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Phenological growth stages of sorboid group within *Malinae* (*Rosaceae*) according to the BBCH scale

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Abstract. The development of a unified system for monitoring the developmental stages of sorboid plants within the subtribe *Malinae* holds significant economic and ecological importance. The study aimed to develop a comprehensive phenological system for sorboid plants based on the extended BBCH scale. The research was conducted during 2024-2025 at the collection sites of the National University of Life and Environmental Sciences of Ukraine and covered 49 species-level taxa representing the genera *Aria*, *Aronia*, *Cormus*, *Hedlundia*, *Micromeles*, and *Sorbus*, as well as the nothogenera ×*Amelasorbus*, ×*Arsorbus*, ×*Pyraria*, ×*Sorbaronia*, ×*Sorbocotoneaster*, and ×*Sorbopyrus*. The methodology involved regular field observations of individual plants, with developmental stages documented through systematic in situ photography throughout the growing season. The development of the extended scale was based on the principles of the decimal BBCH coding system and incorporated refined morphological descriptors for both vegetative and reproductive organs. To account for secondary and tertiary growth cycles observed under recent climatic shifts, a dual-indexing system was implemented to document successive proleptic shoots. The proposed scale consists of eight principal growth stages, substantially adapted to reflect the specific biological traits of sorboid plants. Key modifications include improved descriptors for bud and inflorescence emergence, a numerical system for recording multiple growth flushes (stages 31-39), and a redefinition of late-season stages to emphasise structural and physiological markers, such as leaf fall and winter dormancy, rather than transient optical traits. This standardised coding system provides high precision for bioclimatic monitoring, winter hardiness assessment, and the international exchange of scientific data on sorboid genetic resources. The results of the study can be applied in practice for monitoring the development of sorboid plants in forestry, horticulture, and biodiversity conservation

Keywords: *Aria*; *Aronia*; Cormus; *Hedlundia*; *Micromeles*; *Sorbus*; intergeneric hybrids; nothotaxa; phenology

Introduction

The subtribe *Malinae* (*Rosaceae*) comprises plants of considerable economic and ecological importance. While widely recognised for including globally important fruit crops, this group also occupies a prominent position in forestry and wood-processing industries. Many species of *Malinae* are integral components of natural forest communities, where they play a vital role in supporting biodiversity as a primary food source for forest avifauna and wildlife. From a silvicultural perspective, certain members of this subtribe are valued for the technical properties of their timber. As such, these plants contribute to both the ecological stability and the economic potential of forest stands, representing an important element in sustainable forest management. They are also valuable as fruit, ornamental, and medicinal plants.

Within the *Malinae*, a distinct group of sorboid plants is identified by their compound infructescences, bearing multiple fruits. Historically, these were unified within a broad circumscription of the genus Sorbus sensu Hedlund. Throughout the 20th century, taxonomic opinions diverged from this broad classification of *Sorbus sensu* lato to its segregation into the distinct genera *Aria, Chamaemespilus, Cormus, Micromeles, Sorbus* sensu stricto, and *Torminalis*, with *Aronia* also recognised as a separate genus (Fay & Rich, 2022a). The validity of such a division has been further substantiated by molecular phylogenetic studies. Species of these genera interbreed with one another, forming numerous hybridogenous taxa, for which new generic and nothogeneric names have been proposed. Nevertheless, M.F. Fay & T.C.G. Rich (2022b) continued to adhere to traditional concepts of *Sorbus* sensu lato.

Such divergent classification systems are often impractical for professionals working in botany, forestry, horticulture, ornamental gardening, and nature conservation. Addressing this, S.L. Mosyakin *et al.* (2022) proposed the conservation of the name *Aria* against *Chamaemespilus* and *Torminalis*. This proposal, based on the close taxonomic affinity of these genera, was subsequently accepted by the General Committee (Wilson, 2024). S.L. Mosyakin *et al.* (2025) indicated that, as a result, only four generic names: *Sorbus* sensu stricto, *Cormus, Aria*, and *Hedlundia* are retained for the sorboid species occurring in Western Eurasia, while most other names of hybridogenous genera and nothogenera have become unnecessary. A minor addition is the nothogenus ×*Arsorbus* (= *Aria* × *Sorbus*), which Z.-H. Feng *et al.* (2024) proposed to accommodate a single nothospecies. Furthermore, J.-H. Ma *et al.* (2023) and J. Hu *et al.* (2025) have demonstrated that the establishment of new genera for East Asian sorboid species is not molecularly substantiated. J.-H. Ma *et al.* (2003) employed plastome phylogenomics to resolve the relationships among East Asian sorboid species. Their findings confirmed that *Micromeles* is a monophyletic group, sharing a stable evolutionary history with *Aria, Chamaemespilus, Cormus, Sorbus* s.s., and *Torminalis*. By establishing the monophyly of these six traditional lineages, they provided the molecular evidence needed to show that creating additional genera for East Asian taxa would be redundant, as these species fit clearly into the existing framework. J. Hu *et al.* (2025) expanded upon this by conducting a broader molecular phylogenetic analysis, focusing on the taxonomic implications for the *Maleae* tribe. They reinforced the monophyletic status of the aforementioned core genera. Their work highlights that since the current six-group structure is robustly supported, any further splitting of East Asian sorboids lacks phylogenetic justification.

Regarding the flora of Ukraine, M.M. Fedoronchuk (2022) noted that eight sorboid species occur naturally, one of which is of conservation concern. Beyond native taxa, a significant number of sorboid plants have been introduced and cultivated in the country. Phenology, the study of recurring biological events and their timing in relation to biotic and abiotic forces, serves as a fundamental discipline for understanding ecosystem dynamics. In the contemporary context of global environmental change, D. Papagiannopoulou & T. Tsitsoni (2022) emphasised that phenological observations provide highly sensitive indicators of climate-driven shifts within biota. Beyond its role in bioclimatic monitoring, phenology remains indispensable for assessing ecological synchrony, predicting agricultural cycles, and managing biodiversity conservation. By integrating long-term observational data with predictive modelling, this field offers essential insights into the adaptive strategies of species and the functional stability of diverse habitats.

The BBCH (Biologische Bundesanstalt, Bundessortenamt, and the Chemische Industrie) scale was established to provide a standardised framework for phenological observations, offering a detailed description of plant developmental stages through a consistent coding system. The system was developed to encompass a diverse range of taxa, assigning identical codes to analogous growth stages across different species. This framework is structured into principal and secondary growth stages, ensuring high precision in bioclimatic monitoring and the international exchange of scientific data. While initially designed for major arable crops, the scale has since been extensively adapted for various horticultural and silvicultural species, including fruit crops and forest trees. These adapted scales already encompass a significant number of economically important plants, and the list of taxa for which BBCH-compliant descriptions are available continues to expand annually.

This study aimed to establish a standardised phenological framework for sorboid plants by developing an extended BBCH scale. In doing so, this study addresses a significant gap in current botanical, horticultural, and silvicultural knowledge, providing a unified tool for the monitoring of these diverse taxa.

Materials and Methods

The study was conducted at the collection orchard of the Educational, Research and Productive Laboratory of Genetic Resources, Introduction and Breeding of Rare Fruit and Ornamental Plants, within the Prof. V. L. Symyrenko Department of Horticulture at the National University of Life and Environmental Sciences of Ukraine (NULESU). The site was located in the village of Pshenychne, Bila Tserkva district, Kyiv region (50°05'17" N, 30°13'04.0" E). This region is situated within the Forest-Steppe natural zone. According to the Köppen climate classification scheme, the area is characterised by a typical warm-summer humid continental climate (Dfb). The basis for this research was the extensive collection of sorboid plants maintained by NULESU, which represents one of the most comprehensive genetic repositories of this group in the region (Mezhenska *et al.*, 2018; Mezhenskyj, 2019). This collection served as the primary resource for selecting the 49 species-level taxa included in the observations. Phenological monitoring was conducted during 2024-2025. Visual documentation of the phenological progression was performed by capturing sequential images of each growth stage *in situ* within the orchard to ensure precise identification and standardisation. All research activities were conducted in accordance with the Convention on Biological Diversity (CBD, 1992) and relevant Ukrainian legislation. The plant material was sourced exclusively from the ex situ collection maintained at NULESU, and no sampling from natural populations was performed. Phenological observations were non-destructive and did not affect plant welfare.

The taxonomic selection for this study was based on modern generic concepts proposed for sorboid plants. Firstly, segregated systems substantiated by molecular phylogenetic evidence were adopted, as established by C.S. Campbell *et al.* (2007) and J.H. Sun *et al.* (2018). This approach aligned the sample selection with current evolutionary data, ensuring that the diversity of the *Malinae* was represented through distinct generic entities rather than a broad traditional circumscription. Furthermore, the taxonomic framework of this study incorporated the proposal by A.N. Sennikov & A. Kurtto (2017) regarding the establishment of the hybridogenous genera for sorboids. The subsequent nomenclatural refinements suggested by S.L. Mosyakin *et al.* (2022; 2025) were also followed, which simplify the system of sorboid genera in Europe through the conservation of the name *Aria*. This also included the recognition of the established nothogenus ×*Arsorbus*, as proposed by Z.-H. Feng *et al.* (2024). The systematic treatment of Eurasian taxa belonging to *Micromeles,* followed by L.O. Mezhenska *et al.* (2018). This classification has gained robust support from the molecular phylogenetic studies of J.-H. Ma *et al.* (2023) and J. Hu *et al.* (2025), which demonstrated that the alternative establishment of several new genera for East Asian sorboid species, as proposed by K. Rushforth (2018, 2019), was not supported due to polyphyly. Consequently, the selected taxa encompassed the full range of both generic and hybridogenous entities recognised within the group.

A complete list of the investigated taxa and their abbreviations used in the figures is provided in Table 1. In this work, it was adopted the classification of S.L. Mosyakin *et al.* (2022; 2025), which subsumes the sorboid genera *Aria, Torminalis, Chamaemespilus*, and the hybrids between them (hybrid genera and nothogenera) into a single genus, *Aria*. Consequently, a total of 49 species-level taxa were included in the observations, representing all genus-level sorboid plants: *Aria, Aronia, Cormus, Hedlundia, Micromeles, and Sorbus*. This also encompassed the nothogenera: ×*Amelasorbus,* ×*Arsorbus,* ×*Pyraria,* ×*Sorbaronia,* ×*Sorbocotoneaster,* and ×*Sorbopyrus*.

Table 1. Sorboid taxa included in the investigation

Taxon	**Abbreviation**
×*Amelasorbus jackii* Rehder	ASj
×*A. raciborskiana* Browicz & Bugala	ASr
Aria adeana (N. Mey.) Mosyakin, Fedor. & McNeill	Aad
A. albovii (Zinzerl.) Mezhenskyj	Aal
A. bristoliensis (Wilmott) Mosyakin, Fedor. & McNeill	Abr
A. buschiana (Zinzerl.) Mezhensky	Abu
A. chamaemespilus (L.) Host	Ach
A. devoniensis (E.F. Warb.) Mosyakin, Fedor. & McNeill	Ade
A. edulis (Willd.) M.Roem.	Aed
A. fedorovii (Zaikonn.) Mezhenskyj	Afe
A. latifolia (Lam.) M. Roem	Ala
A. pannonica (Kárpáti) Sennikov & Kurtto	Apa
A. subfusca (Ledeb. ex Nordm.) Mosyakin, Fedor. & McNeill	Asf
A. torminalis (L.) Beck	Ato
A. sudetica (Tausch) Beck	Asd
Aronia arbutifolia (L.) Pers.	Aar
A. melanocarpa (Michx.) Elliott	Ame
A. ×*prunifolia* (Marshall) Rehder	Apr
×*Arsorbus thuringiaca* (Nyman) Z.H. Feng & Su Liu	ASt
Cormus domestica L.	Cdo
Hedlundia borbasii (Jáv.) Sennikov & Kurtto	Hbo
H. hostii (J. Jacq. ex Host) Mosyakin, Fedor. & McNeill	Hho
H. hybrida (L.) Sennikov & Kurtto	Hhy
H. intermedia (Ehrh.) Mosyakin, Fedor. & McNeill	Hin
H. kuznetzovii (Zinserl.) Mezhenskyj	Hku
H. liljeforsii (T.C.G. Rich) Mosyakin, Fedor. & McNeill	Hli
H. mougeotii (Soy.-Will. & Godr.) Sennikov & Kurtto	Hmo
H. takhtajanii (Gabrielian) Mezhenskyj	Htk
H. tamamschjanae (Gabrielian) Mezhenskyj	Htm
H. teodori (Liljefors) Sennikov & Kurtto	Hte
Micromeles alnifolia (Siebold & Zucc.) Koehne	Mal
M. megalocarpa (Rehder) Mezhenskyj	Mme

Table 1, Continued

Taxon	Abbreviation
×*Pyraria irregularis* (Münchh.) C.A.Wimm.	PAi
×*Sorbaronia fallax* (C.K.Schneid.) C.K.Schneid. subsp. *fallax*	SAf
×*S. f.* subsp. *mitschurinii* (A.K.Skvortsov & Maitul.) Stalažs	SAm
×*S. kovalevii* Mezhenskyj	SAk
×*Sorbocotoneaster pozdnjakovi*i Pojark.	SCp
×*Sorbopyrus kurjanovii* Mezhenskyj, nom. nud. (= *Sorbus aucuparia* L.× *Pyrus communis* L.)	SPk
Sorbus americana Marshall	Sam
S. ×*arnoldiana* Rehder	Sar
S. aucuparia L.	Sau
S. commixta Hedl.	Sco
S. commixta Hedl. × *S. monbeigii* (Cardot) N.P.Balakr.	Scm
S. decora (Sarg.) C.K.Schneid.	Sde
S. koehneana C.K.Schneid.	Sko
S. maderensis (Lowe) Dode	Sma
S. rehderiana Koehne	Sre
S. sambucifolia (Cham. & Schlecht.) M.Roem	Ssa
S. serotina Koehne	Sse

Note: abbreviations are used in figures
Source: developed by the authors

The development of the phenological coding system for sorboid plants was based on existing BBCH scales established for other members of the *Malinae*. Specifically, the framework drew upon the descriptors for *Malus domestica* (Meier *et al.*, 1994; Martínez *et al.*, 2019), *Pyrus communis* (Meier *et al.*, 1994), *Eriobotrya japonica* (Martinez-Calvo *et al.*, 1999), *Cydonia oblonga* (Martínez-Valero *et al.*, 2001), and *Crataegus germanica* (Atay, 2013). Due to the specific biological traits of sorboid taxa and recent extreme climatic shifts, the standard scale was significantly adapted and expanded. Furthermore, the technical descriptions were revised for stylistic and grammatical clarity to ensure international standardisation.

Results and Discussion

The standard BBCH scale for pome fruit (Meier *et al.*, 1994; Meier, 2001) was substantially adapted to reflect the biological characteristics of sorboid taxa and their developmental dynamics under changing climatic conditions. The proposed version consists of eight principal growth stages and forty-five secondary stages (Table 2). The primary modifications involve morphological refinements of bud and inflorescence descriptions, the introduction of a numerical system for recording multiple polycyclic (proleptic) growth flushes, and the redefinition of several late-season stages based on physiological rather than purely visual criteria. Detailed justification for these adjustments is provided in the subsequent sections, grouped by principal growth stages.

The onset and duration of phenological stages in plants are primarily determined by the air temperature regime. Due to global warming, significant deviations from the long-term climatic norm are being observed. This was particularly evident during the 2024-2025 period (Table 3).

Table 2. BBCH growth stages of sorboid plants

Code	Stage, description
	Principal growth stage 0: Leaf bud development
00	Dormancy: leaf buds and the thicker inflorescence buds closed; covered by brown, reddish-brown, or olive-coloured scales
01	Beginning of leaf bud swelling: bud visibly swollen; bud scales elongated with light-coloured patches
03	End of leaf bud swelling
07	Beginning of bud burst: first green leaf tips just visible
09	Leaf tips visible: leaf tips approx. 5 mm above bud scales
	Principal growth stage 1: Leaf development
10	First leaves visible: green leaf tips 10 mm above bud scales; first leaves separating
11	First true leaves unfolded
15	Most leaves unfolded; full size not yet reached
19	First leaves fully expanded
	Principal growth stage 3: Shoot development
31	Beginning of shoot growth: axes of developing shoots visible
32	Shoot approx. 20% of final length
35	Shoot approx. 50% of final length
39	Shoot reach approx. 90% of final length: the terminal bud has begun to form; shoot tip remains herbaceous and non-lignified
	Principal growth stage 5: Inflorescence emergence
51	Inflorescence bud swelling: bud scales elongated with light coloured patches.
52	End of bud swelling: light coloured, bud scales visible
53	Bud burst: leaf tips enclosing flower clusters visible
54	First leaves separating: leaf tips 10 mm above scales
55	Flower bud visible (still closed)
56	Green bud stage: individual flower separating
57	White/pink/red bud stage: flower stalks and petals elongating
58	Early balloon stage: individual flowers enlarged but remain closed
59	Balloon stage: petals forming a hollow ball (just before opening)
	Principal growth stage 6: Flowering
60	First flowers open (sporadic)
61	Beginning of flowering: appox. 10% of flowers open
63	Appox. 30% of flowers open
65	Full flowering: at least 50% of flowers open
66	Beginning of flower fading: first petals fading or beginning to fall
67	Flowers fading: at least 50% of petals fallen, withered or brown, flowers no longer functional
69	End of flowering: all petals fallen, withered or brown (often still attached).
	Principal growth stage 7: Development of fruit
71	Fruit set: ovary growing; abscission of unfertilised or defective ovaries may occur
73	Second fruit fall (facultative)
75	Fruit approx. half final size
77	Fruit approx. 70% final size
79	Fruit reached final size
	Principal growth stage 8: Maturity of fruit
81	Beginning of ripening: first appearance of specific colour
85	Advanced ripening: increase in intensity of specific colour
87	Fruit ripe for picking: typical size and specific colour reached

Table 2, Continued

Code	Stage, description
89	Fruit ripe for consumption: optimum flavour and firmness reached. (In certain taxa, this stage is attained only after the process of bletting)
	Principal growth stage 9: Senescence, beginning of dormancy
90	Fruit overripe: fruit abscission begins; remaining fruits lose turgor and undergo shrivelling
91	Shoot growth completed: terminal bud set; foliage still fully green
92	Beginning of leaf discolouration: onset of leaf yellowing or reddening characteristic of the species
93	Beginning of leaf fall: the abscission layer formed; first leaves start to drop
95	Advanced leaf fall: approx. 50% of leaves fallen; significant discolouration of remaining foliage
97	End of leaf fall: all leaves fallen (marks the start of winter dormancy)
99	Winter dormancy: full metabolic rest

Note: in the event of secondary or tertiary growth flushes (proleptic growth), stages 31-39 recorded with corresponding sequence indices (e.g., 31-II, 39-II); in the event of secondary or tertiary flowering flushes (off-season bloom), stages 60-69 are recorded with corresponding sequence indices (e.g., 61-II, 65-II)
Source: developed by the authors based on U. Meier *et al*. (1994), and U. Meier (2001)

Table 3. Comparison of mean temperatures in Kyiv

Month / Indicator	Climate norm (1991-2020), °C	2024, °C	2025, °C
January	-3.2	-2.6	+2.1
February	-2.3	+2.9	-3.7
March	+2.5	+4.8	+7.4
April	+10.0	+12.8	+11.1
May	+15.8	+16.3	+13.6
Average annual temperature	+9.0	+11.4	+10.4

Source: data of the B. Sreznevskyi Central Geophysical Observatory

In 2024, the mean temperature in February was positive rather than negative, which is atypical for the regional climate. Furthermore, January and March 2025 were the warmest on record, with 26 temperature records documented during this period. Such substantial thermal anomalies and the resulting extension of the growing season necessitated the adaptation of the BBCH scale. While Table 2 presents the complete extended BBCH scale for sorboid plants, the specific biological and methodological rationale for key modifications requires detailed explanation. The following subsections address these adaptations systematically, grouped by principal growth stages.

Principal growth stage 0-3 (Fig. 1). According to U. Meier *et al.* (1994) and U. Meier (2001), in the BBCH scale for pome fruits, both closed leaf buds and inflorescence buds are designated by the same code 00 within principal growth stage 0. However, while principal growth stage 0 further describes leaf bud development, a separate principal growth stage 5 (inflorescence emergence) is allocated for the development of inflorescence buds. Principal growth stages 1 and 2 follow stage 0 and describe the development of leaves and shoots, whereas principal growth stages 6 and 7 follow stage 5 to describe the development of flowers and fruits. Among the investigated taxa, *Sorbus sambucifolia* and ×*Sorbocotoneaster pozdnjakovii* consistently exhibit the earliest onset of bud swelling, bud burst, and leaf development, whereas these stages occur noticeably later in *Aria adeana* (Fig. 1b), *A. bristoliensis*, *A. edulis*, *A. pannonica*, *Cormus domestica*, *Hedlundia liljeforsii* (Fig. 1a), *H. takhtajanii*, *H. tamamschjanae*, ×*Sorbopyrus kurjanovii*, *Sorbus americana*, *S. koehneana*, and several other taxa, reflecting pronounced interspecific variation in growth rhythm.

The standard BBCH definition of stage 39 in pome fruits ("Shoots reach about 90% of final length") primarily reflects linear growth and does not adequately distinguish between temporary growth cessation and the onset of structural maturation. A physiological criterion was therefore introduced in this study: the initiation of terminal bud formation while the shoot tip remains herbaceous and non-lignified. This modification allows clear differentiation between the mid-summer pause in elongation (stage 39) and the definitive completion of shoot growth in autumn (stage 91).

Stage 39 describes the mid-summer cessation of linear growth and is functionally distinct from stage 91 ("shoot growth completed") by the presence of a soft, herbaceous tip, as opposed to the fully lignified wood and dormant bud set observed in autumn. To account for the dynamic nature of vegetative development, the BBCH scale was adapted to record multiple growth flushes. While the first flush typically concludes in mid-summer (stage 39-I), subsequent proleptic growth (secondary and tertiary flushes) was documented by repeating the stage 3 sequence with Roman numeral indices. This differentiation is particularly important for assessing winter hardiness, as late-season flushes (e.g., stage 39-III) often fail to reach full lignification before the onset of dormancy (stage 91).

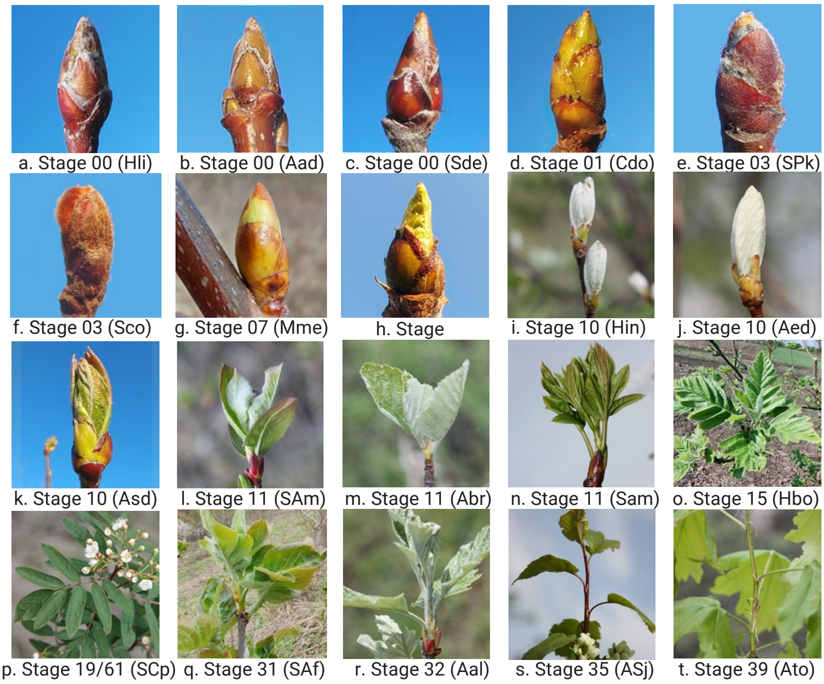
a. Stage 00 (Hli) b. Stage 00 (Aad) c. Stage 00 (Sde) d. Stage 01 (Cdo) e. Stage 03 (SPk)
f. Stage 03 (Sco) g. Stage 07 (Mme) h. Stage i. Stage 10 (Hin) j. Stage 10 (Aed)
k. Stage 10 (Asd) l. Stage 11 (SAm) m. Stage 11 (Abr) n. Stage 11 (Sam) o. Stage 15 (Hbo)
p. Stage 19/61 (SCp) q. Stage 31 (SAf) r. Stage 32 (Aal) s. Stage 35 (ASj) t. Stage 39 (Ato)

Figure 1. BBCH growth stages for leaf bud, leaf, and shoot development of sorboid plants
Source: authors' photo

Principal growth stage 5-6 (Fig. 2). The developmental stages of inflorescence buds in sorboid plants closely parallel those of leaf buds, particularly during swelling and bud burst (Fig. 2a-Fig. 2d). However, the horticultural term "mouse-ear stage" (codes 10 and 54), commonly applied to pome fruits, is inappropriate for sorboid taxa and was therefore excluded. Instead, the neutral and morphologically accurate designation "first leaves visible" was adopted, ensuring clarity and reproducibility in phenological observations. Stage 57 was refined to "white/pink/red bud stage", capturing the interspecific variation in petal colouration and enhancing the accuracy of early floral coding for diverse taxa (Fig. 3l). To improve the resolution of early floral development, an "Early balloon stage" (stage 58) was introduced prior to the standard "balloon stage" (stage 59), characterised by enlarged but still closed individual flowers (Fig. 2m). Stage 60 marks the sporadic opening of the first flowers, while the beginning (stage 61) and full flowering (stage 65) were defined as approximately 10% and at least 50% of flowers open, respectively (Fig. 2n, Fig. 2q). Although most sorboid species exhibit white petals, pink-flowered taxa include *Aria chamaemespilus* and its derivatives *A. sudetica* and *Hedlundia hostii*, underscoring the ornamental value of this phenological phase within the *Malinae* (Fig. 2.36).


a. Stage 50 (The) b. Stage 51 (Cdo) c. Stage 52 (Ala) d. Stage 52 (Hho) e. Stage 54 (Asd)
f. Stage 54 (Sre) g. Stage 55 (Apr) h. Stage 55 (Sar) i. Stage 56/15 (Hku) j. Stage 56/15 (Ssa)
k. Stage 56/15 (SAf) l. Stage 57/19 (Mal) m. Stage 59 (Ame) n. Stage 60 (Sse) o. Stage 63 (Sko)
p. Stage 63 (Ach) q. Stage 65 (Hhy) r. Stage 66 (Aar) s. Stage 67 (Sau) t. Stage 69 (Abu)

Figure 2. BBCH growth stages for reproductive development and flowering of sorboid plants
Source: authors' photo

Flower senescence is initiated at stage 66, when the first petals fade or abscise (Fig. 2r). Stage 67 ("flowers fading") corresponds to the loss or withering of at least 50% of petals, and stage 69 ("end of flowering") is reached once all petals have fallen or fully withered, even if a few remain temporarily attached (Fig. 2s, Fig. 2t). This standardised approach provides a reliable framework for comparing flowering dynamics across taxa and for guiding management decisions in fruit production, ornamental horticulture, and phenological research.

Principal growth stage 7-8 (Fig. 3a-Fig. 3o). Fruit development in sorboid plants occurs at various times depending on the genotype. This phase, like other phenological phases, is strongly influenced by environmental conditions. Although 2024-2025 were generally warmer than average, May 2025 proved to be colder than normal, which somewhat slowed the rapid plant development that had commenced in March. Consequently, the early onset of vegetation did not result in early fruit ripening. The fruits of sorboid plants exhibit great diversity in colouration. Most species possess light or dark red and red-orange fruits, which occur in ×*Amelasorbus, Aria* (Fig. 3k), ×*Arsorbus, Hedlundia* (Fig. 3l), *Micromeles,* ×*Sorbocotoneaster,* ×*Sorbopyrus,* and *Sorbus* (Fig. 3o). While the fruits of ×*Amelasorbus jackii* are typically dark red, the accession in the collection produces dark blue fruits, suggesting a possible backcross with *Amelanchier*. White fruits are found in *Sorbus koehneana* and a collection accession of *S. maderensis* (Fig. 3m), while white fruits with a pink blush are characteristic of *S.* ×*arnoldiana* 'Maiden Blush'. Yellow fruits occur in *S. commixta* × *monbeigii* 'Joseph Rock' and one of the accessions of *S. decora*. *Cormus domestica* and ×*Pyraria irregularis* possess a yellow ground colour with a blush of varying intensity as an overcolour. Black fruit colouration is typical of *Aronia melanocarpa*, ×*Sorbaronia fallax* subsp. *mitschurinii*, and some accessions of ×*S. fallax* subsp. *fallax* (Fig. 3n), though the latter also includes burgundy-fruited cultivars. Dark purple fruits are found in *Aronia* ×*prunifolia* and ×*Sorbaronia kovalevii* (Fig. 3p), while brown fruits are characteristic of *Aria devoniensis, A. torminalis*, and *Micromeles megalocarpa*. At the early stage of fruit growth, the abscission of unfertilised or defective ovaries may occur (stage 71) (Fig. 3c, Fig. 3d). Stage 73 ("second fruit fall"), while typical of pome crops, is less pronounced in sorboid plants. The ovary and young fruits are green; therefore, the appearance of specific colouration indicates the beginning of ripening (stage 81), which gradually increases in intensity. Ripe fruits (stage 87) (Fig. 3m-Fig. 3o) reach full size and acquire typical colouration and flavour. According to O. Raspé *et al.* (2000), most *Sorbus* species are characterised by bitterness due to specific glycosides, primarily parasorbic acid, which reduces their palatability to the point of being inedible in their raw state.

Stages 87 and 89 correspond to harvest maturity and consumer ripeness for pome fruits, respectively. However, for autumn and winter apple and pear varieties, stage 89 is a commercial characteristic rather than a phenological phase. In summer varieties, harvest maturity and consumer ripeness coincide, whereas for autumn and winter varieties, consumer ripeness occurs significantly later, potentially even during the following growing season. This stage is determined using a complex of chemical and physical methods (starch-iodine test, flesh firmness, and soluble solids content). Some species within the *Malinae*, such as medlar (*Crataegus germanica*), produce fruits that are entirely inedible at stage 87 due to their hard flesh and intense astringency caused by phenolic compounds (Atay, 2013). They become palatable only after a ripening process called bletting, during which the macerated flesh acquires a delicate consistency and sweet flavour. This process can occur either on the tree or during storage after harvest. A similar progression towards consumer ripeness is characteristic of sorboid plants such as *Cormus domestica*.


a. Stage 69 (Hmo)
b. Stage 71 (Asr)
c. Stage 71 (Cdo)
d. Stage 71 (Asd)
e. Stage 75 (Scm)
f. Stage 75 (SCp)
g. Stage 75 (Afe)
h. Stage 77 (Pai)
i. Stage 81 (Sau)
j. Stage 81 (SAf)
k. Stage 85 (Asf)
l. Stage 85 (Htm)
m. Stage 87 (Sma)
n. Stage 87 (SAf)
o. Stage 87 (Sre)
p. Stage 90 (SAk)
q. Stage 91 (Apa)
r. Stage 92 (Ast)
s. Stage 97 (Htk)
t. Stage 90/97 (SAf)

Figure 3. BBCH growth stages for fruit development, ripening, and senescence of sorboid plants
Source: authors' photo

Principal growth stage 9 (Fig. 3p-Fig. 3t). At stage 90, the fruit enters the phase of senescence. The formation of an abscission layer in the stalk causes many fruits to fall naturally. For those that remain on the tree, the primary characteristic is shrivelling – a visible contraction of the skin and flesh caused by significant moisture loss and the breakdown of cellular structures. At this stage, the fruit's internal tissues lose their commercial quality, typical texture, and flavour profile entirely. ×*Sorbaronia fallax* plants produce black fruit that ripen in August and remain on the branches throughout autumn and winter. Although they shrivel and lose some moisture, they retain their value due to their high phenolic compound content. It is essential to distinguish between the enzymatic maceration of the mesocarp at stage 89 and physiological degradation at stage 90 (Fig. 3p). For *Crataegus germanica* and *Cormus domestica*, the breakdown of cellular structures during bletting is a functional requirement for achieving consumer ripeness (stage 89), resulting in a palatable, sweet, and soft texture. Conversely, the degradation observed at stage 90 is a symptom of senescence, characterised by shrivelling and desiccation. While bletting represents the peak of organoleptic quality for these species, stage 90 marks the irreversible loss of commercial and culinary value due to uncontrolled tissue breakdown and moisture loss.

By renaming the standard BBCH stage 95 ("50% of leaves discoloured") to "advanced leaf fall" and stage 97 ("all leaves fallen") to "end of leaf fall", the monitoring focus shifts from transient optical changes to the tangible loss of biomass and the definitive cessation of the tree's assimilatory functions. This modification ensures higher precision in recording the transition to winter dormancy, particularly in sorboid taxa where defoliation often occurs concurrently with, or even precedes, total chlorophyll degradation. While phenological observations are inherently visual, focusing on leaf fall rather than discolouration enhances the methodology by replacing a subjective optical assessment with a quantifiable structural event. For sorboid plants, where autumnal pigmentation can be prolonged and variable, defoliation serves as a more definitive proxy for the completion of the physiological growth cycle.

The vegetative cycle was considered complete once the plants reached stage 97 (Fig. 3s, Fig. 3t). However, it is worth noting the occasional occurrence of marcescence, where withered leaves are retained on the branches throughout the winter dormancy period. While this phenomenon can serve as a distinctive taxonomic or adaptive marker for certain sorboid taxa, it was recorded as a supplementary qualitative observation rather than a formal phenological phase, as it represents a deviation from the typical physiological defoliation sequence. It was concluded that there is no requirement to introduce a separate BBCH code for leaf persistence. Instead, the completion of the vegetative cycle is recorded at stage 97, with the occurrence of marcescence noted as a supplementary qualitative attribute (e.g., marked as "97 m"). This approach avoids overcomplicating the phenological scale while ensuring that this distinctive taxonomic trait is accurately documented without distorting the primary data on the cessation of growth.

In the standard BBCH scale, stage 99 is traditionally defined as "harvested product". However, for sorboid taxa, this definition introduces significant chronological and biological inconsistencies. In many fruit-bearing species, the harvest maturity occurs well before the completion of leaf senescence (stages 95-97). Following a strict numerical sequence would incorrectly place the harvest at the absolute end of the physiological cycle. Principal growth stage 9 is fundamentally dedicated to senescence and dormancy. While harvesting is an agricultural operation, it does not necessarily align with the plant's physiological entry into rest. In several sorboid species, fruits persist on the branches throughout the winter. In such cases, "harvested product" is an irrelevant marker for the plant's natural biological progression. Consequently, stage 99 has been redefined as "winter dormancy". This shift ensures that the scale reflects the definitive cessation of metabolic activity and the attainment of full seasonal rest, providing a logically consistent conclusion to the annual vegetative cycle.

The proposed coding system is applicable across a wide range of sorboid genera and their hybrids, enabling comparative phenological analyses across climatic gradients and management regimes. This framework provides a standardised basis for forest introduction trials, orchard management, winter hardiness assessment, and integration of phenological datasets in broader ecological and climate-oriented research.

The scale for pome fruits, developed by U. Meier *et al.* (1994) for *Malus domestica* and *Pyrus communis*, was incorporated into the BBCH Monograph (Meier, 2001) with minor amendments and additions. In the work of R. Martínez *et al.* (2019), dedicated to one of *Malus domestica* cultivars, this scale is presented with certain adjustments and refinements in the descriptions of some secondary stages. The authors explicitly discard terms such as "mouse-ear stage", "T-stage", and similar horticultural expressions in their descriptions. The use of the "fruit set" description for both stage 69 (belonging to the principal growth stage "flowering") and stage 71 (principal growth stage "fruit development") introduces conceptual ambiguity. They also discard stage 87 "fruit ripe for picking", noting that apples become suitable for harvesting and consumption only at stage 89. Stage 99 is absent from their scale; the phenological sequence concludes at stage 97, defined as "winter rest period". All leaves fallen". The results of this study, despite the biological differences shown between the apple fruit and pears, essentially coincide with those obtained by U. Meier (1997) for the phenological stages of pome fruits. The sequential progression of the main stages of growth indicates that reproductive development partially overlaps with vegetative growth.

R. Martínez-Valero *et al.* (2001) described the phenological stages of the quince tree using the BBCH General Scale in combination with a previous phenological coding system for fruit trees by another author. They defined the secondary stages of the Principal growth stage "flowering" in a manner that differs from the standard BBCH scheme. While in the BBCH scale the opening of the first flowers and the beginning of flowering are marked by codes 60 and 61 respectively, and codes 62 and 65 indicate the opening of 20% and 50% (full flowering) of flowers, in quince the "petals visible" stage is marked with code 61, "petals begin to separate" with code 62, and "open flowers" with code 65. There are also discrepancies between the coding of the "fruit reached final size" stage, which corresponds to code 79 in the BBCH scale, while R. Martínez-Valero *et al.* marked it with code 78. In their system, complete leaf fall is interpreted as the end of vegetation and the onset of winter dormancy and is coded as 93, whereas in the standard BBCH scale, this code denotes only the beginning of leaf fall.

For sorboids, the original descriptions were systematically revised, and several new secondary stages were introduced to provide finer resolution of inflorescence development and shoot maturation. Specifically, the introduction of stage 58 "early balloon stage" and the redefinition of stage 39 allow for a more precise discrimination between closely related phenological events compared to the baseline scale. While our study introduces several morphological refinements and additional stages for sorboid plants, E. Atay (2013) adhered strictly to the standard BBCH scale for medlar, without introducing any morphological refinements or adjustments. He also fully accepted stage 89 "fruit ripe for consumption: fruit have typical taste and firmness" without addressing the specific physiological features of the onset of consumer ripeness in medlar fruits.

The description of the phenological stages of the loquat tree was established according to the BBCH scale by J. Martinez-Calvo *et al.* (1999). The loquat tree differs from other pome fruit tree species in that it has persistent leaves and three flushes of growth per year;

flowering occurs during autumn and winter, and fruit harvest occurs during spring. Considering that the loquat, as a subtropical plant, has differences in growth and development compared to plants of the temperate zone, three mesostages (1-3) were used, corresponding respectively to autumn, spring, and summer growth. Mesostage 0 is used for the generative phase. The authors demonstrated the advantages of applying the BBCH scale over other scales, which allowed loquat varieties to be better characterised. In J. Martínez-Calvo *et al.* (1999), repeated vegetative growth phases within a single growing season are accounted for by subdividing the vegetative phase into mesostages corresponding to the seasons of the year. Three mesostages (1-3) are used to represent autumn, spring, and summer growth, respectively. Within each mesostage, the complete sequence of codes of principal growth stage 0 (010-019, 020-029, 030-039) is repeated, describing identical morphological events of bud development (dormancy, swelling, and bud burst). Thus, in loquat, growth repetition is formalised through seasonal segmentation rather than by distinguishing biologically independent growth flushes. The same morphological stage is assigned different codes depending on the season in which it occurs, which is appropriate for a species with a clearly expressed seasonal growth pattern.

In contrast, in the BBCH-based scale developed for sorboid plants, a fundamentally different principle of scale adaptation is applied. In the event of secondary or tertiary growth flushes, the base BBCH code remains unchanged, while growth repetition is recorded by introducing sequential cycle indices (e.g., 31-II, 39-II, 31-III). This approach enables the documentation of biologically independent growth flushes, irrespective of the calendar season in which they occur. This distinction has important functional and adaptive implications, particularly for assessing shoot maturation and winter hardiness. While preserving the universality and comparability of the BBCH scale, this approach simultaneously extends its descriptive capacity for polycyclic growth in woody plants under changing climatic conditions. The same coding principle is also applied to cases of off-season flowering.

Conclusions

The extended BBCH scale developed in this study provides a comprehensive, standardised, and biologically justified framework for the detailed description of phenological growth stages across the diverse sorboid group. By assigning identical codes to analogous principal and secondary growth stages, the scale facilitates high-resolution bioclimatic monitoring and ensures terminological consistency, comparability, and reproducibility in international scientific communication. The proposed framework fills a critical methodological gap, as no unified BBCH-based system previously existed for sorboid taxa.

Significant modifications were introduced to account for the unique developmental dynamics of sorboids, most notably their capacity for repeated proleptic shoot growth flushes, which have direct implications for plant stability, winter survival, and management under variable climatic conditions. The introduction of secondary growth indices (I, II, III) provides a concise diagnostic tool for recording late-season growth flushes that often remain insufficiently lignified, thereby enabling an objective assessment of frost susceptibility, shoot dieback risk, and long-term structural quality. The replacement of subjective optical criteria (leaf discolouration) with clearly identifiable structural and physiological markers, such as leaf fall and terminal bud formation, substantially improves the operational clarity and consistency of phenological observations. Renaming stage 97 to "end of leaf fall" and stage 99 to "winter dormancy" aligns the BBCH framework with functionally meaningful phenological thresholds, facilitating accurate identification of the completion of assimilatory activity and the onset of dormancy.

The explicit distinction between harvest maturity (stage 87) and consumer ripeness (stage 89) is particularly important for sorboid species with physiologically delayed fruit palatability, such as *Cormus domestica*, and prevents the conflation of biological phenological phases with purely agronomic or technological criteria, thereby preserving the conceptual and physiological integrity of the BBCH system. Furthermore, the clear separation of consumer ripeness (stage 89) from fruit senescence (stage 90) ensures correct interpretation of late-season fruit persistence in several sorboid species.

Overall, this extended BBCH framework presented here constitutes an effective and versatile tool for the management of sorboid genetic resources, long-term phenological monitoring, winter hardiness assessment, and integrated horticultural, silvicultural, and ornamental plant planning, as well as for the assessment of adaptive responses of woody perennials to ongoing climate change.

Furthermore, the indexing approach and morphological refinements established in this study provide a methodological template for the future adaptation of BBCH scales for other underutilised or taxonomically complex woody perennials. Future research should focus on the practical validation of this scale across broader geographic ranges to quantify the correlation between specific secondary stages and the adaptive capacity of sorboid hybrids to extreme weather events.

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Conflict of Interest

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Фенологічні фази росту рослин сорбоїдної групи підтриби *Malinae* (*Rosaceae*) за шкалою BBCH

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Анотація. Розробка уніфікованої системи для моніторингу стадій розвитку сорбоїдних рослин підтриби *Malinae* має велике економічне та екологічне значення. Метою дослідження було розробити комплексну фенологічну систему для сорбоїдних рослин на основі розширеної шкали BBCH. Дослідження проводилося протягом 2024-2025 років на колекційних ділянках Національного університету біоресурсів і природокористування України і охоплювало 49 таксонів на рівні видів, що представляли роди *Aria*, *Aronia*, *Cormus*, *Hedlundia*, *Micromeles* і *Sorbus*, а також нотороди ×*Amelasorbus*, ×*Arsorbus*, ×*Pyraria*, ×*Sorbaronia*, ×*Sorbocotoneaster* та ×*Sorbopyrus*. Методологія передбачала регулярні польові спостереження за окремими рослинами, а стадії розвитку документувалися за допомогою систематичної фотозйомки на місці протягом усього вегетаційного періоду. Розробка розширеної шкали базувалася на принципах десяткової системи кодування BBCH і включала вдосконалені морфологічні дескриптори як для вегетативних, так і для репродуктивних органів. Щоб врахувати вторинні та третинні цикли росту, які спостерігаються в умовах останніх кліматичних змін, було впроваджено систему подвійної індексації для документування послідовних пролептичних пагонів. Запропонована шкала складалася з восьми основних стадій росту, які суттєво адаптовані для відображення специфічних біологічних особливостей сорбоїдних рослин. Ключові зміни включали вдосконалені дескриптори для появи бруньок і суцвіть, числову систему для реєстрації множинних спалахів росту (стадії 31-39) та переосмислення стадій пізнього сезону з метою акцентування уваги на структурних і фізіологічних маркерах, таких як опадання листя і зимовий спокій, а не на тимчасових оптичних ознаках. Ця стандартизована система кодування забезпечує високу точність біокліматичного моніторингу, оцінки зимостійкості та міжнародного обміну науковими даними про генетичні ресурси сорбоїдних рослин. Результати дослідження можна використовувати на практиці для моніторингу розвитку сорбоїдних рослин у лісовому господарстві, садівництві та при збереженні біорізноманіття

Ключові слова: *Aria*; *Aronia*; *Cormus*; *Hedlundia*; *Micromeles*; *Sorbus*; міжродові гібриди; нототксони; фенологія