Conference Paper

Comparative Characteristics of Pine, Spruce and Larch Pigmental Complex Seasonal Variability in Industrial Pollution Conditions

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Abstract

The present research will analyse the technogenic load influence on chlorophylls *a* and *b* and carotenoid maintenance in Preural coniferous forest-forming trees during the vegetative period by using spectophotometery; it will also reveal species-specific reactions. The ecological species-specificity of the adaptations of pine, spruce and larch pigmental complexes to industrial pollution in the conditions of the Ufa industrial center (UIC) is shown: similar adaptive tendencies are not revealed, multidirectional reactions of separate pigments often depend on the vegetation period. Needles are characterized by rather good formation and stability of the pigmental structure concerning chlorophylls *a* and *b*. However, in pollution conditions the share of chlorophylls *a* and *b* significantly increases against a background decrease the share of carotenoids. Despite the considerable photosynthetic activity of larch, which exceeds that of pine and spruce, its pigmental complex is more sensitive to industrial pollution.

Keywords: Preural forest-forming trees, industrial pollution, pigmental complex, chlorophylls *a* and *b*, carotenoids, pigments ratio, vegetative dynamics

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1. Introduction

In city conditions, a whole complex of factors is present which indirectly (for example, through leaf area decrease) or directly influences on decrease of tree photosynthetic activity. These factors consist of higher air temperatures, asphalt covering, increased density and salt impurity of soil (causing water osmotic binding), increased atmosphere turbidity that reduces sunshine receipt, etc. In technogenic stress conditions, suspended matter in the air (dust and soot, which leads to stomata stoppering, CO_2

absorption delay, changes in leaf optical properties and heat balance) and toxic emissions (many of which destroy photosynthesis pigments) are added. Seasonal photosynthetic activity changes occur with leaf area changes. In standard conditions during vegetation, photosynthetic activity increases until leaf plate formation is complete and then declines with age. Various technogenic pollutants not only bring an imbalance in the seasonal formation of plant pigmental complex when compared with control conditions, but also differently influences on the content and ratio of the pigments of wood plants' assimilative organ. An analysis of the modern literature shows that in conditions of industrial pollution, depending on the region of the research, the type of pollution (polluting factories) and wood plant species, either increase/decrease of all pigments maintenance, or increase one while the others decline can be observed, or no statistically reliable changes can be observed at all. Most often, chlorophyll *a* is more labile concerning any violations of the natural pigmental complex. The degree of photosynthetic organ formation and tolerance of plants to technogenic loading can be judged by the ratios 'Hl *a* / Hl *b*' and '(Hl *a* + Hl *b*) / Carotenoids', which are markers of anthropogenic impact on the environment. As a rule, in response to air pollution the first of the presented ratios decreases, while the second increases. Some authors specify that a decrease in 'Hl *a* / Hl *b*' size can characterize gas resistance of plants. In general, it is argued that in conditions of chronic industrial pollution the common reaction for all plants species is intensive destruction of all pigments [1–23].

According to our previous research, the hydrocarbonic pollution type in certain cases causes not suppression, but stimulation of the various growth processes in wood plants (for example, on the level of the morphology of leaves, needles, shoots, root systems, dendrochronology, etc.), although this often depends on the species. Therefore, the purpose of this work is to analyse the influence of hydrocarbonic technogenic load on chlorophyll *a*, chlorophyll *b* and carotenoid maintenance during the vegetative period in the needles of coniferous Preural forest-forming trees, on the ratio of these pigments and the identification of species-specific reactions. The specificity of the influence of hydrocarbonic pollution type, the ambiguity of wood plants' adaptive reactions to technogenic factors and the lack of information on the vegetative dynamics of pigmental complex in conditions of industrial pollution define the relevance of the conducted research.

2. Methods

Ufa is a large industrial centre in the Preurals. The main industrial factories influencing the ecological situation of the city are located in the northern part: Bashneft Ufaneftekhim, Bashneft-UNPZ, Bashneft-Novoil, Ufaorgsintez, Ufa combined heat and power plants 1, 3, 4, etc. The petrochemical profile of production causes the emission of a number of toxicants, such as sulphur dioxide, carbon oxide, nitrogen dioxide, hydrogen sulphide, hydrogenium chloride, ammonia, fluorine, chlorine, phenol, chloroform, formaldehyde, benzene, xylol, toluene, benzopyrene, etc. Their concentration in the city air basin exceeds the threshold limit values several times [24]. In accordance with distance from the petrochemical factories and the wind rose, the area of research was conditionally divided into 2 zones: a zone of strong pollution (300 m from oil refineries) and a control zone (in the southern part of the city, 50 km from oil refineries).

Forest cultures of pine (*Pinus sylvestris* L.), spruce (*Picea obovata* Ledeb.) and larch (*Larix sukaczewii* Dyl.) serve as research objects. Forest stands of the studied species with the most similar taxation characteristics (presented in Table 1) were allocated into zones with comparable soil and relief conditions. A control trial area and pollution trial area were organized for each of the forest stands of the studied species.

Table 1: Taxation characteristics of trial areas in pine, spruce, and larch forest stands in UIC conditions.

Wood Species	Location	Forest Stand Formula	Average Age, Years	Average Diameter, cm	Average Height, m	Density
Pine (P)	Pollution zone	10P	57	24	18	0.8
	Control	10P	74	26	25	0.7
Spruce (Sp)	Pollution zone	9Sp 1Lm*	46	24	20	1.0
	Control	10Sp	59	24	22	1.0
Larch (Lch)	Pollution zone	9Lch 1P	60	30	20	0.8
	Control	10Lch	73	32	27	0.8
Source: Authors' own work.						
Note: * Lm – lime						

In order to determine the pigments content, the needles of this year's generation were selected from 20 model trees at the krone bottom of the trial area during each month of the vegetative period over the past decade from 11:00 to 14:00 h. The needles were crushed and carefully mixed to obtain the average data for all trial area for the month. Samples weighing 0.1 g were filled with 10 ml of 96% ethanol and maintained for 12 hours in a dark room in order to avoid pigments destruction. The concentration of pigment in an extract was defined by a KFK – 5M spectrophotometer

(Russia), the content of pigment in the needles (in mg / g of damp weight) was counted, considering the extract volume and sample weight [25]. Also, the pigment ratios 'Hl *a* / Hl *b*' and '(Hl *a* + Hl *b*) / Carotenoids' were calculated.

3. Results

In pollution conditions, the following adaptive reactions of the pigmental complex are revealed (Figure, Table 2):

– In pine, a sharp and reliable increase in chlorophylls *a* and *b* maintenance is observed from May to July; in August, in contrast, a sharp and reliable decrease in their content is noted; throughout the vegetative period, a sharp decrease in carotenoid maintenance is observed. As a result, total pigments maintenance undergoes considerable increases or decreases without precise tendencies throughout the vegetative period.

– In spruce, a sharp and reliable increase in chlorophylls *a* and *b* maintenance from May to June is observed: in July and August, in contrast, a sharp and reliable decrease in their content is noted; no precise tendencies in changes in carotenoid maintenance throughout the vegetative period are observed. As a result, the total pigments maintenance during the vegetative period has similar dynamics to those of the chlorophylls: a sharp and reliable increase until June and a decrease until August.

– In larch, throughout the vegetative period precise tendencies concerning chlorophylls *a* and *b* and pigments sum maintenance were not found: in different months, they increase or decrease; only in carotenoids is a decrease noted from June to August.

In normal conditions during vegetation, the plants' photosynthetic activity has to increase and decrease until the end of vegetation. In our case, hydrocarbonic pollution introduces specific changes: a considerable decrease until July in chlorophylls *a* and *b*, carotenoids and the sum pigments maintenance and a sharp increase in August are noted in the dynamics of all three species in strong pollution conditions and in the control zone. Such a 'two-phase' pigmental system reaction to stressful factor increase is described in many sources (for example, [26]). It is supposed that:

> Apparently, when violations of the homeostasis condition … reach some critical threshold, owing to the limitation of the adaptive opportunities in this mode of functioning and the threat of the development of irreversible system damage, there occurs the involvement in the adaptation process of

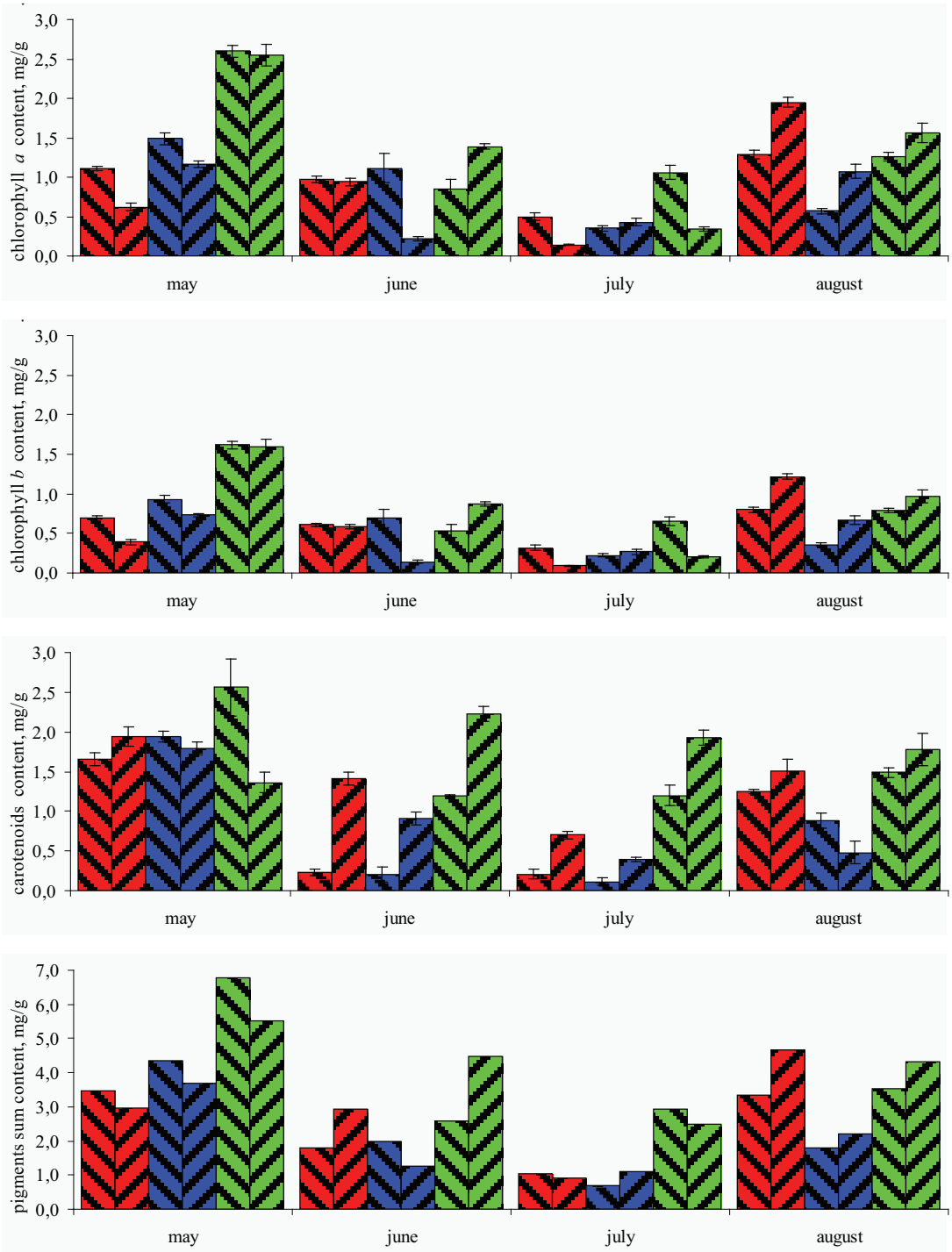

Figure 1: Pine, spruce, and larch needles pigments content (mg/g of damp weight) in UIC conditions during the vegetative period. **Source:** Authors' own work. **Note:** – pine, strong pollution zone; – pine, control; – spruce, strong pollution zone; – spruce, control; – larch, strong pollution zone; – larch, control.

additional energy and plastic resources, which cause a transition to a new steady of functioning regime.

Table 2: Reliability of differences between pigments maintenance in pollution conditions and in control conditions (reliable distinctions are highlighted in bold type).

Month	Chlorophyll a			Chlorophyll b			Carotenoids		
	T_{emp}	T_{tab}	p	T_{emp}	T_{tab}	p	T_{emp}	T_{tab}	p
Pine									
May	**8.83**	**5.04**	**0.999**	**9.12**	**5.04**	**0.999**	1.93	2.31	0.95
June	0.50	2.31	0.95	0.53	2.31	0.95	**13.00**	**5.04**	**0.999**
July	**7.78**	**5.04**	**0.999**	**7.89**	**5.04**	**0.999**	**6.36**	**5.04**	**0.999**
August	**8.38**	**5.04**	**0.999**	**8.59**	**5.04**	**0.999**	1.69	2.31	0.95
Spruce									
May	**3.63**	**3.36**	**0.99**	**3.61**	**3.36**	**0.99**	1.41	2.31	0.95
June	**4.75**	**3.36**	**0.99**	**4.69**	**3.36**	**0.99**	**5.69**	**5.04**	**0.999**
July	1.36	2.31	0.95	1.34	2.31	0.95	**5.21**	**5.04**	**0.999**
August	**5.22**	**5.04**	**0.999**	**5.18**	**5.04**	**0.999**	**2.34**	**2.31**	**0.95**
Larch									
May	0.33	2.31	0.95	0.21	2.31	0.95	**3.16**	**3.36**	**0.99**
June	**4.06**	**3.36**	**0.99**	**4.12**	**3.36**	**0.99**	**10.57**	**5.04**	**0.999**
July	**8.06**	**5.04**	**0.999**	**8.03**	**5.04**	**0.999**	**4.64**	**3.36**	**0.99**
August	2.28	2.31	0.95	2.17	2.31	0.95	1.36	2.31	0.95

Source: Authors' own work.

Table 3: Pigment ratio indices of pine, spruce and larch needles in UIC conditions.

Pigments ratio	Location	May	June	July	August
Pine					
Hl *a* / Hl *b*	Pollution zone	1.6	1.6	1.6	1.6
	Control	1.6	1.6	1.6	1.6
(Hl a + Hl b)	Pollution zone	1.1	6.9	3.9	1.7
Carotenoids	Control	0.5	1.1	0.3	2.1
Spruce					
Hl *a* / Hl *b*	Pollution zone	1.6	1.6	1.6	1.6
	Control	1.6	1.6	1.6	1.6
(Hl a + Hl b)	Pollution zone	1.2	9.0	5.2	1.1
Carotenoids	Control	1.1	0.4	1.8	3.6
Larch					
Hl *a* / Hl *b*	Pollution zone	1.6	1.6	1.6	1.6
	Control	1.6	1.6	1.6	1.6
(Hl a + Hl b)	Pollution zone	1.6	1.2	1.4	1.4
Carotenoids	Control	3.1	1.0	0.3	1.4

Source: Authors' own work.

In our case, we see not only a 'two-phase' reaction in pigments maintenance to seasonal changes, but also species-specific 'multiphase' adaptive reactions of separate pigments to pollution conditions in different months of the vegetative period.

It is shown (Table 3) that differences between the pollution and control zones in terms of the ratio 'Hl *a* / Hl *b*' in all three species are not revealed – it is 1.6 throughout the vegetative period. The ratio '(Hl *a* + Hl *b*) / Carotenoids' serves as a more informative indicator – in pollution conditions, this indicator in all three species considerably increases in comparison with the control zone: this relates to an essential increase in the share of chlorophylls *a* and *b* against a background decrease in the share of carotenoids. This ratio reaches its highest values in spruce and the lowest in larch. In the vegetative period, this parameter undergoes fluctuations, but for pine and spruce it is generally possible to speak about its decrease in the strong pollution zone and in the control zone; in larch, it does not show precise tendencies.

In general, the pigmental complex of larch in terms of its quantitative content considerably exceeds the values for pine and spruce, but at the same time it is more exposed to pollution impact. The quantitative pigment maintenance of pine on the level and on the character of changes is comparable to spruce. At the same time, both in strong pollution conditions and in the control zone, the sum of chlorophylls in all three species is always more than the quantity of carotenoids.

Earlier in UIC conditions, the pigmental complexes of some deciduous wood species were investigated. It was established that when pollution increases, the maintenance of chlorophylls *a* and *b* in oak significantly decreases, but carotenoid maintenance increases; in lime, an increase in chlorophyll *a* and a decrease in chlorophyll *b* is observed, but carotenoid maintenance depends on the vegetation period (an increase until the middle of the period and a decrease until the end); in birch, changes in pigment maintenance depend on the vegetation period – one notes a decrease at the beginning, the highest point in the middle and a decrease until the end of the vegetation period. In pollution conditions, oak and birch leaves are characterized by the rather good formation and stability of pigmental structure concerning chlorophylls *a* and *b*. However, in lime the chlorophyll complex is more sensitive. When pollution increases, in these species the share of carotenoids significantly increases against a background decrease in the share of chlorophylls *a* and *b*. However, the size of this ratio depends on the vegetation period. Despite the considerable photosynthetic activity of lime, which exceeds that of oak and birch many times, its pigmental complex is more sensitive to industrial pollution [22].

Therefore, in conditions of hydrocarbonic pollution among coniferous and deciduous forest-forming trees, common adaptive regularities are not shown: it is possible to observe only similar tendencies in reactions of separately studied parameters of the pigmental complex. However, when comparing coniferous with deciduous trees, it is

possible to allocate larch and lime into a separate group as species with considerable photosynthetic activity and a high sensibility of the pigmental complex to industrial pollution. Other species are characterized by approximately identical maintenance of photosynthesis pigments and their stable ratio in pollution conditions.

4. Conclusions

Thus, despite the fact that the studied wood species belong to the coniferous forest-forming trees, the adaptation of their pigmental complex to industrial pollution with a hydrocarbonic component is species-specific:

- The quantitative maintenance of all studied pigments in larch exceeds pigment maintenance in pine and spruce, sometimes considerably (in pine and spruce, this is approximately identical). The carotenoid maintenance in all studied species is generally higher than the separate maintenance of chlorophylls *a* and *b*, but in larch this ratio is present throughout the vegetative period, in pine, it is only present in the first half of vegetation and in spruce, in 50% of cases throughout the vegetative period (and this is unsystematic). During vegetation, all of the studied species demonstrate decreases in the maintenance of pigments until July and a sharp increase until the end of vegetation.

- The assessment of pigment reaction to the intensification of industrial pollution did not reveal common regularities: all of the studied wood species are characterized by species-specific reactions. In pine, when pollution intensifies, a sharp and reliable increase in chlorophylls *a* and *b* maintenance and a marked decrease in carotenoid maintenance are observed. In spruce, either significant and reliable increases (at the beginning of vegetation period) and decreases (at the end of vegetation period) in chlorophylls *a* and *b* maintenance are observed, but the reaction of the carotenoids does not reveal precise tendencies at all. The reaction of chlorophylls *a* and *b* in larch also does not reveal precise tendencies; at the same time, a decrease in carotenoid maintenance when pollution intensifies is observed.

- It is established that in conditions of prevailing petrochemical pollution and in the control zone, the needles of all the studied species are characterized by stability of the pigmental structure concerning chlorophylls *a* and *b*: the maintenance of chlorophyll *a* always prevails over the content of chlorophyll *b*.

- The ratio of chlorophylls to carotenoids reveals a common regularity: when pollution intensifies, the share of chlorophylls *a* and *b* increases against a background decrease in the share of carotenoids. Moreover, this is a marked trend in pine and spruce, but only a slight one in larch. In the vegetative periods of pine and spruce, this index decreases in the strong pollution zone and grows in the control zone: larch does not show precise tendencies.
- Despite the considerable photosynthetic activity of larch, which exceeds that of pine and spruce, its pigmental complex is more sensitive to industrial pollution.

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