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Seasonal dynamics of photosynthetic pigments (chlorophylls *a*, *b* and carotenoids) in woody plants of the Altai Botanical Garden

This article reflects the results of studies of photosynthetic pigments (chlorophylls *a*, *b* and carotenoids) in 14 species of deciduous plants (trees and shrubs) and one coniferous *Juniperus sabina* L. in the Altai Botanical Garden during two growing seasons. The following species have a high accumulation of pigments: *Acer tataricum* L., *Juglans cinerea* L., *Tilia cordata* L., *Corylus avellana* L., *Cotoneaster lucidus* Schlecht., *Lonicera tatarica* L. For the coniferous species *Juniperus sabina* L. low levels of chlorophylls *a*, *b* and carotenoids are characteristic. *Berberis thunbergii* DC is also distinguished by a low accumulation of photosynthetic pigments. Minor differences between the species were noted in the content of carotenoids, twelve species were included in the group with low and medium content of this pigment. There is no definite pattern in the accumulation of carotenoids, and the data on the types and number of yellow pigments do not differ significantly. As a result of the conducted studies, a correlation was revealed between the content of carotenoids and the content of chlorophyll *a* in most species. The data obtained indicate the presence of species specificity in the content of chlorophylls *a*, *b* and carotenoids. Also, the photosynthetic apparatus of woody plants is sensitive to light and water conditions.

Keywords: content, species, trees, shrub, chlorophyll *a*, chlorophyll *b*, carotenoids.

Introduction

The criteria for the functional state of woody plants are the state of the photosynthetic apparatus of the plant organism, which is very sensitive to external influences: the content of pigments, changes in the anatomical structure of the leaf apparatus. Assimilation activity of plants is the primary metabolic process, the effectiveness of which is determined by growth and reproductive processes. Undoubtedly, photosynthetic structures and processes are indicators of the general state of the plant organism [1]. A number of works are devoted to the study of the structural and functional features of the photosynthetic apparatus of woody plants [2–4]. During introductory movements, changes in physiological functions, plasticity, and the content of chlorophylls and carotenoids, the main photoreceptors of a photosynthetic cell, occur. In this regard, an in-depth study of the biological and physiological characteristics of woody plants in the conditions of the mountain-forest zone of the East Kazakhstan region is relevant.

It is known that chlorophylls and carotenoids play an important role in the processes of photosynthesis. They are responsible for the absorption and conversion of energy in photochemical reactions and the protection of the photosynthetic apparatus from oxidation. In addition, pigments have a variety of biological activities and can affect human health [5]. The similarity of the chemical structure of chlorophyll and heme of the non-protein part of hemoglobin determined the use of chlorophyll preparations in medicine as agents that enhance hematopoiesis and increase immunity. Chlorophyll also has antimicrobial, wound healing, anti-inflammatory, tonic effects, stimulates the heart, respiratory center and neuromuscular system, removes toxins, normalizes blood pressure, and prevents the formation and deposition of calcium [6, 7].

Experimental

The object of the study was 15 species of woody plants growing in the dendroflora area of the Altai Botanical Garden. The content of chlorophylls *a*, *b* and carotenoids was determined in the coniferous species — *Juniperus sabina* L., deciduous species (trees) — *Acer ginnala* Maxim., *Acer tataricum* L., *Betula pendula* Roth., *Crataegus sanguinea* Pall., *Fraxinus lanceolata* Bjrckh., *Padusracemosa* (Lam.) Gilib. *Tilia cordata* L., *Juglans cinerea* L., deciduous species (shrubs) — *Cotoneaster lucidus* Schlecht., *Berberis thunbergii* DC., *Berberis vulgaris* L., *Euonymus maackii* Rupr., *Lonicera tatarica* L., *Corylus avellana* L.

The content of chlorophylls *a*, *b* and carotenoids was determined using a Jenway spectrophotometer mod. 6300 (320–1000 nm, slit 8 nm, single-beam, non-scanning). From each species, fragments of 3 leaves were taken for fixation, in triplicate according to the Godnev method [8]. The pigments were extracted in a

96 % solution of ethanol, porcelain mortar until the consistency of a homogeneous slurry. When determining the concentration of chlorophyll, the pigment was carefully removed from an accurately taken sample, not allowing the loss of a single drop of the extract. The volume of the extract was 10 ml. Further, the values were obtained at optical density D470, D644, D663, which were used for calculations the content of chlorophyll a, chlorophyll b and carotenoids according to the formulas.

Chlorophyll a $12.25 \cdot A_{663} - 2.79 \cdot A_{644}$

Chlorophyll b $21.50 \cdot A_{644} - 5.10 \cdot A_{663}$

Carotenoids $(1000 \cdot A_{470} - 1.82 \cdot cA_{85.02} \cdot cB) / 198$.

To distribute the observed species for each physiological parameter, the data were divided into classes with the lowest, average, and highest values. So, according to the content of chlorophyll a, — low content in the range of 3.34–9.06 mg / l, average — 9.07–14.79 mg / l, high — 14.80–20.51 mg / l, according to chlorophyll b — low content 0.10–0.51 mg / l, average — 2.52–4.93 mg / l, high — 4.94–7.33 mg / l, for carotenoids — low — 4.08–5.95 mg/l, average — 5.96–7.83 mg/l, high — 7.84–9.70 mg/l [9].

Results and discussions

The plants participating in the experiment grow in the arboretum of the Altai Botanical Garden with favorable conditions for the water regime of the soil. The results of studies during two growing seasons showed that photosynthetic pigments of plants are sensitive to changes in temperature and soil moisture. In the studied species, the average value for chlorophyll a in deciduous trees is 11.62 mg/l, deciduous shrubs — 10.81 mg/l; chlorophyll b — 1.57 mg/l; carotenoids in deciduous trees — 6.12 mg/l, deciduous shrubs — 6.68 mg/l. Weather conditions for the growing season 2022 contributed to the increased accumulation of the above pigments by 2–6 mg/l. In the second decade of July 2021 the lowest content of chlorophyll a was noted in the tree species *Fraxinus lanceolata* Bjrckh. — 8.13 mg/l and shrub *Berberis vulgaris* L. — 4.98 mg/l (Fig. 1, 2).

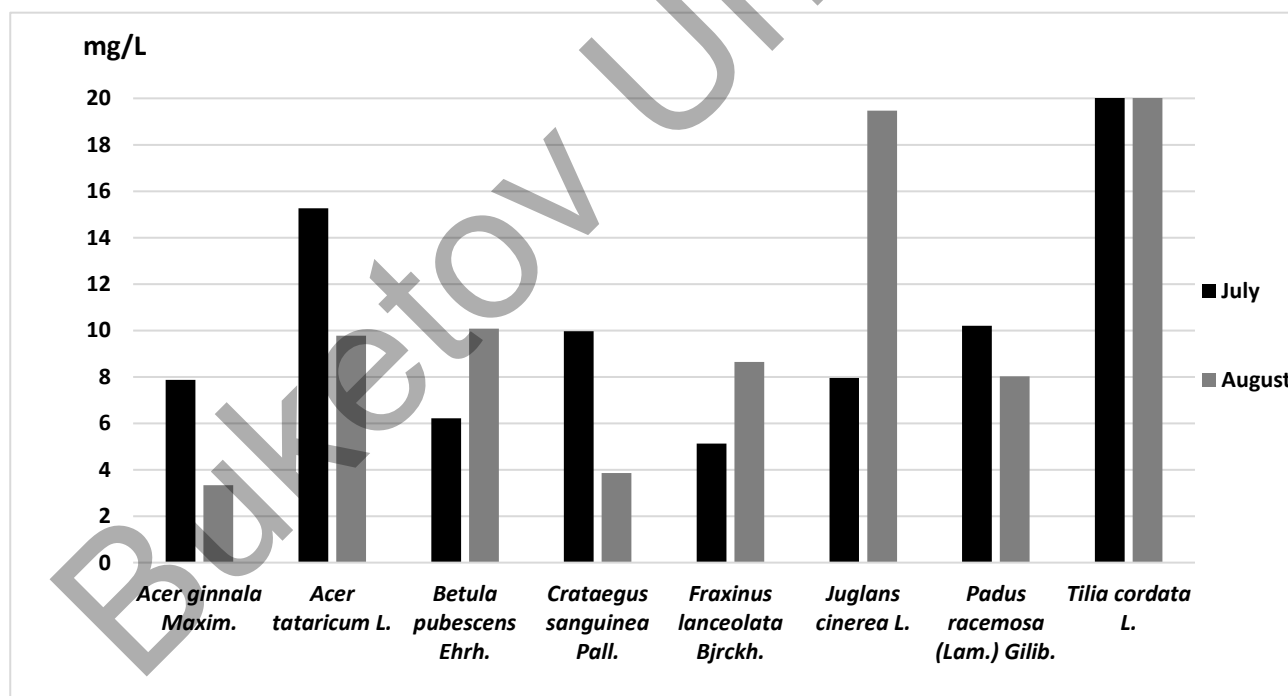


Figure 1. Seasonal dynamics of chlorophyll a content in deciduous species (trees) (mg/l wet matter) for the growing season 2021

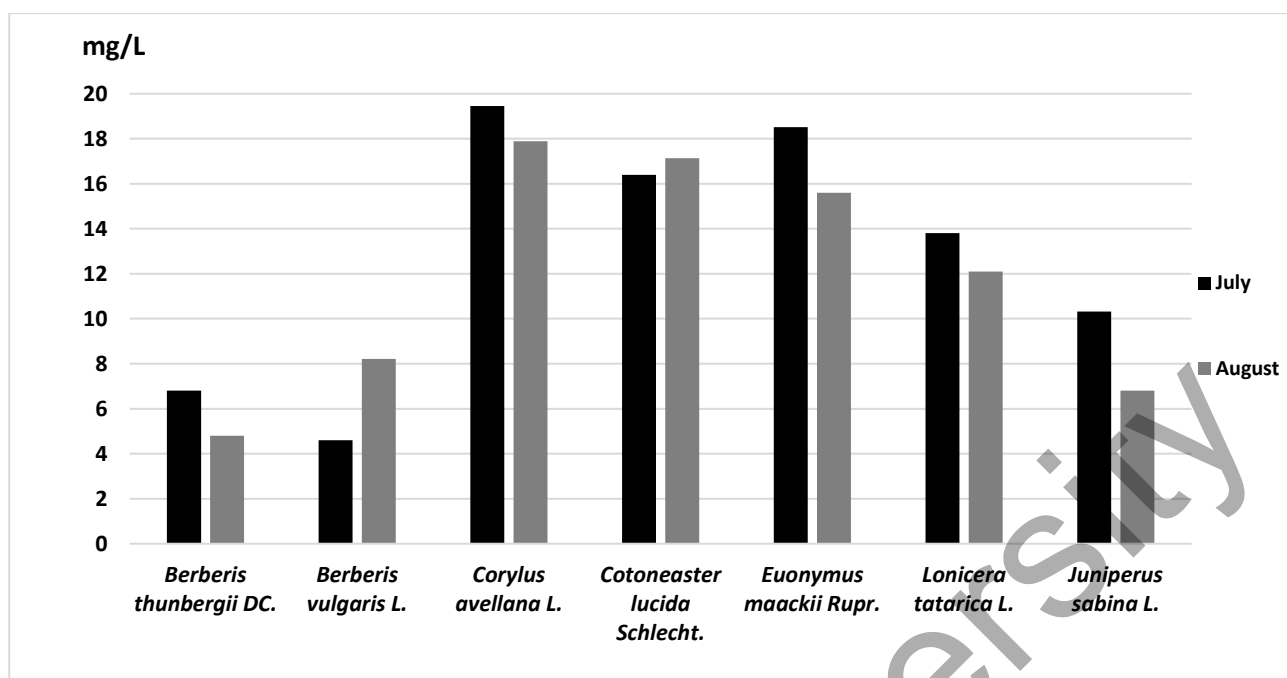


Figure 2. Seasonal dynamics of chlorophyll a content in deciduous species (shrubs) and coniferous species — *Juniperus sabina* L. (mg/l wet matter) for the growing season 2021

The highest value for this pigment was noted in two tree species: *Acer tataricum* L. — 15.26 mg/l, *Tilia cordata* L. — 16.14 mg/l and three shrub species — *Cotoneaster lucidus* Schlecht. — 17.14 mg/l, *Euonymus maackii* Rupr. — 18.51 mg / l and *Corylus avellana* L. — 19.46 mg/l. In *Padusracemosa* (Lam.) Gilib., *Lonicera tatarica* L., *Crataegus sanguinea* Pall. the maximum values for chlorophyll a vary within the following limits (6.80–13.55 mg/l). They are noted at the beginning of the season (first two analyses).

In July 2021 most of the species had a high content of chlorophyll a. Then there was a decrease in the level of this indicator and at the end of the growing season (in the second decade of August), the content of chlorophyll a in the leaves of plants is the lowest. This is clearly expressed in species: *Padus racemosa* (Lam.), *Acer ginnala* Maxim., *Juniperus sabina* L., *Euonymus maackii* Rupr., *Crataegus sanguinea* Pall. At the same time, an increase in this pigment is observed in the following species — *Fraxinus lanceolata* Bjrckh., *Juglans cinerea* L., *Acer tataricum* L., *Corylus avellana* L., *Berberis vulgaris* L., *Cotoneaster lucidus* Schlecht. In the second decade of August (August 17), the maximum accumulation of chlorophyll a was noted only in tree species: *Tilia cordata* L. — 21.66 mg/l, *Juglans cinerea* L. — 19.47 mg/l. During this period, they do not observe coloring of the leaves.

Low level (average values) for the content of chlorophyll a in tree species for the growing season 2021 noted in the coniferous species *Juniperus sabina* L. — 7.95 mg/l, in two deciduous species (trees) — *Acer ginnala* Maxim. — 8.22 mg/l, *Crataegus sanguinea* Pall. — 7.19 mg / l and two deciduous (shrub) — *Berberis thunbergii* DC. — 5.38 mg/l, *Berberis vulgaris* L. — 8.45 mg/l. With a low content of chlorophyll a — 5 species (33.3 %), medium — 4 species (26.6 %), high — 6 species (40.0 %) [9].

In 2022 almost all species have the same accumulation of chlorophyll a during the growing season, with the exception of two dates (8.08. and 22.08.), when the data were out of the general range of figures. So, *Acer ginnala* Maxim. during the growing season, the values for chlorophyll a are constant and only at the end of August 22.08. there is a sharp decrease in it by half to 5.71 mg/l compared with the average value of 11.63 mg/l (Fig. 3).

Betula pendula Roth. the low content of chlorophyll a — 6.62 mg/l was noted in early August (08.08.), and the high content — 18.45 mg/l falls on the end of August. In *Padus racemosa* (Lam.) Gilib. the content of chlorophyll a decreases in August to 5.51 mg/l compared to an average value of 9.30 mg/l. Also at the end of the season (22.08.) it decreases in *Corylus avellana* L. to 12.48 mg/l, the average is 18.24 mg/l and *Euonymus maackii* Rupr. up to 9.99 mg/l, average 13.65 mg/l (Fig. 4).

In the species *Acer tataricum* L., on the contrary, there is a slight increase in this pigment to 18.97 mg/l in the first ten days of August (08.08.) in comparison with the average value of 15.04 mg/l. In *Berberis vul-*

garis L., this indicator increased sharply at the end of August (August 22) to 18.45 mg/l compared to the average of 10.27 mg/l.

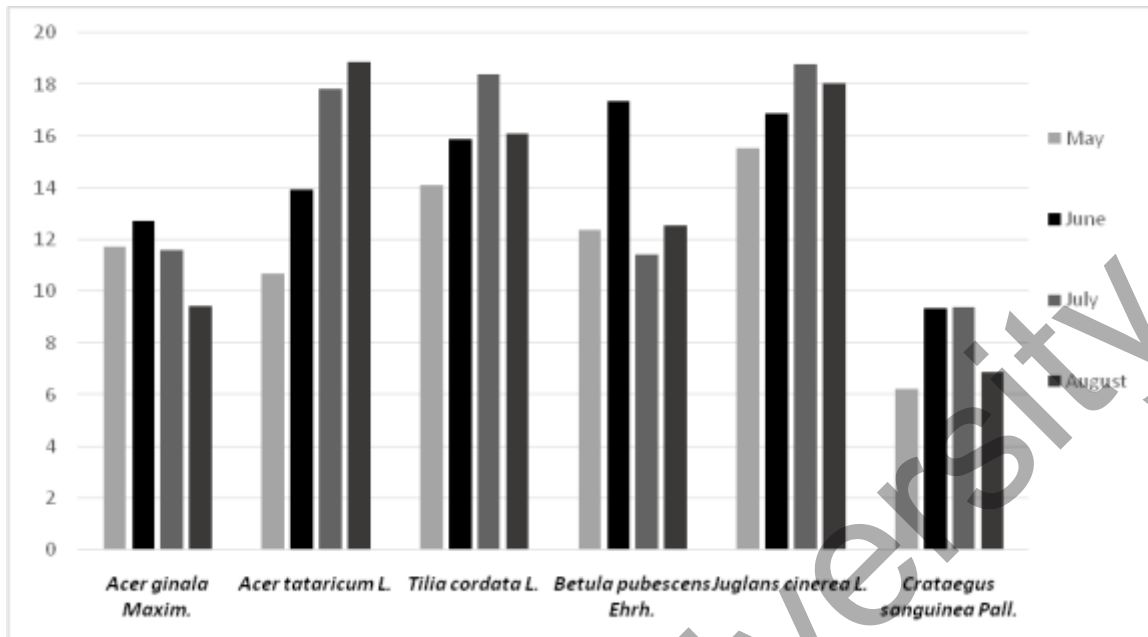


Figure 3. Seasonal dynamics of chlorophyll a content in deciduous species (trees) (mg/l wet matter) for the growing season 2022: 1 — May, 2 — June, 3 — July, 4 — August

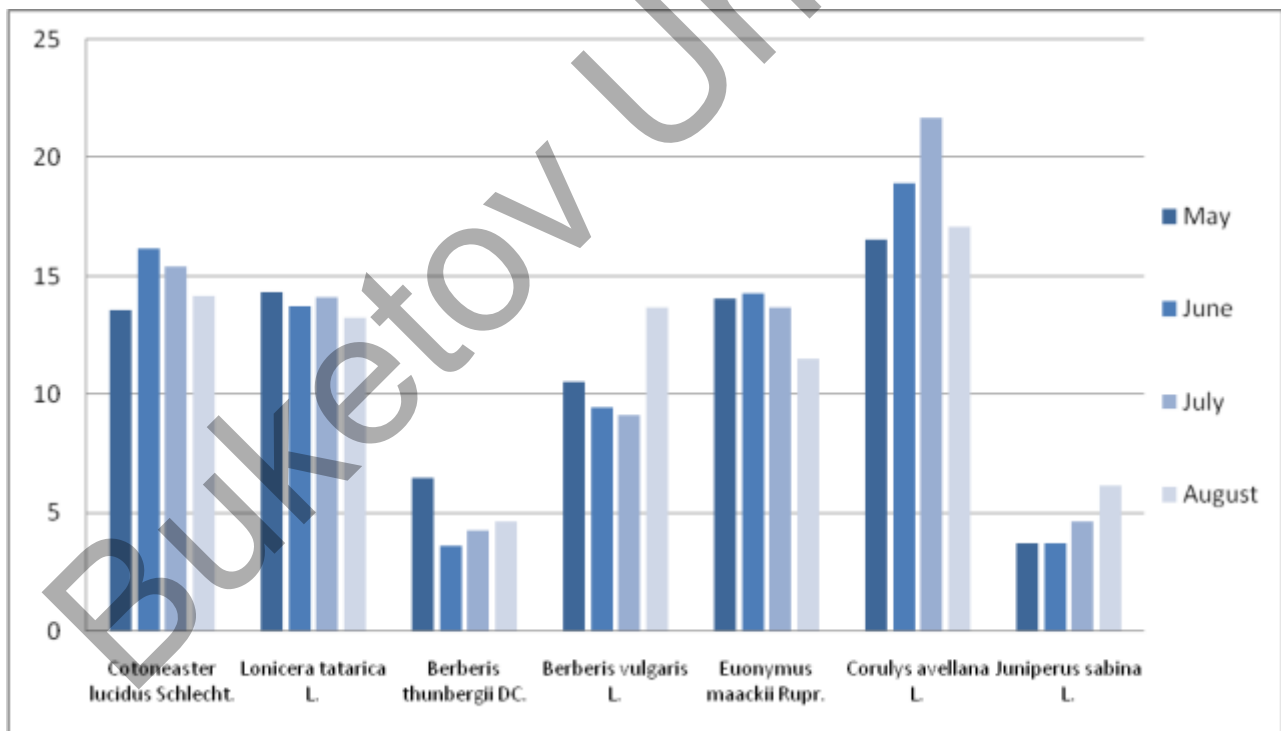


Figure 4. Seasonal dynamics of chlorophyll a content in deciduous species (shrubs) and coniferous species (mg/l wet matter) for the growing season of 2022: 1 — May, 2 — June, 3 — July, 4 — August

If in 2021 by the end of the growing season, there is an increase in chlorophyll a in ten species: *Acer ginnala* Maxim., *Betula pendula* Roth., *Crataegus sanguinea* Pall., *Fraxinus lanceolata* Bjrckh., *Juglans cinerea* L., *Tilia cordata* L., *Cotoneaster lucidus* Schlecht., *Corylus avellana* L., *Euonymus maackii* Rupr., *Lonicera tatarica* L., then in 2022 — in four species: *Acer tataricum* L., *Betula pendula* Roth., *Tilia cordata* L., *Corylus avellana* L. Low content of chlorophyll a during the growing season of 2022 noted in *Crataegus sanguinea* Pall.

taegus sanguinea Pall. — 7.58 mg/l, *Berberis thunbergii* DC — 4.84 mg/l, *Juniperus sabina* L. — 4.40 mg/l. *Acer ginnala* Maxim. there was a rapid decrease in the amount of chlorophyll a at about the same time from 5.08.2021 as of 17.08.2021 (8.84 mg/l to 3.34 mg/l by 2.6 times) and from 8.08.2022 as of 22.08.2022 (13.21 mg/l to 5.71 mg/l 2.3 times).

For chlorophyll b, low rates were noted on average, 1.57 mg / l. Its synthesis is much less than that of chlorophyll a. Its lowest content is in *Juniperus sabina* L. (0.62 mg/l in 2021 and 0.40 mg/l in 2022), the highest in *Corylus avellana* L. (3.71 mg/l in 2021 and 3.96 mg/l in 2022), average values. 10 species have a low content of this pigment, of which 5 are tree species, 4 are shrubs and one is coniferous (66.7 %), the average value was noted in four species (26.6 %), with a high accumulation of one species *Corylus avellana* L. (6.7 %). Its lowest content in *Juniperus sabina* L. is 0.40 mg/l, the highest in *Juglans cinerea* L. is 3.56 mg/l, *Tilia cordata* L. is 2.86 mg/l, *Corylus avellana* L. is 3.96 mg/l, average values.

Carotenoids are an integral component of the antioxidant system of plant protection, causing a response to stress factors. According to the content of this pigment, the average value for species over two years is 6.34 mg/l. *Cotoneaster lucidus* Schlecht has the highest value (9.66 mg/l in 2021 and 7.56 mg/l in 2022), *Corylus avellana* L. (9.71 mg/l in 2021 and 7.33 mg/l in 2022), *Berberis thunbergii* DC (9.24 mg/l in 2021), *Tilia cordata* L. (7.71 mg/l in 2022), *Lonicera tatarica* L. (7.65 mg/l in 2022) and minimal *Fraxinus lanceolata* Bjrckh. (4.13 mg/l in 2021), *Crataegus sanguinea* Pall. (4.39 mg/l in 2022) (Fig. 5–8).

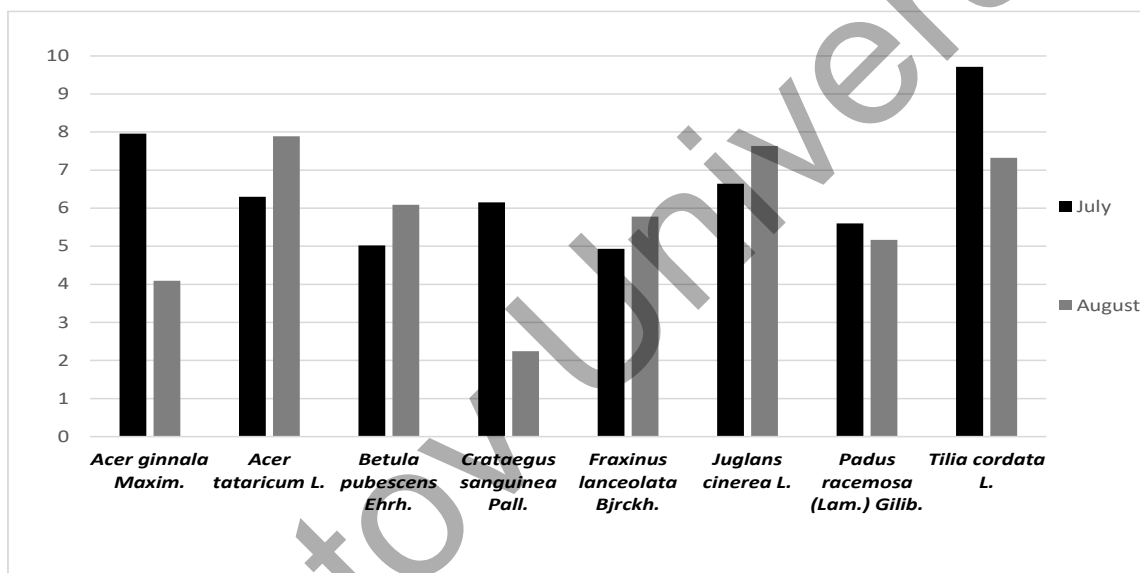


Figure 5. Seasonal dynamics of the content of carotenoids in deciduous species (trees) (mg/l wet matter) for the growing season 2021: 1 — July, 2 — August

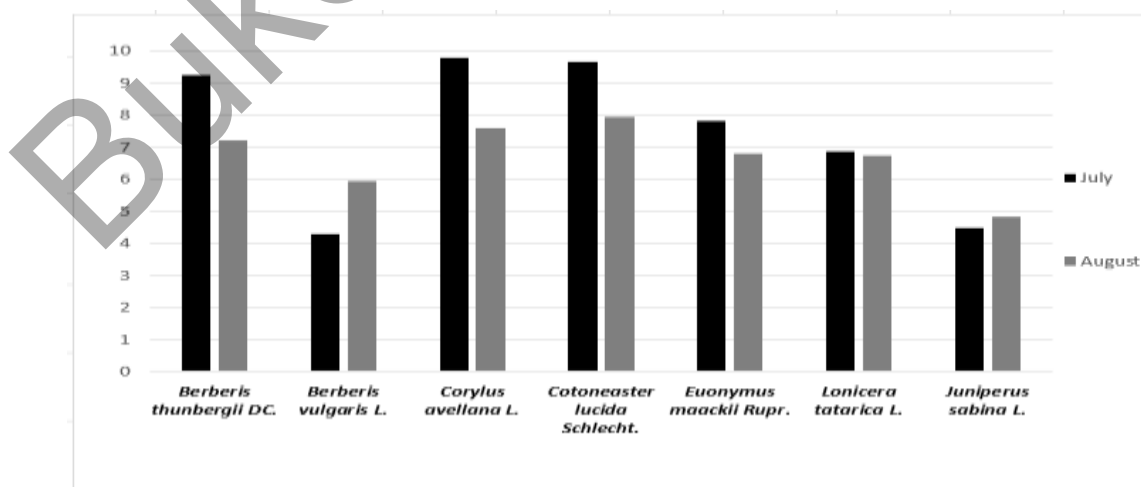


Figure 6. Seasonal dynamics of the content of carotenoids in deciduous species (shrubs) and coniferous species — *Juniperus sabina* L. (mg/l wet matter) for the growing season of 2021: 1 — July, 2 — August

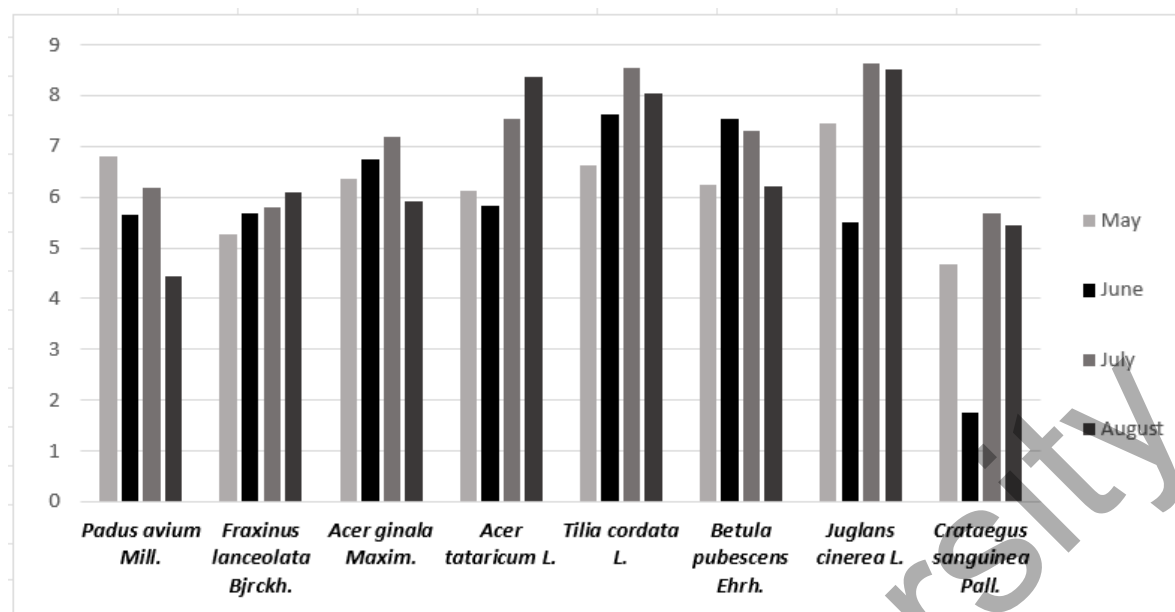


Figure 7. Seasonal dynamics of the content of carotenoids in deciduous species (shrubs) and coniferous species – *Juniperus sabina* L. (mg/l wet matter) for the growing season of 2022: 1 — May, 2 — June, 3 — July, 4 — August

A definite pattern in the accumulation of carotenoids was not revealed, and the data on the types and amounts of yellow pigments do not differ significantly. The high accumulation of this pigment by the end of the growing period of 2021 deciduous species (trees) were characterized: *Acer tataricum* L. — 8.21 mg/l, *Betula pendula* Roth. — 6.08 mg/l, *Juglans cinerea* L. — 7.63 mg/l. Of the deciduous species (shrubs), *Berberis thunbergii* DC contains the most carotenoids. — 9.18 mg/l, *Berberis vulgaris* L. — 5.94 mg/l.

Almost at the same mark for two seasons, the content of carotenoids in *Lonicera tatarica* L. and *Fraxinus lanceolata* Bjrkch. (6.25–6.87 mg/l and 4.99–6.27 mg/l, respectively). The lowest indicator for the content of carotenoids was noted in the coniferous species *Juniperus sabina* L. — 4.65 mg/l in 2021, and 3.57 mg/l in 2022. As a result of the research, it was found that four species have a low content of carotenoids (26.6 %), eight species have an average content (53.3 %) and three species have a high content (20.1 %). During the growing seasons, the data on the accumulation of carotenoids among the studied species differ slightly.

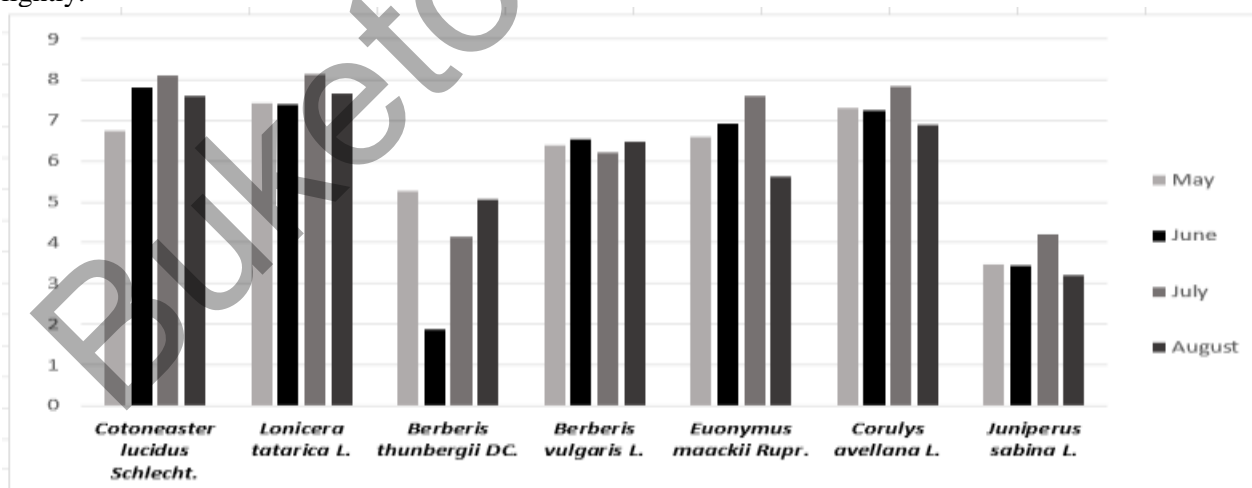


Figure 8. Seasonal dynamics of the content of carotenoids in deciduous species (shrubs) and coniferous species — *Juniperus sabina* L. (mg/l wet matter) for the growing season of 2022: 1 — May, 2 — June, 3 — July, 4 — August

As a result of the analyses performed, a correlation was found between the amount of chlorophyll a and carotenoids. This was clearly confirmed by the highest and lowest values in 25 cases out of 120 determinations in 2022. The same weather conditions at the end of June and July (27.06., 29.07.) 2022. influenced the

equal ratio in the accumulation of chlorophyll a and carotenoids in six species: *Juglans cinerea* L., *Tilia cordata* L., *Corylus avellana* L., *Cotoneaster lucidus* Schlecht., *Euonymus maackii* Rupr., *Lonicera tatarica* L.

In tree species *Crataegus sanguinea* Pall. and *Padus racemosa* (Lam.) Gilib. there is a gradual decrease in the content of pigments: chlorophyll a and carotenoids in the period from 19.07. to 17.08. during the growing season 2021. So, in the first species for chlorophyll a — from 10.19 mg / l to 8.02 mg / l, for carotenoids — from 5.60 mg / l to 5.16 mg / l. In *Crataegus sanguinea* Pall. for chlorophyll a — from 9.96 mg / l to 3.86 mg / l, for carotenoids — from 6.14 mg / l to 3.78 mg / l. The same decrease in the above-mentioned pigments was noted in the shrub species *Euonymus maackii* Rupr. for chlorophyll a — from 18.51 mg / l to 14.27 mg / l, for carotenoids — from 7.81 mg / l to 6.51 mg / l.

Two species of *Cotoneaster lucidus* Schlecht. and *Tilia cordata* L. there is a more active accumulation of chlorophyll a and carotenoids. So, in the first species in 2021 accumulation of chlorophyll a is equal to 18.10 mg/l, in 2022 — 14.79 mg/l, carotenoids in 2021 — 8.34 mg/l, in 2022 — 7.56 mg / l. The second species in 2021 accumulation of chlorophyll a — 18.25 mg / l, in 2022 — 16.01 mg/l, accumulation of carotenoids in 2021 — 8.09 mg/l in 2022 — 7.71 mg / l. which made it possible to refer them to the first class, with a high accumulation.

In terms of chlorophyll a, a high content over two years was noted in *Euonymus maackii* Rupr. — 16.66 mg/l in 2021 and 13.65 mg/l in 2022, respectively, and in *Juglans cinerea* L. 17.18 mg/l and 17.21 mg/l. In terms of carotenoids, *Corylus avellana* L. has a higher concentration of 8.32 mg/l in 2021 and 7.33 mg/l in 2022, respectively.

The results of studies during two growing seasons of *Juniperus sabina* L. needles showed low values of photosynthetic pigments: 4.40 mg/l for chlorophyll a, 0.40 mg/l for chlorophyll b, and 3.57 mg/l for carotenoids. If we take into account the weather conditions (drought and after rain), then after rain the content of chlorophyll a and carotenoids in it increases slightly from 4.10 mg / l to 4.69 mg / l and from 3.06 mg / l to 4.08 mg/l, respectively.

Conclusions

The analyzes performed showed that the accumulation of chlorophylls a, b and carotenoids is specific for each species of woody plants and depends on genetic characteristics, water and light regimes of the plant, leaf age, and other conditions. In the studied species during the growing seasons, the average value for chlorophyll a — in deciduous trees is 11.62 mg/l, deciduous shrubs — 10.81 mg/l, chlorophyll b — 1.57 mg/l, carotenoids in deciduous trees — 6.12 mg/l, deciduous shrubs 6.68 mg/l. Weather conditions 2022 contributed to the increased accumulation of the above pigments by 2–6 mg/l. The lowest concentration of all photosynthetic pigments is observed in three species: *Juniperus sabina* L., *Crataegus sanguinea* Pall., *Berberis thunbergii* DC., the highest is observed in four species: *Acer tataricum* L., *Juglans cinerea* L., *Tilia cordata* L., *Corylus avellana*. Photosynthetic pigments, being a single complex, are in a certain ratio characteristic of each species. Based on the results of the analyzes, a direct relationship was revealed between the content of chlorophyll a and carotenoids.

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Алтай ботаникалық бағының ағаш өсімдіктеріндегі фотосинтетикалық пигменттердің (*a*, *b* хлорофилдері және каротиноидтар) маусымдық динамикасы

Мақалада Алтай ботаникалық бағындағы екі вегетациялық кезеңде 14 жапырақты өсімдіктердің (ағаштар мен бұталар) және *Juniperus sabina* L. бір қылқан жапырақты өсімдігінің фотосинтетикалық пигменттерінің (*a*, *b* хлорофилі және каротиноидтар) зерттеу нәтижелері берілген. Келесі түрлер пигменттердің жоғары жинақталуына ие: *Acer tataricum* L., *Juglans cinerea* L., *Tilia cordata* L., *Corylus avellana* L., *Cotoneaster lucidus* Schlecht., *Lonicera tatarica* L. *Juniperus Sabina* L. қылқан жапырақты түрлеріне *a*, *b* хлорофилі және каротиноидтардың құрамы төмен. Сондай-ақ, фотосинтетикалық пигменттердің төмен жинақталуы *Berberis thunbergii* DC-мен ерекшеленеді. Түрлер арасындағы шамалы айырмашылықтар каротиноидтардың құрамымен белгіленген, 12 түрі осы пигменттің төмен және орташа тобына кіреді. Каротиноидтардың жинақталуының белгілі бір заңдылықтары анықталған жоқ, ал сары пигменттердің түрлері мен саны туралы мәліметтер айтарлықтай ерекшеленбейді. Жүргізілген зерттеулердің нәтижесінде көптеген түрлердегі каротиноидтар мен *a* хлорофилі құрамы арасындағы корреляция анықталды. Алынған деректер бойынша *a*, *b* хлорофилдерінің және каротиноидтардың құрамындағы түрлердің ерекшелігінің болуын көрсетті. Зерттелетін ағаш түрлері *a*, *b* хлорофилдерінің және каротиноидтардың құрамындағы түрге тән реакциямен сипатталады. Ағаш өсімдіктерінің фотосинтетикалық аппараты жарық пен су режиміне сезімтал.

Кілт сөздер: түрлер, ағаштар, бұталар, құрамы, *a* хлорофилі, *b* хлорофилі, каротиноидтар.

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Сезонная динамика фотосинтетических пигментов (хлорофиллов *a*, *b* и каротиноидов) у древесных растений в Алтайском ботаническом саду

В статье отражены результаты исследований фотосинтетических пигментов (хлорофиллов *a*, *b* и каротиноидов) у 14 видов лиственных растений (деревья и кустарники) и одного хвойного *Juniperus Sabina* L. в Алтайском ботаническом саду в течение двух вегетационных периодов. Высоким накоплением пигментов обладают виды: *Acer tataricum* L., *Juglans cinerea* L., *Tilia cordata* L., *Corylus avellana* L., *Cotoneaster lucidus* Schlecht., *Lonicera tatarica* L. Для хвойного вида *Juniperus sabina* L. характерны низкие показатели по содержанию хлорофиллов *a*, *b* и каротиноидов. Также низким накоплением фотосинтетических пигментов отличается *Berberis thunbergii* DC. Незначительные различия между видами отмечены по содержанию каротиноидов, двенадцать видов включены в группу с низким и средним содержанием этого пигмента. Определенной закономерности по накоплению каротиноидов не выявлено, и данные по видам и количеству желтых пигментов разнятся незначительно. В результате проведенных исследований выявлена корреляция между содержанием каротиноидов и хлорофилла *a* у большинства видов. Полученные данные свидетельствуют о наличии видоспецифичности в содержании хлорофиллов *a*, *b* и каротиноидов. Исследуемые древесные виды характеризуются видоспецифической реакцией в содержании хлорофиллов *a*, *b* и каротиноидов. Фотосинтетический аппарат древесных растений чувствителен к световому и водному режиму.

Ключевые слова: вид, деревья, кустарник, низкое и высокое содержание, хлорофилл *a*, *b*, каротиноиды, фотосинтетический аппарат.

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