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Research Article

Phenological phases of development of *Cornus florida* L. under conditions of introduction in Ukraine

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Phenological studies do not lose their relevance and are carried out in very different aspects. They are important for monitoring the response of plants to climate changes, the selection of new cultivars of plants, the introduction of new non-traditional fruit crops, agricultural production, etc. According to the BBCH scale, the phenological phases of development of *Cornus florida* L. (flowering dogwood), an ornamental and fruiting plant from the family Cornaceae Bercht. & J. Presl., with useful medicinal, antioxidant, technical, and ecological properties, are codified. In the climatic conditions of Ukraine (M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, Kyiv (NBG)), *C. florida* plants go through a full cycle of seasonal development. *Cornus florida* biotypes, according to the BBCH scale, are characterized by eight of the ten principal stages of seasonal development, in particular: the development of buds (BBCH 0), leaves (BBCH 1), shoots (BBCH 3), inflorescence (BBCH 5), flowering (BBCH 6), fruit development (BBCH 7), fruit ripening (BBCH 8) and senescence, beginning of dormancy (BBCH 9). *Cornus florida* (subgenus *Cynoxylon* (Raf.) Raf.) differs from species of the subgenus *Cornus* by the descriptive and diagnostic features of phenophases. The development of *C. florida* in the NBG in dry 2021 confirmed its adaptive tolerance to seasonal water deficit, both in the region of the native range of the species (central Missouri) and in the experimental conditions of growing introduced plants in China. *Cornus florida* deserves a wide introduction on the territory of Ukraine.

Keywords: flowering dogwood, phenology, BBCH-scale, plant introduction

Introduction

Phenology is a key feature of plants of all species, as it determines their season and duration of growth and reproduction, as well as their ability to capture variable resources (Chuine and Régnière, 2017). Seasonal phases of plant development are determined by a complex of factors, including taxonomic affiliation, origin, ecological timing, geographical distribution of the species, as well as the growth form and duration of the life cycle of plants (Stuble et al., 2021). The course of vegetative development of plants is also affected by climatic changes (Piao et al., 2019; Fuccillo et al., 2022). Native and introduced or invasive species differ in phenological sensitivity (Willis et al., 2010; Calinger et al., 2013; Zettlemoyer et al., 2019; Giejsztowt et al., 2020; Calinger and Curtis, 2023), as well as various

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phases of plant development (Gallinat et al., 2015; Zohner and Renner, 2019; Zani et al., 2020).

Cornus florida L. (flowering dogwood, Cornaceae Bercht. & J. Presl), based on the results of the analysis of morphological features and molecular biological studies of the genus, is included in the subgenus *Cynoxylon* (Raf.) Raf., which together with the subgenus Syncarpea (Nakai) Q.Y.Xiang forms a separate evolutionary clade (group BB), species of which have large petaloid bracts (Eyde, 1988; Murrell, 1993, 1996; Fan and Xiang, 2001; Xiang et al., 2006; 2008; Xiang and Thomas, 2008; Wadl et al., 2010; Feng et al., 2012; Murrell and Poindexter, 2016; Thomas et al., 2021). The species is distributed in the Southeast of Canada, in the eastern and south-central parts of the USA, and the Northeast of Mexico (Murrell and Poindexter, 2016), which may indicate its significant adaptive plasticity and tolerance to drought and some other extreme environmental factors (Hinckley et al., 1979; Lu et al., 2020). In Canada, however, *C. florida* is an endangered species (Mitchell, 2021). In the region of the native range of the species, the amount of precipitation varies from 760 mm in the north to 2030 mm in the southern Appalachians; soils can be light (sandy), medium, or heavy (clay), according to pH – acidic, neutral or alkaline; according to the hydrothermal regime – dry, raw or well-moisturized; biotopes – shaded, semi-shaded or illuminated. The average annual temperature is +21 °C (in the south) and +7 °C (in the north), with extreme temperatures from +46 °C to -34 °C (McLemore, 1990).

Cornus florida is a very popular species in the USA and is the state tree and symbolic flower of the Commonwealth of Virginia, the state tree of Missouri, and the state flower of North Carolina (https://www.inaturalist.org/ taxa/54777-*Cornus*-florida). *Cornus florida* was selected as the 2018 Flower of the Year by the Virginia Native Plant Society (Hayden, 2018). This species is a desirable ornamental tree in urban and suburban landscapes, especially in temperate regions of North America. The aesthetic value of plants was an incentive for the selection of more than 80 cultivars and 24 varieties (Nowicki et al., 2018). *Cornus florida* has edible fruits that are characterized by a significant (up to 35% dry matter) lipid content (Stiles, 1984). The bark of plants has long been used for medicinal purposes by the Native Americans of North America, who especially valued it for its astringent, diaphoretic, mild stimulant, and tonic effects (Weiner and Weiner, 1980; Moerman, 1998; Diggs et al., 1999). Iridoids, flavonoids, and anthocyanins, which show high antioxidant activity, were found in the leaves and fruits (Graziose et al., 2012; He et al., 2014; Truba et al., 2020). *Cornus florida* plants improve the ecological cycle of calcium (Ca) due to its high concentration in the leaves and rapid decomposition of the latter, and therefore availability in the soil (Borer et al., 2013).

Cornus florida is introduced on all continents except Antarctica, in particular in South America (Colombia, Brazil), in 14 European countries, in Asia (Korean Peninsula, Japan, Philippines), Oceania (New Zealand), and in Australia, and is also listed as invasive species for South Africa (*Cornus florida*, 2022).

In Ukraine, *C. florida* is not a very common introduced species. In 1924, it was introduced into culture in Yalta (Kokhno and Trofymenko, 2005). Now it grows in the collections of botanical gardens and arboretums of Kyiv, Bila Tserkva, Kharkiv, Donetsk, and Askania-Nova (Teslyuk, 2011, 2016). In M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine (NBG) *C. florida* has been cultivated since 2008 (Teslyuk, 2012).

For more than 100 years, flowering dogwood has been actively studied, especially in North America, in very diverse aspects: morphological, anatomical and biological (Shank, 1938; Gunatilleke and Gunatilleke, 1984; Dietrich et al., 1990), functional and physiological (Roberts, 1979; Borer et al., 2013; Lu et al., 2020), biochemical (Fernandez et al., 1996; Vareed et al., 2006; Truba et al., 2020; Al-Khafaji et al., 2023), structurally-population (Pais et al., 2017, 2020), molecular and genetic (Xiang et al., 2006; Hadziabdic et al., 2010, 2012; Zhang et al., 2013; Nowicki et al., 2018), etc.

Phenological observations of *C. florida* were carried out in native locations from different points of view and using various methods. It is the object of the project "The USA National Phenology Network" (*Cornus*, 2016; Crimmins et al., 2022). The greatest attention was paid to the initial, spring phases of plant development. They have been studied and used to determine the effect of air temperature on the initiation of dogwood flowering, to develop spring indices (Schwartz et al., 2013), to analyze trends in spring onset in the temperate regions of the Northern Hemisphere, and long-term changes in plant phenology in the Northeastern United States, and also to clarify the dynamics of the concentration of organic substances in plants during the growing season, etc. (Lieth and Radford, 1971; Reader, 1975; De La Pascua, 2020; Fuccillo Battle et al., 2022).

In modern studies of the seasonal development of various plants, the use of the BBCH scale (Biologische

Bundesanstalt, Bundessortenamt, und Chemische Industrie) is becoming increasingly popular, the main principles of which provide a unified code for similar phases of the seasonal development of each plant species, as well as the recognition of each phenophase by visual morphological features (Hack et al., 1992; Meier et al., 1994; 2009). Codification according to the BBCH scale is used to determine the phases of seasonal development of fruit plants (Larue et al., 2021; Ferrer-Blanco et al., 2022; Paradinas et al., 2022; Ramírez, 2023).

In Ukraine, the phenological features of many local and newly introduced species and cultivars of fruit plants, in particular *Cornus* L. (Klimenko, 1990), *Cydonia* Mill. (Klimenko, 1993), *Chaenomeles* Lindl. (Klimenko and Nedviha, 1999), *Persica* Mill. (is now called genus *Prunus* L.) (Holubkova, 2016), *Cynoxylon* (Raf.) Small (Teslyuk, 2016), *Malus* Mill. (Honcharovska, 2019), *Lycium* L. (Zhurba, 2021). According to the extended BBCH scale are codified phenophases of *Pseudocydonia* (C.K.Schneid.) C.K.Schneid. (Grygorieva et al., 2018), *Elaeagnus multiflora* Thunb. (Grygorieva et al., 2022), Californian endemic *Cornus sessilis* Torr. ex Durand (Klymenko et al., 2021), species of the *Cornus* subgenus (Klymenko and Ilyinska, 2021), as well as the new cultivar *C. mas* L. (Klymenko and Ilyinska, 2023).

The purpose of this study is to codify, following the BBCH scale, phenophases and to find out the course of seasonal plant development of the North American species *C. florida*, introduced in the NBG, in the climatic conditions of Ukraine.

Material and methodology

Study region, weather, and climate conditions

The study was conducted in 2021 in the NBG, located on the right bank of the Dnipro river in the southeastern part of Kyiv on the low Pechersky slopes of the Kyiv Upland in the Zvirynets tract (50° 27ʻ N; 30° 31ʻ E; 197 m. n. r. m.). The main climatic and edaphic factors of NBG are in the range of variation of similar indicators of the native range of *C. florida* (Table 1) (McLemore 1990; https://en.climate-data.org/; https://rp5.ua/Weather_archive_in_Kiev, (airport) [accessed January 29, 2022]. The only exceptions are the minimum amount of average annual precipitation (less in Kyiv) and the absolute maximum temperature: +46.0 °C within the native range of the species versus +39.4 °C in Kyiv. The year of the study (2021) was dry with a very warm spring and hot summer (Figure 1). For five months (March, June, July, September, and especially October), precipitation was significantly lower than normal, and the average monthly temperature in January and March and throughout the summer higher than normal. In particular, the first month of spring seemed dry and quite hot (Figure 1). On the fourth of March, the average daily temperature was equal to the biological minimum (+5 °C), and in the last six days of the month, it exceeded it.

Research objects

Genotypes of *C. florida* were obtained by seedlings from the state of Oregon (USA) in 2008 and introduced to NBG (Teslyuk, 2012). Two genotypes of *C. florida* were used in the studies.

Table 1 Climatic and edaphic factors of Kyiv and the region of native distribution of *Cornus florida* L.

Indicators	Kyiv (NBG)	Region of native distribution *C. florida*
Climate¹	Dfb	Dfb, Dfa, Cfa, Bsh, Bsk
Biotopes	semi-shaded	shaded, semi-shaded, illuminated
Precipitation², mm	649 (540)	760–2,030
Soils	medium (dark gray podzolic, low-humus black soil)	light (sand), medium, heavy (clay)
pH	slightly acidic, neutral	acidic, neutral, alkaline
hydrothermal regime	sufficiently hydrated	dry, raw, well hydrated
Temperature, °C		
average annual	+8.4 (+9.1)	+21 (south) +7 [north]
absolute maximum	+39.4 (+34.7)	+46.0
absolute minimum	-32.2 (-20.0)	–34.0

1 – the climate is given according to the Köppen-Geiger classification (Peel et al., 2007); 2 – precipitation and temperature indicators in 2021 are given in round brackets; Dfb – warm humid continental climate; Dfa – hot humid continental climate; Cfa – humid subtropical climate; Bsh – hot semi-arid climates; Bsk – cold semi-arid climates

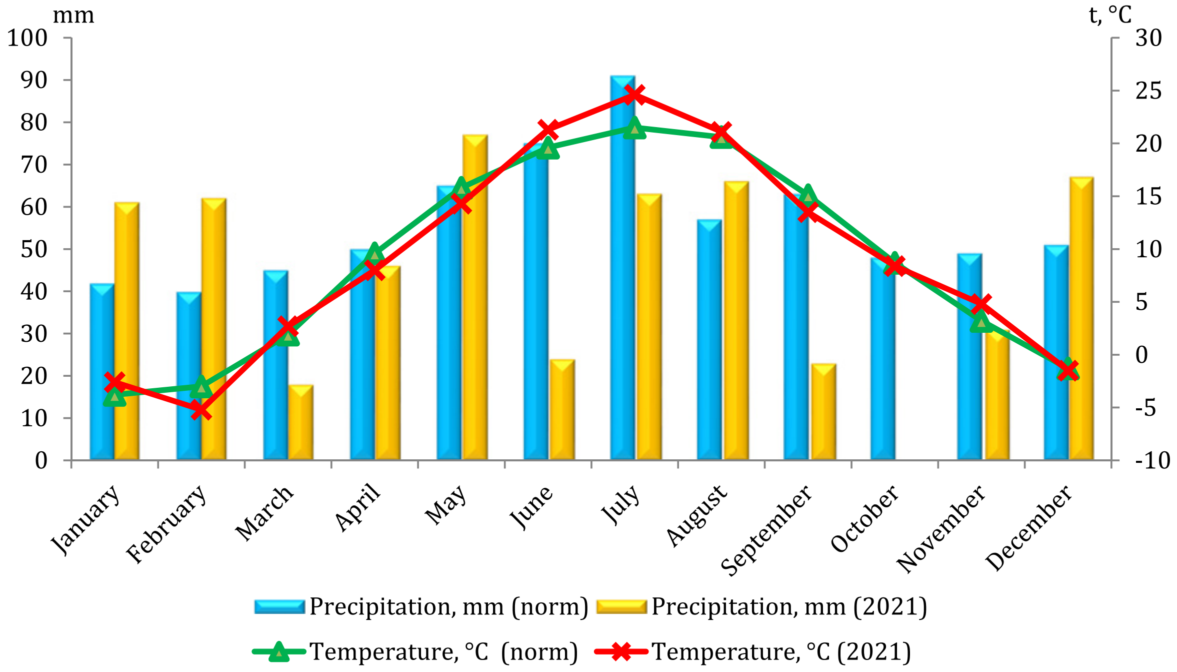

Figure 1 Average monthly precipitation and temperature in Kyiv in 2021

Phenological monitoring

The phenological study began on March 1, 2021. Observations were conducted 2–3 times per week through textual and photographic documentation. The course of seasonal development of *C. florida* genotypes was codified according to the extended BBCH scale (Hack et al., 1992; Meier et al., 1994, 2009; Klymenko and Ilyinska, 2021). For the beginning and end of each phenophase, the active and effective temperatures (t_{act} °C and t_{eff} °C respectively) were determined.

Results and discussion

Cornus florida is characterized by vegetative and complex renewal buds, which are initiated in mid-June and continue to develop until the onset of winter dormancy (Morse, 1907; Feng et al., 2012). Vegetative buds (Figure 2) are formed on shortened and elongated shoots. The formed complex buds consist of two vegetative and one generative bud and have one pair of common cataphylls, which can often be damaged and broken off during the rest period (Figure 2). Each vegetative bud of a complex bud has its own cataphyll, which initially partially covers the generative bud, and later only its axis (Figure 2). The inflorescence is surrounded by four bracts and has an elongated axis, which is formed during the rest period (Figure 2, 3). The development of an elongated axis of the generative bud distinguishes *C. florida* from species of the *Cornus* subgenus, the inflorescences of which are practically sessile (Klimenko, 1990; Klymenko and Ilyinska, 2021). Before the beginning of winter dormancy, the bracts increase in size, thicken, harden, and become scale-like structures surrounding the young flower buds. In the temperate climate of Ukraine (NBG, Kyiv), complex buds are laid in June and reach full development in November (Figure 3).

Figure 2 Vegetative (1) and complex (2) buds of *Cornus florida* L. during the rest period (January 6th, 2022)

Figure 3 Initiation of complex buds of *Cornus florida* L. in NBG (June – November 2021)

Under conditions of introduction, as well as in regions of native distribution (Lamb, 1915; Lieth and Radford, 1971), *C. florida* initiates vegetation with the simultaneous development of generative and vegetative buds, unlike *C. mas* and other species of the subgenus *Cornus*, which initiate seasonal development of flowering phenophase.

Principal growth stage 0: bud development

Vegetative buds of *C. florida* during the resting period are elongated-conical, covered with two scales with pubescent tips (Figure 2). In 2021, the period of rest continued until mid-March (Figure 2). Visually noticeable swelling of vegetative buds (phenophase 0) began in the second half of March (Figure 4, 5). The effective temperature at the beginning of phenophase 01 was insignificant, but at the end of February and in the second half of March, especially in the third decade, the maximum daytime temperatures were high – 10.6–15.0 °C, which contributed to the active development of vegetative buds. Light green areas of the first leaves (phenophase 07) appeared in the second decade of April, and at the beginning of the third decade of the month, the green tips of the leaves were clearly visible (phenophase 09) (Table 2). At that time, the total effective temperature was 89.8 °C. Therefore, in 2021, in the climatic conditions of NBG, the development of vegetative buds of *C. florida* lasted 45 days.

Principal growth stage 1: leaf development

Cornus florida has leaves with short petioles (3–20 mm long), ovate, elliptic, or obovate plates (5–12 × 2–7 cm), wedge-shaped or rounded base and sharply pointed apex. Their pubescence consists of Malpighian hairs. The adaxial surface is green, the abaxial surface is light green and whitish with tufts of truncated hairs in the corners of the secondary veins (Murrell and Poindexter, 2016).

In Kyiv, the opening of the first leaves of *C. florida* (phenophase 10) began almost simultaneously with the development of inflorescences at an effective temperature of 115.0 °C (Table 2, Figure 4, 5a–c). Further growth of the leaves occurred with a significant increase in the effective temperature. The first leaves fully unfolded (phenophase 11) in early May a few days after the beginning of flowering, and in mid-June they reached their final size (phenophase 19).

In a seasonal climate, the development of the leaves of woody plants, as well as the beginning of flowering, are determined by a complex of factors, among which temperature is the leading factor (Linkosalo et al., 2006; Parmesan, 2006; Polgar and Primack, 2011; Gerst et al., 2020; Denéchère et al., 2021). Funderburk and Skeen (1976) established a certain relationship between the dates of leaf opening and flowering of plants based on the results of phenological observations of 42 species of suburban forest near the city of Atlanta (Georgia, USA) during 1967–1971. Before flowering, leaves are formed in those species that begin to bloom after

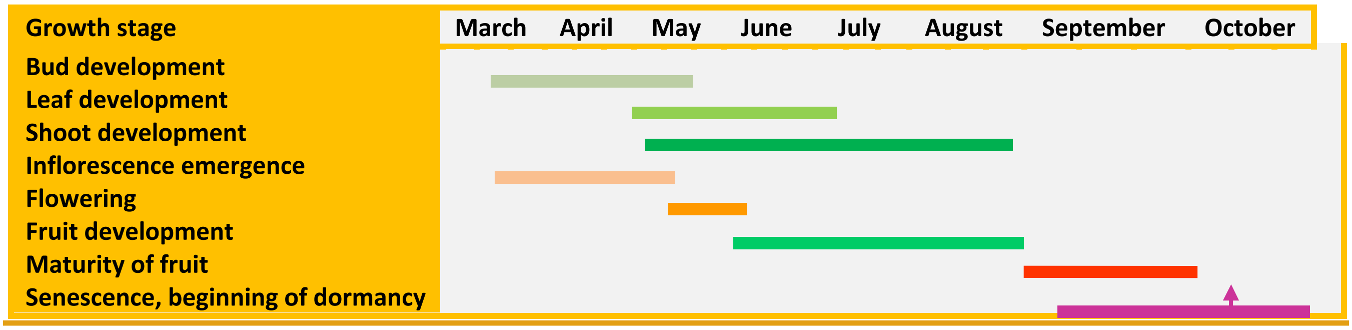

Figure 4 Phenological spectrum of seasonal development of *Cornus florida* L. in NBG, 2021
the arrow shows the beginning of the leaf fall

the 100th day of the year. After flowering, leaves develop in species that bloom until the 90th day of the year. More or less simultaneously with flowering period, the leaves of those species that bloom between 90 and 100 days of the year are formed. A similar sequence of seasonal phases of vegetation was also observed in some species of the genus *Cornus* introduced in NBG. In particular, the plants *C. mas* and *C. officinalis*

Figure 5a Phenological phases of development of *Cornus florida* L.

Figure 5b Phenological phases of development of *Cornus florida* L.

Figure 5c Phenological phases of development of *Cornus florida* L.

Table 2 Seasonal development of *Cornus florida* L. in NBG according to the BBCH scale, 2021

Scale	Characteristics	Date	t_{act}, °C	t_{eff}, °C
Principal growth stage 0: bud development				
01	The beginning of swelling of the buds: the buds (vegetative) are noticeably enlarged, and the scales are elongated, with a light border	16.03	35.9	5.9
03	The end of swelling of the buds: the scales are separated, and light green areas of the buds are visible	29.03		
07	Budding begins: the green tips of the first leaves are visible	01.04		
09	The green tips of the leaves are about 5 mm long	22.04	246.9	89.8
Principal growth stage 1: leaf development				
10	The green tips of the leaves are about 10 mm long; the first leaves begin to develop	30.04	312.0	115.0
11	The first leaves have unfolded, and others are still developing	11.05		
15	More leaves unfolded, and the first pair of leaves reached about half (≈7 cm) of their size	21.05		
19	The first leaves have reached the size typical for the species/variety (≈15 cm)	14.06	1,008.1	526.1
Principal growth stage 3: shoot development				
31	The beginning of the growth of shoots: the axes of the developing shoots are visible; about 10% of the expected length	06.05	389.5	162.5
32	Shoots have reached about 20% of the expected typical length	25.06		
35	Shoots have reached about 50% of the expected typical length	15.07		
39	Shoots have reached about 90% of the expected typical length	27.08	2,739.3	1,963.6
Principal growth stage 5: emergent inflorescence				
51	Bud swelling: bulbous inflorescence buds are closed, flat on top, surrounded by greenish-burgundy bracts	16.03	35.9	5.9
53	Budding: the outer bracts are open, the inner bracts are still closed	29.03		
55	All bracts are open, beginning to increase in size; the tops of individual densely arranged flower buds are visible	15.04		
56	Bracts are completely separated, enlarged, concave, outer – greenish-burgundy, inner – greenish-white; flower buds of the central part of the head are separated from each other; the petals clearly exceed the sepals	22.04		
57	Bracts are petaloid, deviated by almost 45°; flower buds in the "green bud" stage	30.04		
59	Petaloid bracts are pinkish-white, horizontally oriented, and have reached their final size; flower buds in the "yellow bud" stage	10.05	433.1	186.1
Principal growth stage 6: flowering				
60	The first flower opened	11.05	450.2	198.2
61	Beginning of flowering: about 10% of the flowers are open	14.05		
65	Full bloom: at least 50% of the flowers are open, the petals of the first flowers have fallen	16.05		
67	Withering of most flowers: fertilization occurs, petals and stamens fall; senescence of bracts	20.05		
69	End of flowering: bracts, petals, and stamens of all flowers have fallen	27.05	696.7	364.7
Principal growth stage 7: fruit development				
71	Fruit set: all ovaries are green, the same in shape and size	28.05	714.2	377.7
72	Fertilized ovaries are noticeably enlarged; the crown of the sepals of all ovaries is green	06.06		
73	Fertilized ovaries are almost twice as large as unfertilized ones	14.06		
75	The fruits have reached about half their final size; unfertilized ovaries are green and do not fall	15.07		
77	Fruits about 80% of the final size; the crown of the calyx and the column of the ovary begin to die, but remain on the fruit	12.08		
79	Fruits have reached their final size, green; unfertilized ovaries do not fall	20.08	2,606.8	1,866.1

Continuation of Table 2

Scale	Characteristics	Date	t_{act}, °C	t_{eff}, °C
	Principal growth stage 8: maturity of fruit			
81	The beginning of fruit ripening: a change in the colour of the fruit from light green to yellowish and to light pink; unfertilized ovaries are light green; the crown of the calyxes and the columns of the ovaries are brown	27.08	2739.3	1963.6
85	The color of the fruits progresses, becoming light red; unfertilized ovaries are yellowish-green; the crown of the cups and the column of fruits and ovaries acquire a dark anthocyanin color	01.09		
87	Increasing color intensity; 80% of the fruits have reached technical ripeness; the beginning of shedding of unfertilized ovaries	16.09		
89	All fruits are ripe for consumption: they have a typical taste and firmness; almost all unfertilized ovaries have fallen	04.10	3258.7	2293.0
	Principal growth stage 9: senescence, beginning of dormancy			
91	The growth of the shoots is complete, the leaves are still green	31.08	2815.0	2019.3
92	The leaves begin to change color	02.09		
93	The beginning of falling leaves	11.10		
95	Half of the leaves have changed color or fallen off	18.10		
97	All the leaves have fallen	29.10		
99	The beginning of the winter rest period	30.10	3466.3	2380.6

t_{act}, °C and t_{eff}, °C were calculated at the beginning and end of each phenophase

Siebold & Zucc. (subgenus *Cornus*) unfurl the leaves after flowering. According to our data, in 2021, their flowering began on March 30 – April 5, that is, 89–91 days from the beginning of the year. In *C. florida* (subgenus *Cynoxylon*) in DeKalb County (Georgia, USA), leaf development began on the 88th day of the year, and flowering was observed on the 101st day (Funderburk and Skeen, 1976). In NBG (Kyiv), the leaves of *C. florida* began to develop on the 121st day from the beginning of the year, and the first flowers opened on the 132nd day (Table 2). Therefore, in this species, the sequence of development phases is preserved regardless of the geographical location of the plants. While the date of the beginning of a separate phenophase varies and is determined, in a certain way, by the degree of influence of a complex of exogenous factors.

Principal growth stage 3: shoot development

After the unfolding of the first pair of leaves (stage 31), the first internode becomes visually visible, just as in species of the subgenus *Cornus* (Klymenko and Ilyinska, 2021). Formed vegetative shoots (phenophase 39) have from four to five to seven to eight internodes. The longest length (15–18 cm) is typical for the second internode, and the smallest (3–4 cm) for the last one. At the end of the growing season, the leaves of the distal node often remain underdeveloped. The main growth of shoots terminates at the end of August (Table 2).

Principal growth stage 5: inflorescence emergence

Cornus florida (subgenus *Cynoxylon*) has a cymoid head inflorescence, in contrast to species of the *Cornus* subgenus (*C. mas*, *C. officinalis*, etc.), which have botryoid umbel inflorescences (Feng et al., 2011, 2012), which is well demonstrated on the fifth stage (phenophase 5) of the seasonal development of plants.

In 2021, the dormant period of generative buds of *C. florida* continued until almost mid-March, just like vegetative buds. Visually noticeable swelling of the buds (phenophase 51) began with cracking of the outer bracts (Figure 5a–c). The inner bracts remained still closed (Table 2). After almost a month, all the bracts separated from each other and started to enlarge, resulting in the apices of several flower buds (phenophase 55). Phenophase 56 is characterized by intense growth and color change of bracts and the development of flower buds (rolled petals rise on the calyx). Distinct features of phenophase 57 are a deviation of enlarged bracts at an angle of about 45° and well-developed and separated flower buds (“green bud“ stage). The final stage of development of generative buds (phenophase 59) is characterized by horizontally oriented petaloid bracts that have reached the final size and shape (broadly obovate with a notch at the top) and typical (pinkish-white in our plants) color and closed flower buds with yellow petals ("yellow bud" stage).

Cornus florida bracts complete development during phenophase 5. In NBG in 2021, their development and functioning lasted 52 days. In *C. florida* plants from the state of North Carolina (Raleigh, USA), bracts existed for a shorter time, about a month (Feng et al., 2012), which, we believe, reflects a certain dependence between the duration of their functioning and temperature and geographical factors. In our plants, a distinct synchronicity was also observed between the growth processes of bracts, vegetative buds, and typical leaves (Table 2, Figure 4, 5a–c). At the same time, practically, bracts developed (phenophase 53), vegetative buds bloomed, and light green areas of leaves appeared (phenophase 07). The full development of the bracts (phenophase 59) corresponded to the unfolding of the first pair of leaves (phenophase 11). Therefore, the vegetation of *C. florida* in NBG (2021), as well as in the region of its native range (Lamb, 1915; Reader, 1975; Funderburk and Skeen, 1976), begins with the simultaneous development of vegetative and generative buds.

Cornus florida has two features: intensive growth of bracts, as a result of which they acquire a petaloid shape, and lack of growth of peduncles, due to which the flowers are sessile. In *C. mas*, the bracts remain green and change little in size, and the peduncles are elongated at the beginning of flowering, as is characteristic of umbrellas (Gunatilleke and Gunatilleke, 1984; Klymenko and Ilyinska, 2021). Later, the bracts of *C. florida* fall off, and in *C. mas* they remain on the plant until the end of the vegetation period or even longer.

Principal growth stage 6: flowering

The flowers of *C. florida* are sessile, as is characteristic of a head-shaped inflorescence, and are very small. Hypanthium appressed-hairy, sepals 0.5–0.8 mm long, petals cream or greenish-yellow, 3.0–3.5 mm long (Murrell and Poindexter, 2016). From 15 to 35 flowers develop in one flower head (Gunatilleke and Gunatilleke, 1984). About 20 flowers were observed in the inflorescences of plants introduced in NBG. Corolla and stamens fall after flowering. In *C. florida*, in contrast to *C. mas*, anthers crack in mature flower buds, while in the latter after flower opening (Gunatilleke and Gunatilleke, 1984).

In Kyiv, as well as in the homeland of the species (Reader, 1975; Funderburk and Skeen, 1976), the flowering of plants begins simultaneously with the development of leaves. In 2021, in NBG, flowering of *C. florida* (phenophase 6) started on May 11 at an effective temperature of 198.2 °C (Table 2, Figure 4), which according to our data is six weeks later than *C. mas* varieties. The flower in the central part of the inflorescence was the first to open (phenophase 60), which is typical for cymoids. In the second half of flowering (phenophase 67), aging of the bracts was observed – the brightness of the color decreased, and brown spots appeared. Later they began to fall. At the end of flowering (phenophase 6), most of the bracts have fallen. In 2021, the flowering period lasted 17 days, which is close to similar data obtained in 2010–2012 (Teslyuk, 2012). Then, a flowering of *C. florida* in NBG continued for 12–18 days from May 5–12 to May 22–23. Therefore, the start date and duration of flowering of *C. florida* in different years in Kyiv (NBG) more or less coincide.

The flowering period of plants occupies a special place in the history of phenological observations. Perhaps this is the first phase of seasonal development, which began to be documented long before the emergence of phenology as a separate scientific discipline (Sparks and Menzel, 2002; Aono and Kazui, 2008). In floristic publications, from ancient to modern, flowering is one of two phenophases (the other is fruiting), which is necessarily given for all species. For example, according to "The Flora of North America North of Mexico", the flowering period of *C. florida* within its native range begins in March and ends in June, respectively, in its southern and northern parts (Murrell and Poindexter, 2016).

The onset of flowering, as well as other phenophases of *C. florida* in the region of native distribution, has been studied for more than 100 years (Smith, 1915; Wyman, 1950; Lieth and Radford, 1971; Funderburk and Skeen, 1976). It has been established that the date of the beginning of flowering varies geographically (Wyman, 1950) and is not constant in one locality from year to year (Smith, 1915). Plants in the southernmost part of the native range of the species, in particular in the state of Florida (Glen St. Mary, USA) bloom first (in mid-February or early March) (Wyman, 1950; Reader, 1975). Then the flowering of plants spreads to the north. In DeKalb County, Georgia (33° 51‘ N) in 1968, the first flowers opened on April 8, and the average date of onset of flowering during 1967–1971 ranged from April 6 to 10 (Funderburk and Skeen, 1976). In the capital of the USA (Washington DC; 38° 53‘ N), in 1914, flowering began in mid-April and lasted almost until the last decade of May (Lamb, 1915). According to Thomas Mikesell (Smith, 1915), in the city of Wauseon

(Fulton County, Ohio; 41° 33′ N) during 1883–1899 and in 1912, the flowering of the flowering plant began as early as last, and at the latest on May 30 and lasted 17 days. In the Arnold Arboretum of Harvard University (Boston, MA (42° 17′ N) during 1940–1950, flowering was observed in mid-May (Wyman, 1950). In the state of Maine (Portland, USA; 43° 40‘ N) and in the southern part of Ontario (Canada) *C. florida* begins to bloom in the second half of May (Wyman, 1950; Reader, 1975). Reader (1975) summarized previously known data and with the help of volunteers for four years (1970–1973) obtained indicators (1,200 observations) about the beginning of flowering of plants in almost the entire territory of the native range of *C. florida*. The author established that annual fluctuations in the date of flowering are usually caused by the sum of air temperatures above 2.2 °C in the 6 weeks before its onset, and geographical variations depend on environmental conditions, which confirms the previously established relationship between the date of dogwood flowering and air temperature (Reader, 1975).

The flowering period of *C. florida* in Kyiv (50° 27′ N) practically coincides with those in the northernmost part of its native range (about 47° N), according to Reader (1975). The duration of flowering of the species in Kyiv (12–18 days) and in the city of Wauseon, Ohio (17 days), according to the data of Mikesell (Smith, 1915), is also close, which confirms the conclusion of Funderburk and Skeen (1976) regarding the narrow range of dates flowering of this species. However, in Case Estates Botanical Garden (Weston, Massachusetts; 42° 21′ N) in 1984, flowering lasted five to six weeks (Gunatilleke and Gunatilleke, 1984), which is due, apparently, to very specific microclimatic growing conditions plants.

Principal growth stage 7: fruit development

Cornus florida is a cross-pollinated self-incompatible species, therefore, not all ovaries are fertilized (Gunatilleke and Gunatilleke, 1984). The development of the fruits of this species has been studied much less compared to the flowering phase. According to our data, after flowering (phenophase 71), all ovaries have almost the same shape, color (green), and size. In them, the crown of the calyx and the column of the ovary are also well-developed. In the future, unfertilized ovaries stop developing. A visually noticeable increase in the size of the fertilized ovaries (phenophase 72) is observed approximately one and a half weeks after the end of flowering, and the final size of the fruits after 12 weeks (phenophase 79).

According to Gunatilleke and Gunatilleke (1984) at the Case Estates Botanical Garden (27 km from Boston, Massachusetts, USA), differences in the size of fertilized and unfertilized ovaries of *C. florida* were noticeable four weeks after pollination, and fruit development lasted 16 weeks. The shorter duration of the period of fruit development in Kyiv is probably caused by a significant summer drought in 2021, especially in summer. The summer months of the Boston region, near which the Case Estates Botanical Garden is located, are characterized by higher average monthly temperatures (24. 2, 27. 8, 26. 9 °C, respectively, June, July, August) and average precipitation (90, 76, 90 mm, respectively, June, July, August). Therefore, *C. florida* plants are better adapted to high summer temperatures and react more sensitively to a low level of moisture supply.

Cornus florida differs from *C. mas* in some features of the biological development of fruits. In it, in particular, unfertilized ovaries do not fall off until the end of fruiting and the crown of the calyx and column of the ovary do not die. Whereas the "Fruit Development" phenophase of *C. mas* and other species of the subgenus *Cornus* is known to be characterized by two waves of dying of unfertilized ovaries and gradual elimination of the crown of the calyx and column of the ovary (Klimenko, 1990).

Principal growth stage 8: maturity of fruit

Cornus florida drupes are ellipsoidal, usually red, very rarely yellow (13–18 × 6–9 mm), endocarps are also ellipsoidal (10–12 × 4–7 mm), smooth.

In Kyiv in 2021, fruit ripening (phenophase 81) began at the end of August (Table 2). Fruits began to gradually change color from light green and yellowish to light red, and unfertilized ovaries to yellowish (Figure 4, 5a–c). During phenophase 85, the color of the crown of the calyxes, fruit columns, and unfertilized ovaries changed. After reaching the stage of technical ripeness of fruits (phenophase 87), unfertilized ovaries began to fall. In heads with fully mature fruits, unfertilized ovaries are usually absent (phenophase 89).

So, in Kyiv in 2021, the fruit ripening process lasted about six weeks, which is twice as long (six weeks against three) as in 2010–2012 (Teslyuk, 2012). The difference in the duration of the fruit ripening process is probably due to the use of different observation methods, as well as the very hot and dry summer and autumn of 2021 (Table 1). Ripe fruits of *C. florida* plants introduced in NBG, as well as in the region of native distribution of the species, do not fall for a long time, just like *C. officinalis* and unlike *C. mas* and *C. sessilis*.

According to our data in NBG (2021), the fruits of *C. florida* began to ripen almost a month earlier, compared to the early cultivars of *C. mas*, and almost simultaneously with its late cultivars.

Forms with red fruits are most characteristic of *C. florida*. However, since the beginning of the last century (Rehder, 1921, 1927), the yellow color of fruits has been known. Rehder (1921) described a new yellow-fruited form (*C. florida* f. *xanthocarpa* Rehder) based on a specimen found in North Carolina (USA) in the herbarium of the Arnold Arboretum (Boston, Massachusetts, USA) and plants with yellow fruits from Long Island (New York state, USA). Later, in 1927, the author slightly changed the taxonomic rank of such plants and considered them not forms, but a variation of the flowering dogwood (*C. florida* var. *xanthocarpa* Rehder), that is, those of native origin. In the future, there will be a discussion about the status of these plants. Specimens described by Rehder (1921) and Howard (1961) were considered the variety. MacDonald (1968) found eight plants of *C. florida* with yellow fruits in the state of Tennessee (USA), of which five were spontaneous and three were found in commercial nurseries. The author concluded that the yellow-fruited varieties of *C. florida* come from plants of native flora. It was also established that two anthocyanins, peonidin, and petunidin, are absent in the exocarp of yellow fruits of *C. florida* (Chester and Stone, 1964). All *C. florida* biotypes introduced in the NBG have red fruits. So, for this species, as well as for *C. mas*, red-fruited and yellow-fruited forms are characteristic.

As already noted, fruiting is the second phenophase (the first is flowering) of the seasonal development of plants, which attracts the special attention of not only agrarians but also scientists of many botanical disciplines, including florists. For example, in the flora of North America (Flora of North America north of Mexico) it is indicated that the fruits (stones) of *C. florida* ripen during August – October (Murrell and Poindexter, 2016). According to Day and Monk (1977), the ripening of *C. florida* fruits begins when plant biomass stops increasing, that is, vegetative organs stop growing, and leaves begin to change color. For example, in the Southern Appalachians in southwestern North Carolina, fruit ripening and leaf color change began almost simultaneously, October 6–8 (Day and Monk, 1977). In the genotypes we studied, the main growth of shoots ended at the end of August. Almost at the same time, the first reddening fruits became noticeable, and the leaves began to change color on September 2 (Table 2, Figure 4, 5a–c). Therefore, it can be assumed that the processes of completion of vegetative growth of plants and ripening of fruits are interrelated and genetically determined, while the initial date of these processes, like other phenophases, is largely determined by a complex of exogenous abiotic factors, including geographical location.

Principal growth stage 9: senescence, beginning of dormancy

The last, autumn, phenophase of *C. florida* in Kyiv (2021) lasted almost two months (Table 2, Figure 4, 5a–c). The main growth of shoots was completed at the end of August almost simultaneously with the beginning of fruit ripening. The leaves began to change color in September (phenophase 92). Fall began in the second decade of October (phenophase 93) and within two weeks the leaves had completely fallen, probably due to very dry September and October (Figure 2). The rapid fall of *C. florida* confirms the known data on the negative effect of heat stress on the duration of the autumn phenophase and the vegetation period, in general.

Autumn phenology (phenophase 9), visually defined by the change in leaf color and fall, completes the growing season of woody plants of a seasonal climate. The date of onset of senescence and dormancy (phenophase 9) affects the duration of the growing season of plants, but this stage of their development has been little studied (Vitasse et al., 2009; Gallinat et al., 2015; Xie et al., 2015). However, it is known that in a seasonal climate, factors of autumn phenology include short day length, low temperatures, frost, drought or floods, and strong winds, which in a certain combination determine the beginning and duration of the rest period (Gallinat et al., 2015). Low temperatures, heavy rainfall, and severe heat stress lead to early dormancy, while moderate heat and rainfall slow leaf senescence and dormancy onset (Xie, Wang and Silander, 2015).

In the climatic conditions of Ukraine (NBG), plants of *C. florida* (subgenus *Cynoxylon*), as well as the studied genotypes of species and varieties of the subgenus *Cornus* (Klymenko, 1990; Klymenko et al., 2021; Klymenko and Ilyinska, 2021, 2023), undergo a full cycle of seasonal development. In 2021, the growing season of *C. florida*, from the beginning of swelling and budding to the end of October, lasted 230 days. In the territory of native distribution, the vegetation period of *C. florida* lasts from 160 (southern Michigan) to more than 300 days in the state of Florida, which reflects the influence of the geographical coordinates of the area on the specificity of the seasonal development of plants (Lieth and Radford, 1971; Winstead et al., 1977; McLemore 1990; Murrell and Poindexter, 2016). The main climatic factors and edaphic conditions for growing plants in the NBG, according to most indicators, are within the range of their variability in the region of native distribution of the species (Table 1), which serves as a positive bioecological prerequisite for the widespread introduction of *C. florida* into culture as a valuable decorative and medicinal plant.

Conclusions

In the climatic conditions of Ukraine (NBG), plants of *C. florida* (subgenus *Cynoxylon*) go through a full cycle of seasonal development, just like biotypes of species and cultivars of the subgenus *Cornus*. In 2021, the growing season of *C. florida* lasted 230 days. The wide range of variation of climatic factors within the range of the species, its resistance to drought, as well as the seasonal development of *C. florida* in NBG in the dry year of 2021, testify to its adaptive tolerance to seasonal water deficit and serve as a positive bioecological prerequisite for the widespread introduction of *C. florida* into culture in the climatic conditions of Ukraine, as a decorative plant with high aesthetic value and a promising new source of plant raw materials.

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical statement

This article doesn't contain any studies that would require an ethical statement.

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