

The State and Biochemical Composition of Coniferous Plant Wood in Places of Degradation

Irina Bukharina (✉ buharin@udmlink.ru)

Udmurtskij gosudarstvennyj universitet <https://orcid.org/0000-0001-8084-2547>

Konstantin Vedemikov

Udmurtskij gosudarstvennyj universitet

Anna Pashkova

Udmurtskij gosudarstvennyj universitet

Yegor Zagrebin

Udmurtskij gosudarstvennyj universitet

Research

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Abstract

Background. A significant deterioration in the state of dark coniferous forests, which in some cases is accompanied by their drying, has manifested itself throughout the Northern Hemisphere. This process is very dynamic and covers the entire boreal zone from Europe to the North American continent, covering all forest-forming species. Research in the field of the ecological biochemistry of wood opens up wide possibilities for studying the stability of spruce stands. Coniferous wood, including spruce, consists of polymer structural components (cellulose, hemicellulose and lignin) and non-structural components (including extractives, ash and other minor substances). Extractives with high biological activity, which are produced as protective compounds during the life of plants from external environmental stresses, play an important protective function in coniferous wood.

The structure of wood and its biochemical composition can change under various influences. The content of extractives varies greatly not only in different areas, but also from specimen to specimen, depending on their condition. In this regard, the aim of our research was to study the content of extractives in spruce wood in specimens of different life states.

Methods. This work presents the results of studies on the characteristics of the biochemical composition of Siberian spruce (*Picea obovata* L.) in mass drying conditions in the territory of the Udmurt Republic (Russia). The enumeration method was used to create a plot taxation. A study of the biochemical composition of wood was carried out based on the content of extractives from specimens in various life states.

Results. Trial plot stands are characterized by low tree density in the main canopy. According to biochemical analysis, the highest content of extractives was observed in specimens with good and satisfactory vitality. In trees with an unsatisfactory life state, biochemical parameters were low, which is associated with the lack of self-regulation in dead wood.

Conclusions. Obviously, the substances under study play a large role in the adaptive reactions of *Picea obovata*, and the increase in their production is a response to negative environmental factors.

Background

The importance of dark coniferous stands of the Northern Hemisphere is their global role in the distribution of organic carbon, where they play a conservation role (Taylor et al. 2007). A significant deterioration in the state of dark coniferous forests, which in some cases is accompanied by their drying, has manifested itself throughout the Northern Hemisphere. This process is very dynamic and covers the entire boreal zone from Europe to the North American continent, covering all forest-forming species (Bahtenko, 2008; Rysin, 2009). The mass drying of spruce over a large area of the European part of the Russian Federation after abnormally high temperatures in 2010 caused considerable interest among researchers studying the problem of spruce stand resistance to adverse environmental conditions, anthropogenic stress, pests and diseases (Ivanchina & Zalesov, 2017; Negrón, 2018). Research in the field of the ecological biochemistry of wood opens up wide possibilities for studying the stability of spruce stands. Coniferous wood, including spruce, consists of polymer structural components (cellulose, hemicellulose and lignin) and non-structural components (including extractives, ash and other minor substances). Extractives with high biological activity, which are produced as protective compounds during the life of plants from external environmental stresses, play an important protective function in coniferous wood. The study of extractive substances in wood is most actively carried out in foreign countries to understand their nature and role as natural activity inhibitors for woody microbiota (Korotkov et al. 2014). Good literature reviews on extractives are presented in foreign works (Scheffer, Morrell, & Oregon State University. Forest Research Laboratory, 1998; Yang, 2009; T. Singh & A. Singh, 2012). Also, studies on conifer extractives in pharmacology are actively conducted in the Russian Federation (Obolenskaya et al. 1991; Caudullo et al. 2016).

The structure of wood and its biochemical composition can change under various influences. Therefore, to identify patterns, it is necessary to have a relatively clear idea of the influence exerted by individual environmental factors. The content of extractives varies greatly not only in different areas, but also from specimen to specimen, depending on their condition (Prusakova et al. 2008). In this regard, the aim of our research was to study the content of extractives in spruce wood in specimens of different life states.

Materials And Methods

The research was carried out on the territory of the Udmurt Republic (here in after the UR). The area of the republic is 42.06 thousand km². Udmurtia is located in the European part of the Russian Federation, in the basins of the Kama and Vyatka rivers, west of the Ural Mountains, between parallels 56°00' and 58°30' north latitude, and meridians 51°15' and 54°30' east longitude. The territory of the UR stretches broadly north to south for about 320 km, and west to east for 200 km. Significant elongation of the territory from north to south and hilly-rugged terrain causes major differences in temperature, humidity, wind, and rainfall between the northern and southern parts of the republic. In this regard, the territory of the UR is located within two landscape zones: taiga (boreal/south-taiga zone) and subtaiga (boreal-subboreal/coniferous-deciduous forest zone). Its border coincides with the northern border of a range of *Quercus* and *Corylus*; it is conditionally drawn between the settlements of the republic of Vavozh - Nylga - Izhevsk - Votkinsk (Fedorova et al. 2016) (Fig. 1).

To assess the taxation parameters and the condition of spruce stands, 100 × 100 m sample plots were laid. The test plots (here in after - TP) were laid in two forest districts (Zavyalovo and Yagan) located in the subtaiga zone (boreal-subboreal/coniferous-deciduous forest zone). In each forest district, two trial plots were laid. Trial areas were laid in stands predominantly made up of spruce where they are actively drying out, and in acidic types of forests. The soils in the trial plots are sod-podzolic, and loamy in granulometric composition.

The main taxation parameters of the stand (species composition, average diameter ($D_{av.1.3}$, cm), average height (H_{av} , m), average age (A_{av} , years), density (ΣG , m²/ha), and stock of dead wood (M , m³) were determined according to generally accepted methods (Scheffer et al., 1998). Stand productivity was determined

according to B.D. Zhilkin's method. This method is based on the distribution of trees into classes relative to the average diameter of the stand: Class I – 1.46 and above, II – 1.45 ... 1.16, III – 1.15 ... 0.86, IV – 0.85 ... 0.76, V class – 0.75 or less (Ostroukhova et al. 2018).

Trees were divided into three groups based on their life state: 1) good (the crown is thick or slightly sparse, the needles are green/light green; individual branches have dried up); 2) satisfactory (openwork crown; needles light green); 3) unsatisfactory vitality (needles are yellowish, up to 2/3 of the crown with drying branches; fruiting bodies of fungi, presence of hollows, dead specimens). To study the biochemical characteristics of wood, three specimens were selected within each group.

Wood samples were taken only from Siberian spruce (*Picea obovata* L.). Cores were taken using an age drill at a height of 0.3 m from the root neck of the tree. Coniferous extractives were fractionated in accordance with their chemical nature by sequential extraction with solvents of increasing polarity. The extractives were identified using hot distillation in a Soxhlet apparatus – water-soluble substances with hot water, resinous substances with an alcohol-toluene mixture. The tannin content was determined using the permanganometric method (Babkin, 2017). The analyses were carried out in the laboratory of Ecological and Fire Safety of the Federally Funded Educational Institution of Higher Education Udmurt State University (Izhevsk).

Sample variance analysis was used to estimate the significance of sample differences (Lakin, 1990). Mathematical processing of the results and visualization of the data was performed in the statistical analysis environment R (Mastickij, 2015).

Results

Taxation Characteristics

An analysis of the distribution of trees by diameters relative to the average revealed a regular distribution of plants in the main canopy. Comparing the diameters of living and dead spruce specimens revealed that most of the dead trees have a trunk diameter above average. In terms of productivity, it was established that TP plantings belong to productivity class III. The average taxation characteristics of the stands on the studied TP are presented in Table 1.

Table 1
Average taxation characteristics of stands on trial plots (Udmurt Republic, 2019)

No.	Forest district, forest unit (quarter, allotment)	A _{av.} ±σ, years	H _{av.} ±σ, m	D _{av.1,3} ±σ, cm	ΣG, m ² / hectare M, m ³	ΣG, m ² / hectare*	M, m ³ **	Plant producti- vity***	Composi- tion****	Note
1	Zavvalovo, Suburban (78, 3)	70 ± 7.3	21 ± 2.0	27.9 ± 7.1	10.7 107.0	14.9	67.2	III,2 III,1	9S1F + B 90% spruce, 10% fir, 5% birch	Rare, unstable new growth: spruce, birch, aspen; Undergrowth: Euonymus, rosehip, bird cherry; LGC (living ground cover) rare: horsetail, bracken, sorrel, sedge, hybrid clover, sow thistle, cotton grass; Edge of swamp.
2	Zavvalovo, Suburban (158, 3)	67 ± 3.8	23 ± 1.9	26.0 ± 5.7	11.1 119.9	17.9	87.5	III,2 III,0	9S1F 90% spruce, 10% fir,	Rare, unstable new growth: spruce, birch; No undergrowth; LGC rare: horsetail, bracken, sorrel, hoofed grass, meadow bluegrass, hybrid clover.
3	Yagan (115, 8)	60 ± 3.7	18 ± 1.5	25.9 ± 12.9	6.0 52.8	16.6	93.8	III,9 III,5	10S 100% spruce	No new growth. Rare undergrowth: mountain ash, forest raspberries, goat willow. Height 1.5-2 m. LGC: field sow thistle, cat grass, meadow bluegrass, hybrid clover, horsetail, bracken fern.
4	Yagan (214, 8)	65 ± 3.7	22 ± 1.1	21.4 ± 4.4	2.95 30.7	5.9	31.1	III,8 III,9	10S 100% spruce	Rare, stable new growth: Spruce less than 500/ha; Thick undergrowth, height 2 m: aspen, mountain ash, buckthorn, bird cherry, elderberry; LGC is dense: stitchwort, goatweed, bracken, cottongrass, sorrel, sedge.
Note: * - absolute density taking into account dead trees (in this case, the cross-sectional area of the trunk at a height of 1.3 m);										
** - stock of dead wood in the trial plot;										
*** - the denominator shows productivity taking into account dead trees;										
**** - S (spruce), F (fir), B (birch).										

Table 2
The content of extractives in the wood of *Picea obovata* L. in different life states (Udmurt Republic, 2019)

No.	Forest district, forest unit (quarter, allotment)	The total content of extractives,% of sample			The content of water-soluble extractives, % of sample			The content of tannins, % of sample		
		good	satisfactory	unsatisfactory	good	satisfactory	unsatisfactory	good	satisfactory	unsatisfactory
1	Zavvalovo, Suburban (78, 3)	8.41 ± 0.40 8.23... 8.58	6.78 ± 0.10 6.37...7.19	9.91 ± 1.74 2.43...17.38	7.20 ± 0.20 6.33...8.06	6.62 ± 0.09 6.22...7.02	7.57 ± 1.58 0.79...14.36	6.63 ± 0.33 5.99...7.26	5.83 ± 0.08 5.67...5.99	4.06 ± 1.35 1.42...6.69
2	Zavvalovo, Suburban (158, 3)	12.98 ± 0.18 12.20... 13.77	17.04 ± 1.02 12.65... 21.42	7.83 ± 1.28 2.32...13.33	10.25 ± 0.14 9.63... 10.87	11.93 ± 0.57 9.45...11.37	6.63 ± 1.26 1.22...12.03	6.06 ± 0.85 5.23...8.03	5.83 ± 0.08 5.48...6.18	4.05 ± 1.34 -1.74...9.84
3	Yagan (115, 8)	11.06 ± 0.12 10.53... 11.58	14.90 ± 0.21 13.99... 15.81	5.82 ± 0.65 3.02...8.62	7.98 ± 0.57 5.52...10.44	9.98 ± 0.14 9.38...10.59	4.97 ± 0.44 3.08...6.85	6.47 ± 0.22 5.50... 7.45	6.72 ± 0.09 6.31...7.13	3.30 ± 0.45 1.35...5.25
4	Yagan (214, 8)	11.57 ± 0.16 10.87... 12.27	14.48 ± 2.64 3.10...25.87	9.90 ± 1.74 2.43...17.38	6.41 ± 0.09 6.02...6.80	10.60 ± 2.33 0.58...20.62	3.34 ± 0.65 0.57...6.11	5.161 ± 0.73 4.84... 5.47	7.78 ± 1.85 -0.19...5.74	2.45 ± 0.31 1.13...3.78

The plantings on the trial plots are characterized by low tree density in the main canopy. The density varies from 2.95 to 11.1 m²/ha with a large number of dead trees (absolute density, taking into account dead trees, 5.9 ... 17.9 m²/ha). Stands with similar density are described as woodlands.

The enumeration taxation in all study areas revealed a rather large amount of dead wood. Depending on the TP, its stock was 31.1 ... 93.8 m³/ha, which increases the risk of forest fires. In the trial plots in the Yagan Forest District, the stock of dead wood exceeds the stock of living trees, and in the Zavvalovo Forest District, dead wood accounts for more than 50% of the living wood stock.

Thinning of the main canopy led to a change in the plant community. In the living ground cover, nemoral forest herbs (European ungulate (*Asarum europaeum* L.) and wood sorrel (*Oxalis acetosella* L.) begin to be replaced by field forbs (field sow thistle (*Sonchus arvensis* L.), cat grass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis* L.), hybrid clover (*Trifolium hybridum* L.) and others).

New conifer growth was not present on test plots in the Yagan Forest District, and was present on test plots in the Zavvalovo Forest District, but was insufficient (less than 500/ha) and of poor quality (not hardy). Woody vegetation included common raspberry (*Rubus idaeus* L.), mountain ash (*Sorbus aucuparia* L.), forest honeysuckle (*Lonicera xylosteum* L.), and silver birch (*Betula pendula* Roth.), the latter of which is beginning to form the main canopy.

Extractives Content

A comparative study of the total content of extractives in wood in three spruce groups revealed significant differences ($p < 0.001$), which mainly lie in the content of resin and tannins in trees of satisfactory and unsatisfactory vitality ($p < 0.000$); no significant differences ($p > 0.05$) were found in the "water-soluble extractives" group. The highest content of all groups was found in plants with a satisfactory life state, and the lowest was in dry trees (Fig. 2).

A study of the content of extractives in various TPs revealed that both the total content of and individual types were statistically significant only for TP3 and TP4 ($p < 0.005$), which are located in the Yagan Forest District. For the test plots in the Zavvalovo Forest District, no significant differences were found for any category of extractives ($p > 0.05$).

When analyzing the combined influence of both grouping factors (in terms of vitality and TP), it was found that the greatest difference in average values for extractives composition is associated with tree vitality ($p < 0.001$) while habitat plays a smaller role ($p < 0.01$); the exception is resinous content ($p < 0.000$). Variance analysis indicated that the interaction between the two factors is insignificant. Each of them has a separate impact (Fig. 3).

Discussion

Thinning of the main canopy is the main environmental factor that leads to a change in the plant community. Based on the data obtained, it can be said that mass drying has resulted in the trial plots losing the main features of spruce forest ecosystems. Birch and other deciduous species are beginning to form the main canopy. Meanwhile, there is mass growth in meadow vegetation, which forms dense groundcover that does not allow spruce seedlings to take root.

All the factors listed above form a favorable background for the development of xylophages (Alyab'ev, 2013; Kirker et al. 2013). Despite the fact that, in recent years, after the drought of 2010, climatic factors (including temperature, humidity, and precipitation) were more favorable for the development of dark conifers, their drying continued alongside an increase in the population density of bark beetles. The spread of the bark beetle (*Ips typographus*) is the main cause of death among spruce in the territory of the UR (Maslov, 2010; Magney et al. 2019). In particular, within the study areas, we also revealed significant stocks of

dead conifer biomass with characteristic xylophage traces. However, in plants, as in any living organisms, there are adaptive mechanisms that ensure the survival of the species under various stress conditions. One response to external adverse factors (including damage by phytophages) is the synthesis of a number of secondary metabolites with a high level of biological activity, which provide for biochemical adaptation in plants (Bahtenko, 2008; Prusakova et al. 2008; Zagoskina, 2015; Makeeva, 2017).

The results of a biochemical analysis of wood revealed that the content of extractives in trees is associated with their life state. The highest content of all metabolite groups was observed in specimens of satisfactory vitality. Although this wood group shows signs of drying, the increased extractives content in the wood indicates functioning defense mechanisms. However, significant variation in the studied biochemical parameters of trees of satisfactory vitality may indicate a possible breach in homeostasis. As we noted, enhancing extractives formation processes is one of the strategies plants use for metabolic adaptation to various stress factors. In particular, extractives increase resistance to phytophages. Plant cells respond to mechanical damage or pathogens by increasing their formation of extractives, in particular tannins and resins, which leads to lower insect pest survival and fertility rates (Martem'yanov, 2009; Zinov'eva et al. 2009; Heldt, 2015). Meanwhile, trees with good vitality are in a more stable physiological state, so this group is characterized by a smaller range of variation in the content of extractives with relatively high average values. Trees of unsatisfactory vitality had the lowest biochemical parameter values, which indicates the absence of homeostasis in dry plants.

Conclusion

This research allows us to state that an active change in the plant community in coniferous stands is underway as a result of the degradation of the main canopy. Spruce plantings are characterized by low tree density in the main canopy which is facilitating a natural succession from dark coniferous forests to soft-leaved ones. The combination of these factors forms a favorable environment for the bark beetle population to spread (*Ips typographus*), which is the main cause of death for spruce in the territory of the UR. One internal mechanism in response to external stress factors (including damage to organs by phytophages) is the intensification of the formation of internal metabolites, in particular tannins and resins. The results of our biochemical analysis of wood showed that one of the factors determining the content of extractives in wood is tree vitality. It is likely that a high content of tannins and resins in weakened trees indicates that the plant's internal resources were mobilized. In this way, the content of extractives can be an indicator of the conditions of spruce species and can be used in the selection of trees to create sustainable plantings in forest cultivation. However, for a more complete understanding of the dynamics of extractives in trees in various states, a series of additional studies and data calibrations are necessary that account for seasonality, climatic factors and the degree of damage caused by pathogenic agents.

Declarations

List of Abbreviations

UR – Udmurt Republic; TP – the test plots; $D_{av.1.3}$ – average diameter, H_{av} – average height; A_{av} – average age; ΣG – density; M – stock of dead wood; RFBR - Russian Foundation for Basic Research.

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of supporting data

The tree regions and associated tree attributes used in the study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

I. Bukharina conducted a description of the forest, conducted an analysis of the results, led the writing of the manuscript. K. Vedernikov conducted a study of the state of the areas of coniferous stands, made figure 1 and tables 1 and 2, participated in the writing of the manuscript. A. Pashkova conducted statistical processing of the results, participated in the writing of the manuscript. Ye. Zagrebin made biochemical analyzes of wood, prepared figures 2 and 3.

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References

1. Alyab'ev, A.F. (2013). Usyhani eel'nikov Podmoskov'ya [Drying of spruce forests near Moscow]. *Vestnik MGUL - Lesnoj Vestnik [Forest Herald]*, 6(98), 159–166. (in Russian)
2. Babkin, V.A. (2017). Ekstraktivnye veshchestva drevesiny listvennicy: Himicheskij sostav, biologicheskaya aktivnost', perspektivy prakticheskogo ispol'zovaniya [Extractive things of larch wood: Chemical composition, biological activity, prospects for practical use]. *Innovatika i Ekspertiza [Innovation and Expertise]*, 2(20), 210–223. (in Russian)
3. Bahtenko, E.Yu. (2008). Mnogoobrazie vtorichnyh metabolitov u ssuhih rastenij [The variety of secondary metabolites of higher plants]. Vologda: VGPU. (in Russian)
4. Caudullo, G., Tinner, W., & de Rigo, D. (2016). *Picea abies* in Europe: Distribution, habitat, usage and threats. In J. San-Miguel-Ayaz (Ed.), *European Atlas of Forest Tree Species* (pp. 114–116). Luxembourg: Publication Office of the European Union.
5. Fedorova, T. E., Fedorov, S. V., & Babkin, V. A. (2016). Oligolignans in the wood of *Picea obovata* Ledeb. *Russian Journal of Bioorganic Chemistry*, 42(7), 712–715. <https://doi.org/10.1134/S1068162016070062> (in Russian)
6. Heldt, H.-W. (2015). *Biochimija rastenij [Plant biochemistry]*. Moscow: Binom, Laboratorija Znaniy. (in Russian)
7. Ivanchina, L.A., & Zalesov, S.V. (2017). Vliyaniye tipa lesa na ustojchivost' elovyh drevostoev Prikam'ya [Influence of the type of forest on the stability of spruce stands of Prikamye]. *Permskij Agrarnyj Vestnik [Perm Agrarian Bulletin]*, 1(17), 38–43. (in Russian)
8. Kirker, G.T., Blodgett, A.B., Arango, R.A., Lebow, P.K., & Clausen, C.A. (2013). The role of extractives in naturally durable wood species. *International Biodeterioration & Biodegradation*, 82, 53–58. <https://doi.org/10.1016/j.ibiod.2013.03.007>
9. Korotkov, S.A., Stonozhenko, L.V., Erasova, E. ., & Ivanov, S.K. (2014). Ustojchivost' i dinamika elovyh i lipovyh nasazhdenij severo-vostochnogo Podmoskov'ya [Stability and dynamics of spruce and linden plantations of the northeastern Moscow Region]. *Vestnik MGUL - Lesnoj Vestnik [Forest Herald]*, 4, 13–22. (in Russian)
10. Lakin, G.F. (1990). Biometriya: Uchebnoye posobiye dlya biologicheskikh spetsial'nykh nauk VUZov [Biometrics: A textbook for biological specialties of universities] (4th ed.). Moscow: Higher School. (in Russian)
11. Magney, T.S., Bowling, D.R., Logan, B.A., Grossmann, K., Stutz, J., Blanken, P.D., Frankenberg, C. (2019). Mechanistic evidence for tracking the seasonality of photosynthesis with solar-induced fluorescence. *Proceedings of the National Academy of Sciences*, 116(24), 201900278. <https://doi.org/10.1073/pnas.1900278116>
12. Makeeva, I.Yu. (2017). Fiziologo-biohimicheskie otvety Solanum tuberosum na dejstvie kofejnoj kisloty [Physiological and biochemical responses Solanum tuberosum to the action of caffeic acid] (PhD Thesis). Orel. (in Russian)
13. Martem'yanov, V.V. (2009). Znachenie fenol'nyh soedinenij pri indukcii otveta berezy povisloj na ee povrezhdenie gusenitsami neparnogo shelkopryada [The values of phenolic compounds during the induction of birch flowers hanging on its way by unpaired silkworm caterpillars]. In *Materialy dokladov VII Mezhdunarodnogo simpoziuma po fenol'nym soedineniyam: fundamental'nye i prikladnye aspekty [Materials of the reports of the VI International Symposium on Phenolic Compounds: Fundamental Aspects]* (pp. 165–166). Moscow: IFR RAS; RUDN. (in Russian)
14. Maslov, A.D. (2010). Koroed-tipograf i usyhanie elovyh lesov [Printing bark beetle and drying of spruce forests]. Moscow: VNIILM. (in Russian)
15. Mastickij, S.E. (2015). *Statisticheskij analiz i vizualizaciya dannyh s pomoshch'yu R [Statistical analysis and visualization of relatives using R]* (S. E. Mastickij & V. K. Shitikov, Eds.). Retrieved from <https://www.ozon.ru/context/detail/id/33061125/> (in Russian)
16. Negrón, J. (2018). Biological aspects of mountain pine beetle in Lodgepole pine stands of different densities in Colorado, USA. *Forests*, 10(1), 18. <https://doi.org/10.3390/f10010018>
17. Obolenskaya, A.V., El'nickaya, Z.P., & Leonovich, A.A. (1991). Laboratornye raboty po himii drevesiny i cellyulozy: Uchebnoe posobie dlya vuzov [Laboratory work on the chemistry of wood and cellulose: A manual for universities]. Moscow: Ekologiya [Ecology]. (in Russian)
18. Ostroukhova, L.A., Fedorova, T.E., Onuchina, N.A., Levchuk, A.A., & Babkin, V.A. (2018). Opredeleniy ekolichestvennogo sodержaniya ekstraktsionnykh veshchey iz dereva, komej, kory derevov khvoynykh vidov Sibiri: listvenitsy (*Larix sibirica* L.), sosny (*Pinus sylvestris* L.), pihty (*Abies sibirica* L.), eli (*Picea obovata* L.) i kedra (*Pinus sibirica* Du Tour). [Determination of the quantitative content of extraction things from a tree, the roots of the bark of coniferous species of Siberia: larch (*Larix sibirica* L.), pine (*Pinus sylvestris* L.), pihty (*Abies sibirica* L.) spruce (*Picea obovata* L.) and cedar (*Pinus sibirica* Du Tour)]. *Chemistry of Plant Raw Material*, 185–195. <https://doi.org/10.14258/jcpm.2018044245> (in Russian)
19. Prusakova, L.D., Kefeli, V.I., Belopuhov, S.L., Vakulenko, V.V., & Kuznecova, S.A. (2008). Rol' fenol'nyh soedinenij v rasteniyah [The role of phenolic compounds in plants]. *Agrokhimiya [Agrochemistry]*, 7, 58–98. (in Russian)
20. Rysin, I.I. (Ed.). (2009). Geografiya Udmurtii – Prirodnyesloviyairesursy: Uchebnoeposobie [Geography of Udmurtia: Natural conditions and resources: A training manual]. Izhevsk: Izdatel'skiy dom «Udmurtskiy universitet». (in Russian)
21. Scheffer, T.C., Morrell, J.J., & Oregon State University. Forest Research Laboratory. (1998). *Natural durability of wood: A worldwide checklist of species [Technical Report]*. Retrieved from Corvallis, Or.: College of Forestry, Forest Research Laboratory, Oregon State University website: <http://hdl.handle.net/1957/7736>
22. Singh, T., & Singh, A.P. (2012). A review on natural products as wood protectant. *Wood Science and Technology*, 46(5), 851–870. <https://doi.org/10.1007/s00226-011-0448-5>
23. Taylor, A.M., Gartner, B.L., & Morrell, J.J. (2007). Heartwood Formation and Natural Durability—A Review. *Wood and Fiber Science*, 34(4), 587–611.
24. Yang, D.Q. (2009). Potential utilization of plant and fungal extracts for wood protection. *Forest Product Journal*, 54, 37–39.
25. Zagorskina, N.V. (Ed.). (2015). Fenol'nye soedineniya: Fundamental'nye prikladnye aspekty [Phenolic compounds: Fundamental applied aspects]. Moscow: Nauchnyy mir [The Scientific World]. (in Russian)

26. Zinov'eva, S.V., Vasyukova, N.I., Udalova, ZH. V., Gerasimova, N.G., & Ozereckovskaya, O.L. (2009). Uchastie salicilovoj kisloty v ustojchivosti rastenij k paraziticheskim nematodam [The participation of salicylic acid in the resistance of plants to parasitic nematodes]. In *Materialy dokladov VII Mezhdunarodnogo simpoziuma po fenol'nym soedineniyam: fundamental'nye i prikladnye aspekty* [Materials of the reports of the VI International Symposium on Phenolic Compounds: Fundamental Aspects] (pp. 99–100). Moscow: IFR RAS; RUDN. (in Russian)

Figures

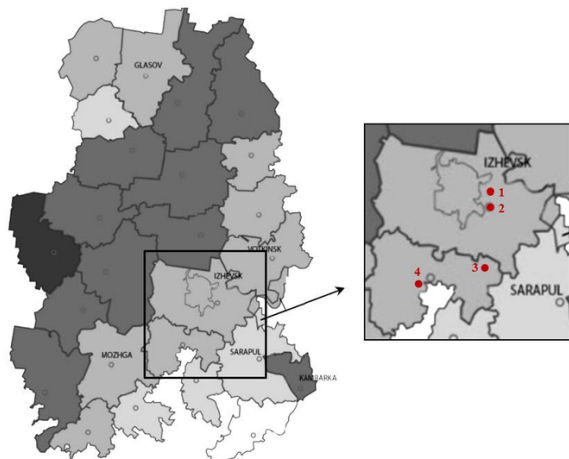


Figure 1

Map of the location of the trial plots (TP) in the Udmurt Republic. Designations: 1 - TP1 (Zavyalovo - 1), 2 - TP2 (Zavyalovo - 2), 3 - TP3 (Yagan - 1), 4 - TP4 (Yagan - 2)

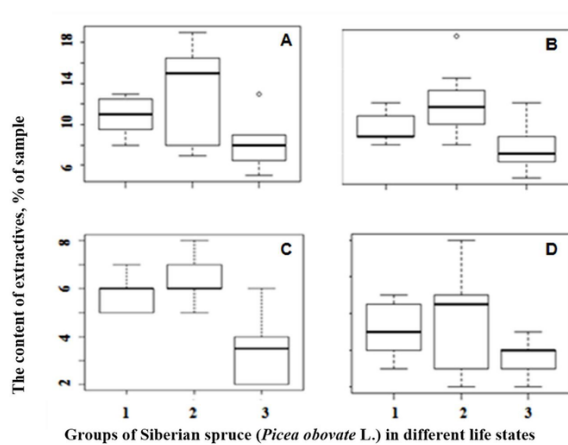


Figure 2

The content of various groups of extractives in Siberian spruce (*Picea obovata* L.) in different life states: A is the total content of extractives; B is water-soluble extractives; C is tannins; D is resinous extractives. Designations: 1- good vitality; 2- satisfactory; 3 - unsatisfactory

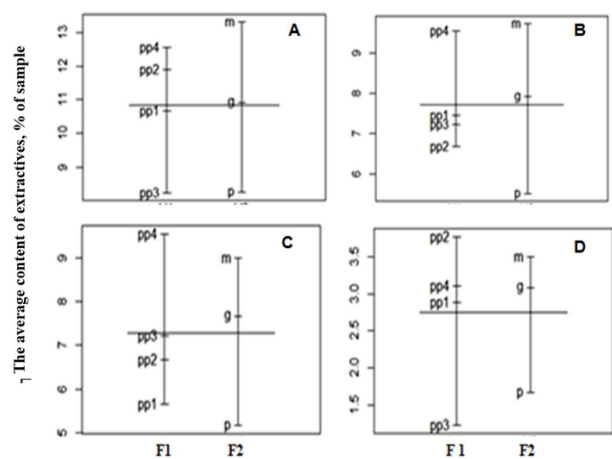


Figure 3

The average content of various groups of extractives in Siberian spruce (*Picea obovata*) L.) in relation to various factors: A is total content of extractives; B is water-soluble extractives; C is tannins; D is resinous extractives. Designations: F1 - test plot (TP): tp1 - TP1, tp2 - TP2, tp3 - TP3, tp4 - TP4. F2 - vitality: g - good vitality; m- satisfactory vitality; p - unsatisfactory vitality