

## POLYCYCLISM AND PHENOLOGICAL VARIABILITY IN THE COMMON OAK (*QUERCUS ROBUR* L.)

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**Abstract** - Polycyclism is the ability for a plant to produce several flushes in the same growing season. The rare phenomenon of common oak (*Quercus robur* L.) summer flowering is proof of complex polycyclism. Common oak summer flowering and the unusual transformation of inflorescences were the starting point for this study of the phenological variability of common oak trees in identical site conditions. This paper presents comparative research of leaf flushing, flowering, and leaf fall phenophases in a common oak with summer flowering and a control tree in which this phenomenon was not observed. Both trees displayed frequent polycyclism (polyphase formation of annual shoots during the growing season), but with different intensities depending on the trees and the years. Compared to the control tree, the tree with summer flowering was characterized by a later onset of leaf-flush phenophase and leaf fall phenophase and a longer retention of the leaves in the crown.

**Key words:** *Quercus robur* L., summer flowering, phenological traits, polycyclism

### INTRODUCTION

The Common oak occupies the largest range in Europe of all the species in the genus *Quercus* as the most represented in the temperate belt of the northern hemisphere. In Serbia, the common oak (*Q. robur* L.) is an autochthonous, widely distributed species, particularly in Vojvodina along the rivers Sava and Danube, in Mačva and Pomoravlje. It is also the most represented tree species after beech and sessile oak (Šoškić, 2006). Common oak adaptation to different site conditions has resulted in a considerable number of forms and varieties of the species (Gajić and Tešić, 1992). Individual differences in this species are often greater and more pronounced than the differences from other species of the same genus (Bacilieri et al., 1994; Kleinschmit et al., 1995; Bodenes et al., 1997; Perić et al., 2006; Bašić et al., 2007; Batos, 2010). A

high degree of the *Quercus* ecological and genetic variance is especially interesting for the systematics in which the precise differentiation of species is attempted nowadays by using chemical markers (secondary metabolites, DNA analysis) (Gomory et al., 2001).

Phenological traits are under the very high influence of hereditary factors and are implemented in the systematics of *Quercus* species (Schlarbaum and Bagley, 1981; Kadomatsu, 1997; Breznikar and Horvat-Marolt, 1998; Figueiredo Goulart et al., 2005). In the establishment of common oak plantations, it is very important to select the suitable individuals as regards the onset of leaf flushing. In this sense, common oak with late leaf flushing has more favorable development potentials (Stamenković et al., 1995) and exhibits greater resistance to predator infesta-

tion (Feeny, 1970; Scalbert and Haslam, 1987; Klapper et al., 2001; Wesołowski and Rowinski, 2008). In addition, in the establishment of seed orchards, it is important to synchronize the flowering times of individuals because good inter-pollination guarantees the production of genetically better quality seeds (Franjić et al., 2011).

Polycyclism, i.e. the polyphase formation of annual shoots, is a characteristic trait of *Quercus* species. This trait characterizes the following *Quercus* species represented in Serbia: *Q. cerris* L. (Janković, 1956; Bobinac and Vilotić, 1998), *Q. robur* L. (Bobinac, 1994a; Franjić, 1996), *Q. petraea* (Matt.) Liebl. (Ponton et al., 2004), *Q. virgiliana* Ten. (Bobinac et al., 2000). Common oak polycyclism is displayed in various phases of its ontogenetic development, but much more often in the youngest phases of development (Bobinac, 1994b). Significant differences between the growth stages are observed in leaf and shoot morphology, anatomy and physiology. Leaf area and size, number of leaf veins, shoot length, chlorophyll content and photosynthesis rate are significantly greater in the shoots of the second growth stage (Masarovicova, 1991; Ponton et al., 2004; Broshilov, 2006). The growth stages also differentiate in leaf color (Borzan, 1993). The leaves of the second growth stage also have a higher number of stomata and smaller stomatal sizes compared to the leaves of the first growth stage (Batos et al., 2006).

Summer flowering is specific proof of the complex polycyclism in *Quercus* species. In Serbia, this phenomenon was observed on the common oak – *Q. robur* and on the large-leaved downy oak – *Q. virgiliana* (Bobinac, 1994a; Bobinac et al., 2000; Bobinac et al., 2001; Bobinac and Tucović, 2005). It was reported that in 1999 common oak summer flowering was observed on only one out of 134 monitored trees in the area of Belgrade and on only one out of 85 clones and one ramet of that clone in the clonal seed orchard in the area of Sremska Mitrovica. Male and female inflorescences on summer shoots are characterized by a more or less early antocladia, i.e. the lignification of sylleptic flower-generative branchlets. In the area of Dalmatia (Croatia), an unusual hermaphro-

ditic unseasonal flowering was observed in only one year by a single “green oak” tree (*Quercus* x *viridis* Trinajstić 1974), which is supposed to be a hybrid *Q. cerris* f. *austriaca* x *Q. ilex*. The flowers consisted of a female inflorescence that was more elongated and with more flowers than usual, and a male inflorescence with developed stamens and pollen (Borzan et al., 1997; Borzan, 2000). These authors have pointed out that the phenomenon cannot be explained by climate changes only. They assumed that it represents a case of a primitive - ancestral condition in the family Fagaceae.

Polyphase growth can be induced by traumatic factors, mechanical injuries, changeable conditions of environmental factors – primarily climate, and their synergistic effect with biotic factors (Sabatier et al., 2003; Girard et al., 2010; Bobinac, 2011). It is supposed that this process is based on the interaction of genotype and environmental factors, i.e. the capacity of common oak ontogenetic adaptation to different environmental conditions (Bobinac, 2011).

This paper analyzes the common oak phenological variability from the aspect of polycyclism and the phenomenon of summer flowering as its specific confirmation.

## MATERIALS AND METHODS

The phenological traits of a common oak tree with frequent summer flowering (tree 1) and a neighboring control tree (tree 2) in which this phenomenon has not been observed to date, were monitored in the City Park at Banovo Brdo (Belgrade, Serbia). The trees were adjacent; they were of approximately the same age, size and crown form, and in full physiological maturity (Fig. 1). Their phenology was monitored in two consecutive years (2005, 2006), once a week during the leaf flushing, flowering, and leaf fall phenophases.

Leaf-flush phenophase, regarded as any stage of leaf development from the onset of the first bud-break to the full size of the leaves, was observed through six development levels (inter-stages) differ-



**Fig. 1.** Leaf fall phenophase of the analyzed common oaks (*Quercus robur* L.) right – tree with summer flowering (1), left – control tree (2). (27<sup>th</sup> Oct. 2005, photo by Batos, B.).



**Fig. 2.** Common oak (*Quercus robur* L.) summer flowering – tree 1 (6<sup>th</sup> Aug. 2007, photo by Batos, B.).

entiated per growth stages. The first two levels (levels 1, 2) refer to budding inter-stages and four levels (levels 3, 4, 5, 6) include leaf-flushing inter-stages, including flowering (Kadomatsu, 1997; Chuine and Cour, 1999; Visser and Holleman, 2001; Richardson et al., 2006). Budding inter-stages last from the onset of the first bud changes – bud swelling and expansion to the opening of bud scales and the emergence of the first young leaflets. Leaf-flush inter-stages last from the opening of bud scales and emergence of the first young leaflets to the maximal leaf development.

Leaf fall phenophase lasts from the onset of leaf drop to complete or almost complete leaf fall. Leaf fall phenophase consists of five levels (inter-stages) expressed by the percentage of fallen leaves, compared to the fully leafed (100%) crown (Schlarbaum and Bagley, 1981).

In the present work we analyzed the differences between the trees and the years of monitoring, as follows: onset and duration of leaf-flushing phenophase during the spring leaf flush (the first growth stage) and the summer leaf flush (the second growth stage), onset and duration of leaf fall phenophase, and the vegetation period. The onset of a phenophase is defined by the total number of calendar days from the beginning of the year to the

date when the onset of the phenophase was recorded. The duration of a phenophase is defined here as the number of days from the onset of the phenophase to the end of the phenophase. The growing season is defined as the number of days from the onset of the spring leaf-flush phenophase to the onset of the leaf fall phenophase, i.e. it is defined as the difference between the number of calendar days to the onset of the leaf drop and the number of days to the onset of leaf flushing (Bunuševac and Žujović, 1971; Hemery et al., 2005).

## RESULTS

### *Leaf-flush phenophase spring leaf flushing (the first growth stage)*

The earliest onset of spring leaf flush (1<sup>st</sup> growth stage) of the tree with summer flowering (tree 1) occurred on April 6<sup>th</sup>, and the latest onset of spring leaf flush was on April 15<sup>th</sup>. Leaf flushing of the control tree (tree 2) started in both years on March 30<sup>th</sup>. In both study years, the onset of leaf flush of tree 1 was 1-2 weeks later than tree 2. The onset of each inter-stage of leaf-flush phenophase in tree 1 also occurred 1-2 weeks later than the control. On average, each leaf-flush inter-stage lasted for 1-2 weeks. Intensive leaf growth, which coincided with the optimum pollination of the male catkins, occurred in the last

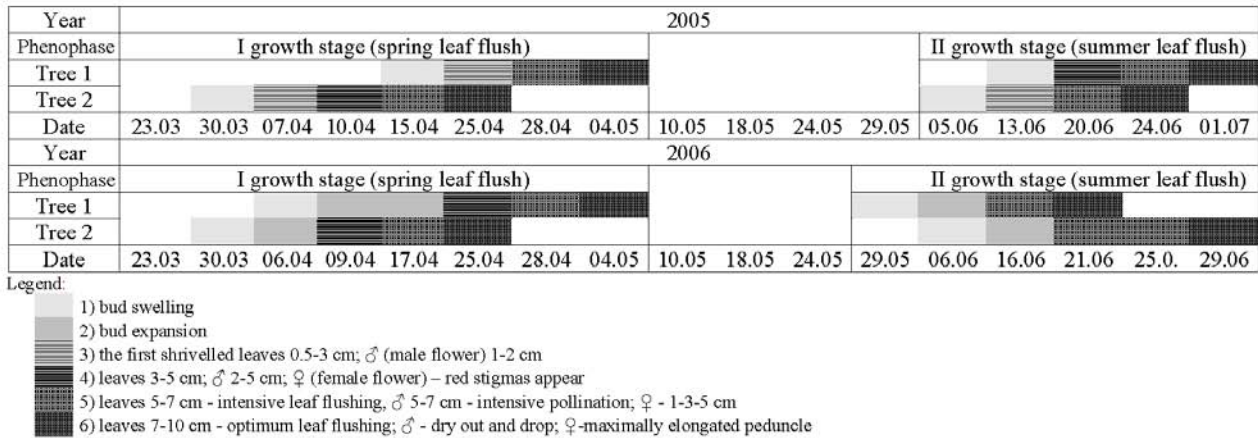


Fig. 3. Common oak (*Quercus robur* L.) leaf-flush phenophase.

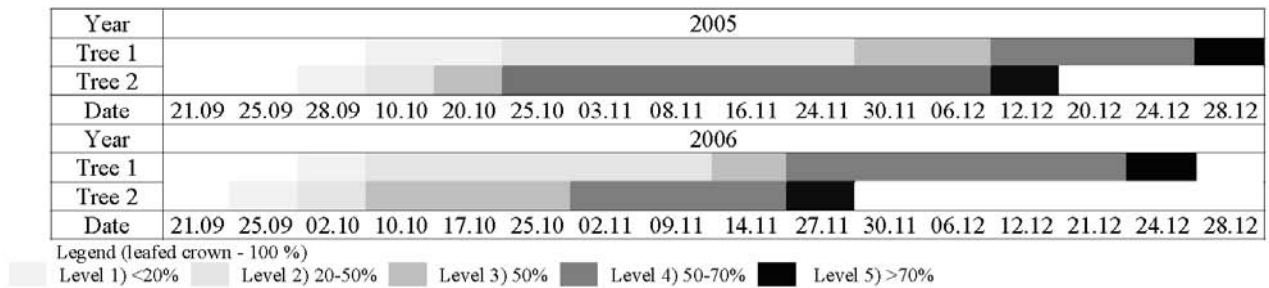
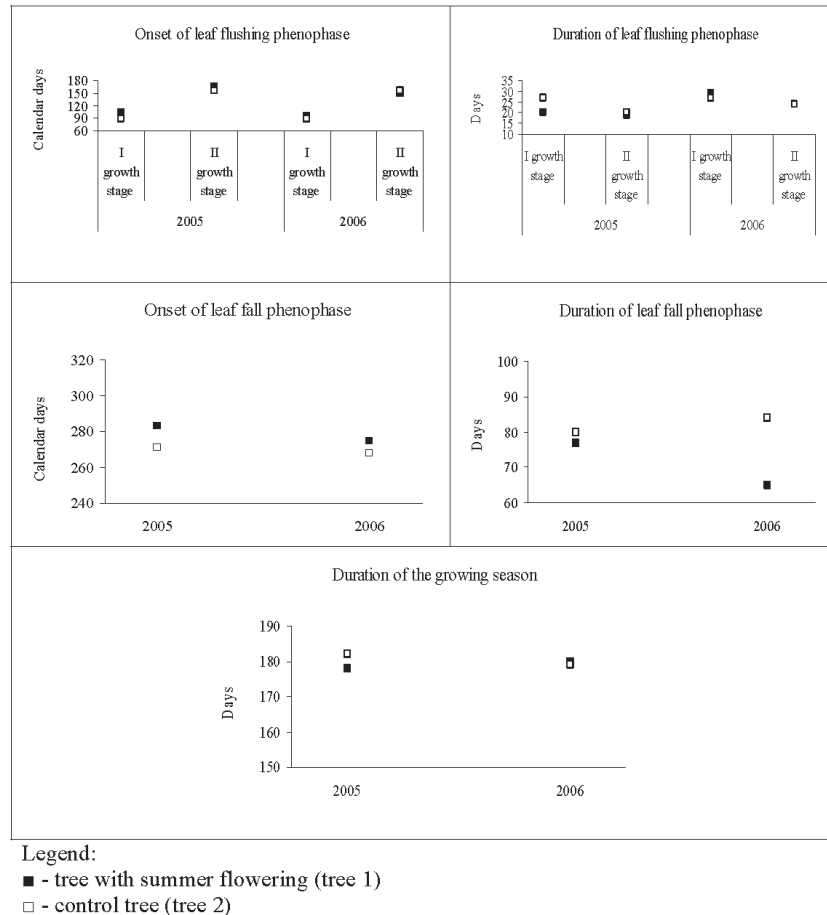


Fig. 4. Common oak (*Quercus robur* L.) leaf fall phenophase.

week of April for tree 1 and in mid-April for tree 2. The pollination period was exceptionally short, only a few days, compared to the period of intensive leaf flush that lasted on average for 1-2 weeks. The maximal extension of leaves in tree 1 occurred in the first week of May and in tree 2 in the last week of April. The period of maximal leaf extension was also the end of the leaf-flush phenophase, as well as the end of pollination, when male catkins dry out and fall, and female generative branchlets extend maximally. The duration of spring leaf flushing depended on the tree and differed from year to year, but there was no clear-cut regularity; in tree 1 it was 20 days in the first year and 29 days in the second year, and in tree 2, it was 27 days both years, i.e., 2.8 weeks (the first year) and 4.1 weeks (the second year) in tree 1 and 3.8 weeks (in both years) in tree 2 (Figs. 3, 5).=

#### Summer leaf flushing (the second growth stage)

Summer growth of shoots (the second growth stage) occurred in both trees, with different intensities per study year. The onset of summer leaf flushing varied per trees and per year; it occurred between May 29<sup>th</sup> and June 13<sup>th</sup> in tree 1 and between June 5<sup>th</sup> and 6<sup>th</sup> in tree 2. The difference between the trees at the beginning of summer leaf flushing in both study years was about 7 days. The summer leaf-flushing inter-stages were somewhat shorter compared to the spring growth inter-stages, i.e. spring leaf flushing. The summer leaf flushing of tree 1 lasted for 19 days in the first year and for 24 days in the second year. As for tree 2, it was 24 days in the first year and 25 days in the second year, i.e. 2.7 weeks in the first year, and 3.4 weeks



**Fig. 5.** Common oak (*Quercus robur* L.) phenological variability: onset and duration of leaf-flushing phenophase, onset and duration of leaf fall phenophase and duration of the growing season.

in the second year for tree 1, and 3.4 weeks in both years for tree 2 (Figs. 3, 5).

Summer flowering, which was observed for the first time in 1999 in tree 1, was displayed as elongated female and individual male inflorescences that contained pollen. From 2004 through 2010 only sclerenchymatous flower-generative branchlets were formed without clear-cut differentiation and full development of male and female flowers. There was no pollen production and no fully formed fruits (Fig. 2).

In contrast to the spring leaf flushing of the summer-flowering tree, which occurred later in both study years compared to the control tree, the onset of summer leaf flushing occurred later in the first year

and in the second year it was earlier compared to the control tree. On average the duration of summer leaf flushing for both years was shorter by one week compared to the duration of the spring leaf flushing of both trees.

The third growth stage was recorded only once, i.e. in 2006 at the beginning of July during the summer leaf flushing. Compared to the second growth stage, which occurred in the whole crown of both trees, the third growth stage was considerably less evident in both trees, i.e. there were only a few shoots. As the third growth stage was recorded only in one year, it cannot be explained in more detail or compared more precisely to the earlier growth stages (Figs. 3, 5).

### *Leaf fall phenophase*

The leaf fall phenophase of the summer-flowering tree lasted from October 2<sup>nd</sup> to 10<sup>th</sup>, and the control tree leaf fall was from September 25<sup>th</sup> to 28<sup>th</sup>, i.e. 1-2 weeks earlier. During the winter, tree 1 retained leaves in its crown through the last week in December, on average for one to three weeks longer than tree 2. Leaf fall lasted in both years longer in tree 1, altogether 80 days in the first year and 84 days in the second year, compared to tree 2, in which it lasted for 77 days in the first year and 65 days in the second year, i.e. 11.4 weeks and 12 weeks in tree 1 and 11 weeks and 9.3 weeks in tree 2, respectively. This means that in both study years tree 1 retained the leaves in the crown on average for 2-3 weeks longer than tree 2. All the parameters of the leaf fall phenophase (onset, cessation, duration) showed the differences, both between the trees and from year to year (Figs. 4, 5).

### *Duration of the growing season*

The differences in the duration of the vegetation period were not great either between the trees or between the years. In tree 1, vegetation lasted for 178 and 180 days respectively, in the first and the second study years, and in tree 2, for 182 days and 179 days, or 25.4 weeks and 25.7 weeks in tree 1 and 26 weeks and 25.6 weeks in tree 2 respectively (Figs. 4, 5).

## DISCUSSION

The reference data on common oak phenology in Serbia are very scarce. The study reported by Batos (2010) presents a broad analysis of the common oak in Serbia, including phenological traits, and points out its very high intraspecific variability. This study points to an earlier commencement and cessation of the common oak growing season compared to the data reported 40-50 years ago (Bunuševac, 1961; Jovanović and Uvalić-Tomić, 1971). It could be assumed that the earlier onset of the vegetation period is a consequence of climate changes. The presented results point to the earlier onset of leaf flushing and a longer leaf re-

tention over the winter, and also support the thesis on the change in vegetation cycle that is affected by weather conditions. There are also changes in leaf-flushing onset but it does not affect the total duration of this phenophase. There are similar observations also in other references. According to Jovanović and Uvalić-Tomić (1971), the earlier beginning of the vegetation period, mostly induced by higher temperatures, did not have a significant impact on phenophase length and did not disturb the phenological balance. In the analysis of the leaf-flushing phenophase in the common oak provenance test in Croatia, Perić et al. (2006) pointed out the significant effect of years on leaf-flushing phenophases, and reported that the leaf-flushing phenophase lasted from 3 to 6 weeks in different years of phenological observation.

The high common oak intraspecific variability also includes the phenological traits whereby its different varieties are selected: the early (*Q. robur* var. *praecox* Čern.) and the late (*Quercus robur* var. *tardiflora* Čern.) common oak, with transient varieties (Erdeši, 1971). According to reference data, the time difference between the trees with the earliest and the latest budburst can be from 3-5 weeks. Crawley and Akhteruzzamax (1988) report the difference of a maximum 3 weeks, unchanged from year to year, and Wesolowski and Rowinski (2008) report a difference of 5 weeks. The researchers in Serbia have reported the difference of 2-3 weeks between the early and late flushing of common oak forms (Gajić and Tešić, 1992), and according to Jovanović and Uvalić-Tomić (1971) it is 3-5 weeks. Based on the presented results, the summer flowering tree in both years of phenological monitoring displayed a later onset of spring leaf flushing and also an earlier onset of leaf fall compared to the control tree of 1-2 weeks. Based on the presented results it can be assumed that the studied summer-flowering common oak tree (tree 1) belongs to a late form of the common oak *Quercus robur* var. *tardiflora* Čern. A full confirmation of the above assumption requires additional phenological monitoring within the scope of the initiated research.

Polyphase formation of annual shoots was frequent in both trees, but with varying intensities which depended on the trees and years. The phenomenon of summer flowering was recorded only on tree 1. Our results show a high phenological variability of the observed trees and years, which confirms the genetic and environmental effects on phenological traits. The previously reported results of phenological research in the area of Belgrade point to the effect of the years, i.e. weather conditions that apparently exert a significant effect on the initiation of common oak phenological processes.

The high polycyclism of the observed common oak trees and the frequent summer flowering of tree 1 points to the processes of shortened cycles of morphogenesis and organogenesis in the study conditions and in the studied common oak phenological divergence.

Further study of the summer-flowering phenomenon requires the protection of the singled-out common oak tree by special measures, which would contribute to the conservation of genetic variability and biological diversity.

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