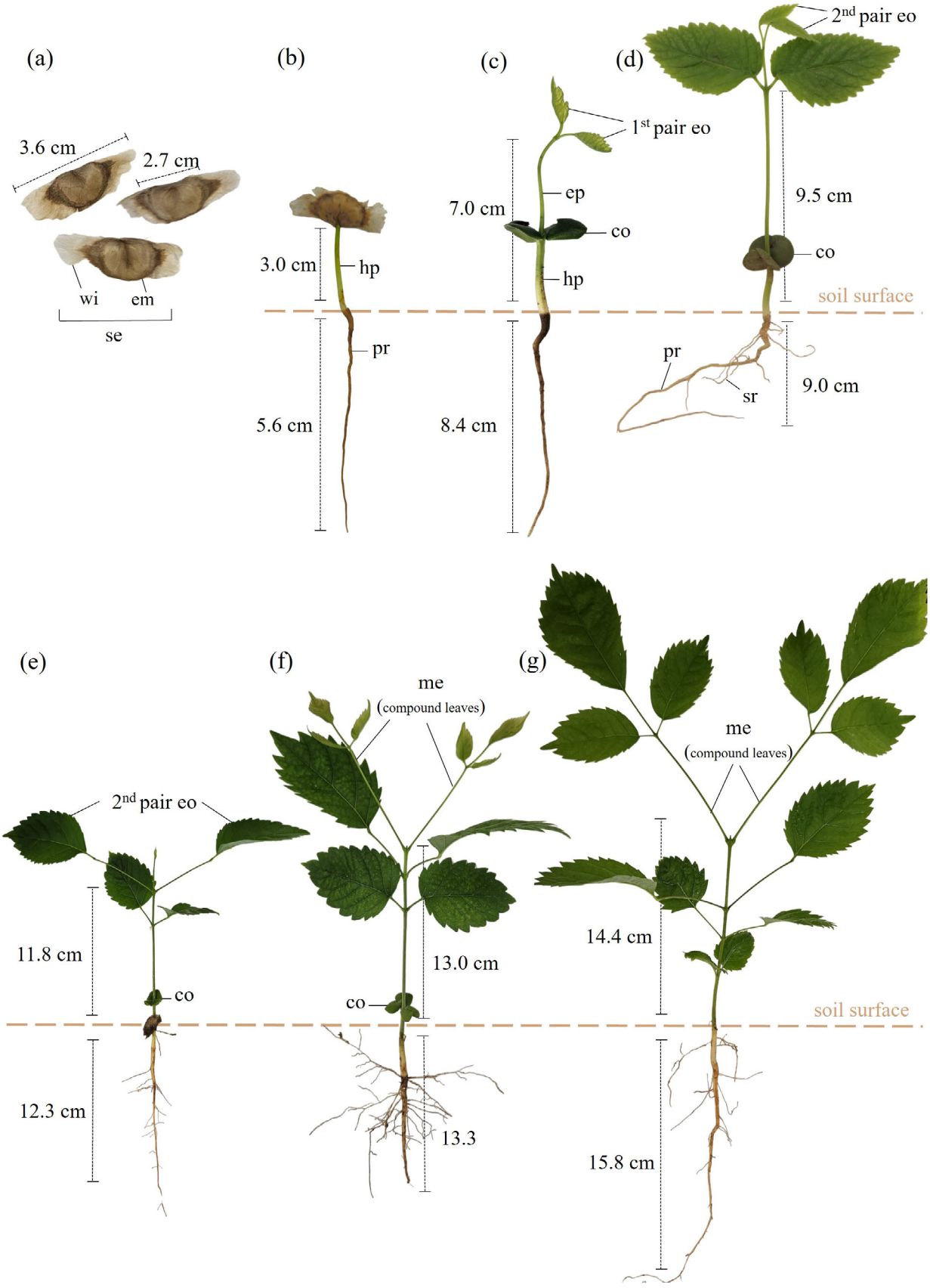


FIGURE 7 Morphology of the two main growth stages—germination and initial development of the forest species *Handroanthus impetiginosus* (co, cotyledon; em, embryo; ep, epicotyl; hp, hypocotyl; me, pair of metaphylls; pair eo, pair of eophylls; pr, primary root; se, seed; sr, secondary root; wi, wing).

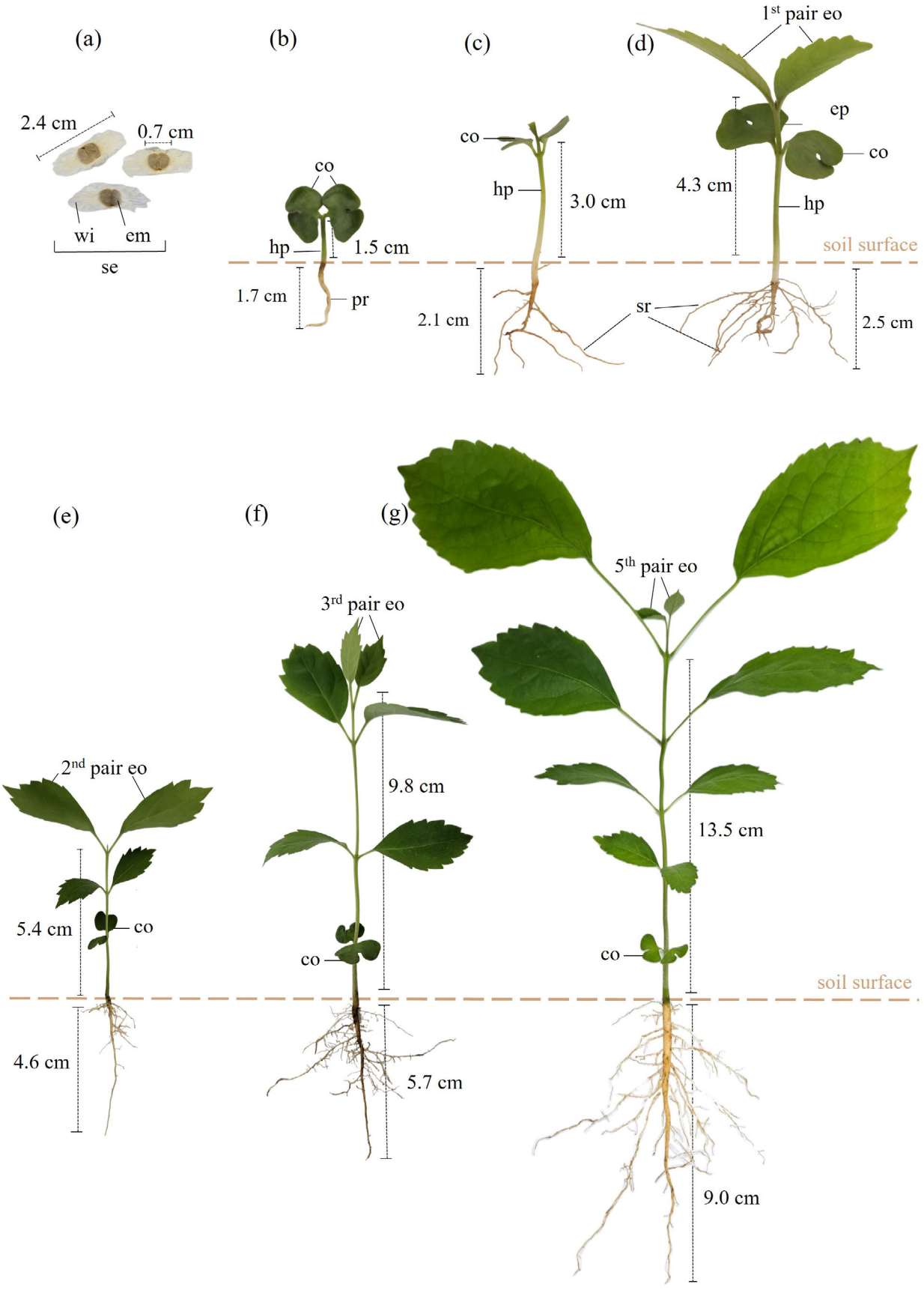


FIGURE 8 Morphology of the two main growth stages—germination and initial development of the forest species *Tabebuia roseoalba* (co, cotyledon; em, embryo; ep, epicotyl; hp, hypocotyl; pair eo, pair of eophylls; pr, primary root; se, seed; sr, secondary root; wi, wing).

TABLE 4 Adapted BBCH scale, mean and total durations (days) of phenophases for the five Brazilian forest tree species (*Bauhinia forficata*, *Ceiba speciosa*, *Handroanthus chrysotrichus*, *Handroanthus impetiginosus* and *Tabebuia roseoalba*).

Bauhinia forficata				
Code	**Sub-stage description**		**Duration (days) ± standard deviation**	**Days after sowing[a]**
Principal growth stage 0: germination				
00-09	Dry seed to emergence (cotyledons above the soil surface)	(Figure 4a,b)	17 (±6)	17
Principal development stage 1: leaf development				
09-11	Emergence—1st visible leaf in the main stem	(Figure 4c)	7 (±3)	24
12	2nd visible leaf on the main stem	(Figure 4d)	10 (±5)	34
13	3rd visible leaf on the main stem	(Figure 4e)	11 (±5)	45
14	4th visible leaf on the main stem		17 (±10)	62
15	5th visible leaf on the main stem	(Figure 4f)	19 (±12)	81
16	6th visible leaf on the main stem		31 (±16)	112
17	7th visible leaf on the main stem		24 (±9)	136
18	8th visible leaf on the main stem	(Figure 4g)	18 (±7)	154
19	9th visible leaf on the main stem		17 (±7)	171
110	10th visible leaf on the main stem		20 (±5)	191
Total duration of the initial development stage			191	
LSD 5%[b]			11.2	
Ceiba speciosa				
Code	**Sub-stage description**		**Duration (days) ± standard deviation**	**Days after sowing[a]**
Principal growth stage 0: germination				
00-09	Dry seed to emergence (cotyledons above the soil surface)	(Figure 5a–d)	14 (±5)	14
Principal development stage 1: leaf development				
09-11	Emergence—1st visible leaf in the main stem		10 (±4)	24
12	2nd visible leaf on the main stem	(Figure 5e)	15 (±5)	39
13	3rd visible leaf on the main stem		17 (±8)	56
14	4th visible leaf on the main stem	(Figure 5f)	25 (±19)	81
15	5th visible leaf on the main stem		23 (±19)	104
16	6th visible leaf on the main stem		16 (±7)	120
17	7th visible leaf on the main stem		16 (±6)	136
18	8th visible leaf on the main stem		15 (±4)	151
19	9th visible leaf on the main stem	(Figure 5g)	16 (±6)	167
110	10th visible leaf on the main stem		17 (±9)	184
Total duration of the initial development stage			184	
LSD 5%[b]			12.2	
Handroanthus chrysotrichus				
Code	**Sub-stage description**		**Duration (days) ± standard deviation**	**Days after sowing[a]**
Principal growth stage 0: germination				
00-09	Dry seed to emergence (cotyledons above the soil surface)	(Figure 6a–c)	27 (±10)	27
Principal development stage 1: leaf development				
09-12	Emergence—2nd visible leaf on the main stem (1st pair of simple and opposite leaves)	(Figure 6d)	13 (±4)	40
14	4th visible leaf on the main stem (2nd pair of simple and opposite leaves)	(Figure 6e)	26 (±9)	66
16	6th visible leaf on the main stem (3rd pair of simple and opposite leaves)		44 (±18)	110

TABLE 4 (Continued)

Code	Sub-stage description		Duration (days) ± standard deviation	Days after sowing[a]
Handroanthus chrysotrichus				
18	8th visible leaf on the main stem (4th pair of simple and opposite leaves)	(Figure 6f)	28 (±16)	138
110	10th visible leaf on the main stem (5th pair of simple and opposite leaves)	(Figure 6g)	33 (±15)	171
Total duration of the initial development stage			171	
LSD 5%[b]			14.4	
Handroanthus impetiginosus				
Code	**Sub-stage description**		**Duration (days) ± standard deviation**	**Days after sowing[a]**
Principal growth stage 0: germination				
00-09	Dry seed to emergence (cotyledons above the soil surface)	(Figure 7a,b)	22 (±10)	22
Principal development stage 1: leaf development				
09-12	Emergence—2nd visible leaf in the main stem (1st pair of simple and opposite leaves)	(Figure 7c)	14 (±4)	36
14	4th visible leaf on the main stem (2nd pair of simple and opposite leaves)	(Figure 7d,e)	22 (±8)	58
16	6th visible leaf on the main stem (3rd pair of simple or compound and opposite leaves)	(Figure 7f)	48 (±19)	106
18	8th visible leaf on the main stem (4th pair of simple or compound and opposite leaves)	(Figure 7g)	42 (±20)	148
110	10th visible leaf on the main stem (5th pair of simple or compound and opposite leaves)		40 (±15)	188
Total duration of the initial development stage			188	
LSD 5%[b]			15.7	
Tabebuia roseoalba				
Code	**Sub-stage description**		**Duration (days) ± standard deviation**	**Days after sowing[a]**
Principal growth stage 0: germination				
00-09	Dry seed to emergence (cotyledons above the soil surface)	(Figure 8a–c)	26 (±9)	26
Principal development stage 1: leaf development				
09-12	Emergence—2nd visible leaf on the main stem (1st pair of simple and opposite leaves)	(Figure 8d)	14 (±4)	40
14	4th visible leaf on the main stem (2nd pair of simple and opposite leaves)	(Figure 8e)	31 (±12)	71
16	6th visible leaf on the main stem (3rd pair of simple and opposite leaves)	(Figure 8f)	57 (±15)	128
18	8th visible leaf on the main stem (4th pair of simple and opposite leaves)		36 (±12)	164
110	10th visible leaf on the main stem (5th pair of simple and opposite leaves)	(Figure 8g)	29 (±8)	193
Total duration of the initial development stage			193	
LSD 5%[b]			11.8	

Note: LSD 5% of sub-stage 00-09 among the five species: 9.0.
[a]Total duration (days) from sowing to the respective stage.
[b]LSD 5% indicates the least significant difference among groups (or means) at a 5% probability.

additional time to reach full maturity. In addition, the presence of biochemical inhibitors, such as abscisic acid (ABA) when produced in high concentrations by the embryo, or chemical inhibitors such as phenolic compounds present in the pericarp or seed coat, can also hinder germination (Bewley & Black, 1994; Ranganathan & Groot, 2023).

Notably, the differences observed in the germination of the five species may be linked to the storage time of some samples used in this study. For example, samples (A2) of *H. chrysotrichus* and *T. roseoalba* stored for 312 and 270 days, respectively, showed low emergence rates: 11.7% and 20.8% (Table 1). Both species have orthodox seeds, with high reserve content that is gradually consumed through aerobic respiration during storage and germination (Ranganathan & Groot, 2023). As storage duration increases and seeds undergo aging, the respiratory quotient (RQ), defined as the ratio of carbon dioxide produced to oxygen consumed, tends to rise, indicating intensified respiratory activity. This physiological process leads to accelerated depletion of energy reserves, particularly carbohydrates and lipids (Ranganathan & Groot, 2023; Zhang et al., 2021). In other words, even though the seeds presented characteristics favorable to longevity and were stored under optimal conditions (or as close to ideal as possible), the longer storage time may have affected the emergence and speed of germination in these two species.

Seed aging or deterioration is an irreversible, cumulative and inexorable process that can cause the accumulation of cellular damage, resulting in delayed seedling emergence, reduced ability to withstand thermal and water stresses and loss of viability (Ranganathan & Groot, 2023). Although minor deterioration may still allow for embryonic root protrusion, it can cause seedling abnormalities such as deformations in the radicle, cotyledon and hypocotyl (Ranganathan & Groot, 2023). In this study, seedlings with visible deformations or deficiencies were excluded from the phenological observations and analyses.

The transition between the main growth stages 0 and 1 is critical for seedling establishment, as this period is when they are most susceptible to biotic and abiotic agents, such as pests and diseases and sensitive to climate variations, particularly temperature (Nautiyal et al., 2023). From the appearance of the cotyledons above the ground (code 09), the first true leaves emerge and the frequency of leaf emergence and phyllotaxis reflects the development and growth patterns of forest species (Martins et al., 2024). For example, this study identified that during initial development, *B. forficata* and *C. speciosa* prioritize the growth of the already emerged leaf before the emergence of the subsequent leaf. Furthermore, both species are taller when they reach sub-stage 110 (emergence of the 10th leaf). However, *B. forficata* prioritizes leaf growth over stem growth. Therefore, planting this species is not recommended when it reaches sub-stage 110. In contrast, *C. speciosa* exhibits characteristics suitable for planting, such as firm stems and a height corresponding to the standard recommended for the definitive planting of forest species (20–30 cm) (Carvalho, 2003; Oliveira et al., 2016).

On the other hand, the species *H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba* prioritize leaf development before subsequent leaf growth (and height), emerging leaves more slowly, particularly in sub-stages 16, 18 and 110. These three species take ~49, 35 and 34 days to emerge the 6th, 8th and 10th leaves and an average of 184 days to complete the initial development stages (00–110). Furthermore, definitive planting is not recommended since these species have an average height of <15 cm at sub-stage 110. Definitive planting for urban afforestation and landscaping is recommended when plants reach between 20 and 30 cm in height, while in forest environments, a minimum height of 50 cm is recommended for seedlings (Oliveira et al., 2016).

It is worth emphasizing that growth and development are interrelated processes that may or may not occur simultaneously. While leaf growth involves an irreversible increase in the physical dimensions of leaves (e.g., area, length and width), development refers to ontogenetic processes at different levels of organization, such as cell differentiation, organ initiation (organogenesis) and appearance (morphogenesis) and extends to crop senescence (Fagundes et al., 2024a).

The adaptation of the BBCH scale proposed in this study provided a greater understanding of the development and growth patterns of five important forest species of the Brazilian flora that have been experiencing significant population declines. By focusing on initial development, this understanding can guide producers in selecting forestry and silvicultural practices to optimize seedling production (Martins et al., 2024). Moreover, the BBCH scale is advantageous compared to other scales due to its simplicity and adaptability to forest species (Finn et al., 2007; Martins et al., 2024) and to different phases of the growth cycle and development stages. Finally, the use of the BBCH scale allowed for the standardization of communication between forestry professionals and researchers, providing a uniform and detailed system for describing (and comparing) the five forest species studied.

5 | CONCLUSION AND FINAL REMARKS

This study presents the first BBCH scale adapted to describe the initial development of five Brazilian forest species: *B. forficata* Link, *C. speciosa* (A.St.-Hil.) Ravenna, *H. chrysotrichus* (Mart. ex DC.) Mattos, *H. impetiginosus* (Mart. ex DC.) Mattos and *T. roseoalba* (Ridl.) Sandwith. The BBCH phenological scale was adapted and coupled to images to identify two main stages: growth stage 0 (germination) and development stage 1 (leaf development) along with 12 sub-stages (codes 00-09 to 110).

The species reached sub-stage 110 (10th visible leaf on the main stem), marking the end of initial development, at approximately 171 days (*H. chrysotrichus*), 184 days (*C. speciosa*) and ~190 days (*B. forficata*, *H. impetiginosus* and *T. roseoalba*), with differences in the duration of the sub-stages (00–110) in all species. The scale proposed

for *B. forficata*, *C. speciosa*, *H. chrysotrichus*, *H. impetiginosus* and *T. roseoalba* has practical applications, providing helpful information for standardizing and optimizing silvicultural techniques. In addition, it is a tool that can be used to assess climate change in the development of these species.

New studies should incorporate meteorological requirements, such as temperature, solar radiation, photoperiod, or shading levels, into describing the phenological scale for the initial development of forest species.

AUTHOR CONTRIBUTIONS

Mábele de Cássia Ferreira: Conceptualization; methodology design; performed experiments; data acquisition; photographs; data curation; data analysis; writing; original draft; reviewing and editing. **Fabrina Bolzan Martins:** Conceptualization; methodology design; writing; reviewing and editing; supervision; project administration and funding acquisition. **Haroldo Felipe da Costa:** Performed experiments.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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