QUALITY CHANGES DURING SUMMER–AUTUMN LONG-TERM STORAGE OF SCOTS PINE (*PINUS SYLVESTRIS* L.) ROUNDWOOD

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Abstract
Latvia at the moment does not have precise data about long-term storage of Scots pine. Long-term storage in warm season may lead to significant damages for high priced timber, income reduction for timber sellers and quality loss risk for timber buyers, therefore, roundwood is transported as soon as possible, because of the risk of blue stain, crooks and insect damages. Results of this study on Scots pine were obtained during summer–autumn season of year 2015. Scots pine timber quality changes in long-term storage were analyzed in 4 sample stacks – set up in summer (25 July) and stored for 100 days. In every sample plot there was a control pile, a pile with harvester spike damages, a pile with bark damages and a pile with harvester spike and bark damages. There were 32 timber assortments in every pile in order to determine also the emplacement effect in stack.
In this study a high correlation was found between pine timber quality changes and meteorological conditions, side surface damages and storage length. By analyzing the proportion of blue stain in cross-section and its changes during storage between control assortments and assortments with bark and harvester damages, significant differences were observed, therefore it can be concluded that not only bark damages influence the proportion of blue stain, but also harvester spike rollers. Based on the results of this study, we can predict maximum storage duration during summer–autumn period in Latvia, and it is set from 9 – 16 days.
Key words: Scots pine, roundwood, storage, blue stain.

Introduction

When the highest quality timber assortments are stored a few days too long, it can significantly influence the price of 1 m^3 because of the quality reduction (blue stain, drying crooks and insect damages). If roundwood has somewhat different color from the natural one, the price for that kind of timber is reduced significantly. Usually wood discoloration has either microbial or non-microbial origin and there could be cases when both factors – biotic and abiotic are involved (Uzunovic *et al*., 2008).

Maximum storage duration is one of the most important factors for reaction time in logistics system. By knowing the maximum storage duration, it will be easier to plan timber transportation and cutting intensity when conducting concentration cuttings in Latvia's state forests in respect to economic value of these resources. Meteorological parameters and timber moisture should be the main reasons for extensive blue stain damages.

Usually blue stain fungi do not cause significant changes in mechanical properties of the wood as they cannot digest components of the wood cell wall (Fleet, Breuil, & Uzunovic, 2001).

Staining fungi – usually caused by different fungal genera, can grow up to 2 cm per day longitudinally along the tracheid and parenchyma of softwoods (Uzunovic & Webber, 1998). Mechanical equipment, especially harvesters, apparently play a significant role in blue stain dissemination (Uzunovic, O'Callahan, & Kreber, 2004).

Millions of dollars annually are spent by forest product industry on fungicides in order to control sapwood staining fungi, but these agents do not have long lasting effectiveness desired and present significant environmental concerns (Hoffman & Breuil, 2004).

There are many other possible ways to control sapwood staining fungi besides the chemical treatment: freezing and snow storage, water storage and storage under an elevated carbon dioxide (CO^2) atmosphere, log drying, reduction of mechanical damage, control of insect vectors and fungal food reduction through 'sour-felling' or biological protection, applying sprinkling system (Shupe *et al*., 2008,Uzumovic *et al*., 2008).

The aim of this research was to determine the quality changes of Scots pine (*Pinus sylvestr*is L.) during summer–autumn long-term storage. By having warmer spring and autumn, forest logging is possible all year long with higher intensity, after that should follow fast harvesting, forwarding and roundwood transportation. This was the reason to establish this research and to understand how to optimize all cycle from harvesting until sawing in mills. In the future this study may help to understand economic losses for every day that timber is overstored and will be practically applicable in timber trade.

Materials and Methods

To assess quality changes of timber in summer-autumn season, four timber storages were created with a variety of side surface damages in order to determine the suitable duration of storage without sacrificing superior timber quality, thus satisfying the interests of buyers and sellers. It is necessary to create all timber storages in a forest under the canopy; in that way including the factor of forest climate conditions.

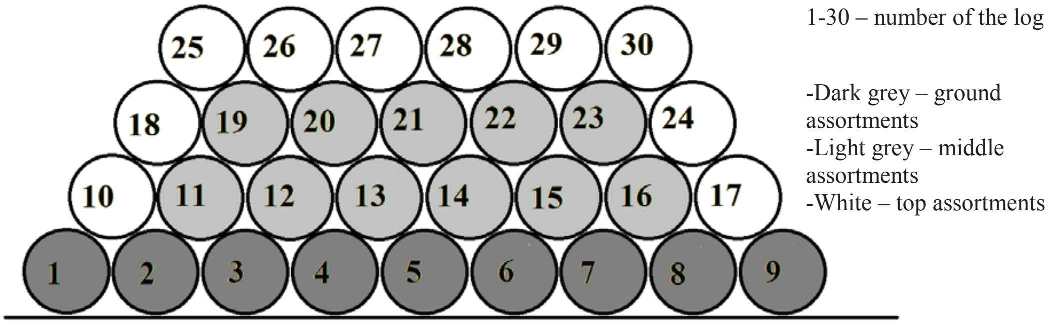

Figure 1. The scheme of assortment emplacement.

One pile consisted of 30 to 32 assortments with a diameter of 10 – 30 cm and the bark thickness 2 mm – 3 cm and a length of 1 m (Fig. 1). Since the discoloration of sapwood and cracks mainly develop from the end plane, it was not necessary to choose assortments longer than one meter, because it is fully enough to evaluate the reduction of quality in 50 cm distance from each of assortment end planes.

H. Solheim (1992) confirmed that in the first two weeks after the bark beetle *Ips typographus* attack, discoloration is not visible. That is why the first sample survey time was set after 15 to 20-day period of storage. Later timber storages were surveyed every 15 – 30 days depending on the season. In each survey 7 – 8 assortments were prepared and described. Sample discs were prepared from the log ends.

Evaluation of the assortment emplacement in the storage (Fig.1):

- 1 – 9 changes in quality are evaluated for assortments standing on the ground;
- 11 – 16 and 19 – 23 changes in quality are evaluated for assortments located in the middle of the stack;
- 10, 17, 18 and 24 to 30 evaluation of assortment emplacement on the top of the stack and its impact on timber quality.

In order to assess variety of preparation ways, 4 timber storages were created at the same time in each plot with different damages of side surface.

1. Control – assortments without side surface damages.
2. Damaged bark – assortments with the side surface of the bark bruised over the entire length.
3. Harvester spike roller damages – assortments that have damages from harvester pike roller, but do not have bruised bark made by debarking knives.
4. Harvester spike roller and bark damages – assortments with bruised bark and damaged side surface by harvester spike roller.

Assortments from every timber storage got the number in accordance with the scheme shown in Figure 1, in order to track these segments every time when resorting the timber storage and when dealing with processing of data. Storages were placed 10 to 15 cm apart from each other to evaluate changes in quality inside and outside the storage. Five discs of the assortment were sawn off in one survey, as shown in the scheme (Fig. 2). For the first disc on the outside only sapwood was sawn 3-5 mm in depth, in order to assess the quality requirements of assortments at purchasing. Every subsequent disc was sawn in 50 mm.

To describe the proportion of blue stain, it is necessary to determine the percentage of sapwood discoloration by excluding heartwood. Therefore, sapwood and blue stain basal area of sample discs was calculated by using special image processing

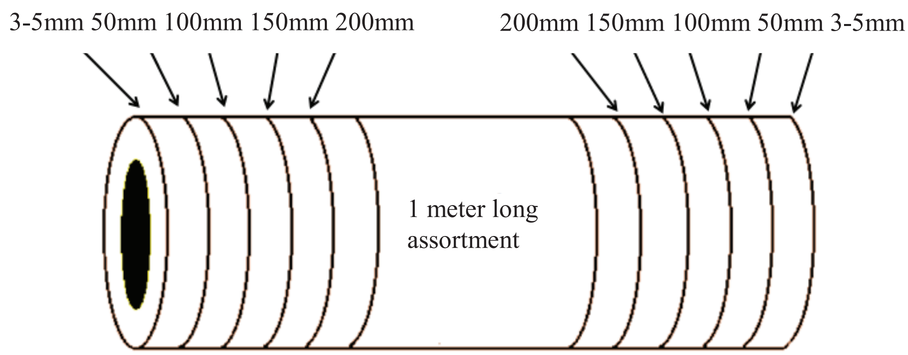

Figure 2. Roundwood cross-cuting section length.

software ′ImageJ′. The total area of sapwood and blue stain was marked with different colors already in the forest. By establishing images with different distance from the end plane we could assess damage intensity in the longitudinal direction. For further data analysis for every sample disc we made the measurement of heartwood basal area, sapwood basal area and area of discoloration. In order to get the meteorological data, temperature and precipitation was obtained from www.meteo.lv by using the data of the nearest meteorological station. The sum of positive temperature and sum of precipitation during storage period was used.

Two independent sample mean values ± 2 standard errors are characterized by a 95% confidence interval. If two independent samples with 95% confidence intervals overlap with each other, then the difference between them will not be statistically significant. To determine the significance of multiple factors, multiple factor linear regression was used. For this analysis IBM SPSS Statistics 20 was used.

Results and Discussion

Blue stain can form in different stages of wood processing. It may appear in storage and delivery stage, as well as on the finished product if conditions are favourable (Shupe, Lebow, & Ring, 2008). Nutrients, oxygen, appropriate temperature and moisture are essential factors for the development of fungus. Assuring optimal conditions for fungus may result in appearance of blue stain already after a few days (Hubbard *et al*., 2005).

At the beginning of timber storage survey – 25 July 2015, attention was paid to the moment when signs of blue stain appeared on the edge plane until 5 mm depth. In the summer season blue stain in the control pine roundwood appeared on the 16th day of storage. When conducting regular surveys of timber stacks, one could observe that on some individuals blue stain starts to develop on day 29 of storage. On pine roundwood with bark damages the first signs of blue stain can be observed on the 12th day, but on some particular individuals signs of blue stain can be observed only after 24 days of storage. A similar trend can be observed also for roundwood with harvester spike roller damages. The first signs of blue stain can be observed already after 10 days of storage, but on some individuals – only after 22 days. The most rapid appearance of blue stain was found on roundwood that has both signs of harvester spike roller and bark damages. The first signs of blue stain were visible already after 9 days of storage, but on some individuals – after 18 days.

From the available information we can conclude that after the appearance of first signs of blue stain, in 9 – 13 days blue stain can be observed on all the stored pine timber samples. In the same way it can be observed that side surface damages of roundwood affect the process of drying, hence the development of blue stain.

In the start of drying process after the tree felling and cross-cutting, the moisture content of sapwood decreases in accordance with current climate, wood properties and bark damages. Decreasing moisture content of wood results in an increased risk of blue stain. When the relative moisture of sapwood decreases below 50%, the risk of wood staining increases noticeably (Peek & Liese, 1974; Liese & Peek, 1984).

Drying process of roundwood depends on the degree of bark damages. Results of Nurmi and Lehtimäki (2011) confirm that in winter season bark is damaged the least. From literature sources and practical knowledge we know that wood dries faster when bark is removed. In past it was done manually with hands. Nowadays, when the wood harvesting process is mechanized, a part of the bark is damaged or removed in debranching procedure by the harvester spike rollers and debranching blades.

Weather conditions are of high importance in the drying process. The most important factors are: temperature, relative humidity, rainfall and wind speed. Stand location and relief also play an important role on temperature under canopy layer. The amount of heat required for evaporation of moisture is transferred from atmospheric air, which takes up wood moisture in the form of water vapour (Heiskanen, 1953).

When preparing logs by harvester, usually bark is bruised in three places in the form of stripes. Also later forwarder and truck with greifer bucket bruises bark in the middle of assortment while loading the timber.

In the further analysis we will look at sapwood discoloration development depending on the duration of storage at a depth of 5mm from roundwood edge plane taking into account the surface damages. Analyzing the impact of storage duration in the summer, it can be observed that the discolouration proportion in the sapwood part increases with storage time. It is also possible to observe that discoloration develops faster and with a greater intensity on the pine roundwood with a side surface damage.

In order to determine whether the discoloration proportion statistically significantly differs between the pine roundwood with a variety of side surface damages taking into account duration of storage, the average indicator values are represented together with ± 2 standard errors.

When analyzing the proportion of blue stain in depth of 5 mm from the edge of the plane and the changes depending on the duration of storage, it can be observed that there are significant differences in proportion of discoloration from day 25 to 70 of

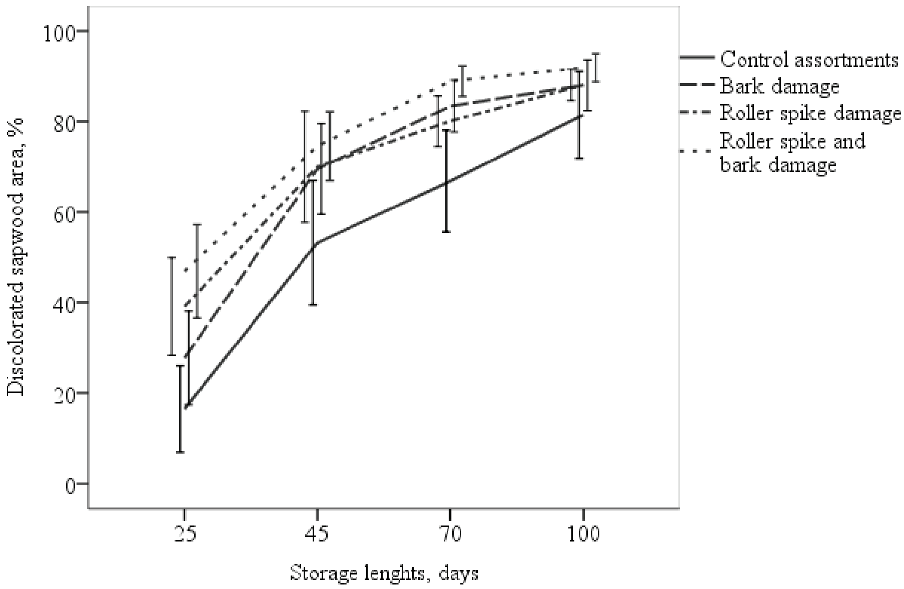

Figure 3. Sapwood discoloration ratio changes depending on the storage duration (± 2 standard errors).

storage between the control timber and timber with a harvester spike roller damages and bark damages. There are also significant differences in proportion of the discoloration when comparing control timber and timber with harvester spike roller damages on the 25th day of storage (Fig. 3).

The control timber discoloration proportion in sapwood part ranges from 16% (25th day of storage) to 81% (100th day of storage). The proportion of discoloration in sapwood of timber with harvester spike roller damages and timber with bark damages ranges from 47% (25th day of storage) to 92% (100th day of storage). In general, it can be observed that the rapid development of discoloration in depth of 5 mm from the edge plane occurs up to 45th day of storage, when the proportion of discoloration in sapwood part reaches:

- 53% for the control timber;
- 70% for wood with bark damages;
- 70% for timber with harvester spike roller damages;
- 75% for timber with harvester spike roller damages and bark damages.

Thereby, roundwood that is processed by harvester is subjected to a greater risk of being infected with a fungus, not only because a big part of bark is being bruised, but also because of the damages made by harvester head feed rollers (Uzunovic, O'Callahan, & Kreber, 2004).

Also K. Lee and J.N. Gibbs (1996) concluded that damages caused by harvester head feed rollers on the side surfaces of Pinus nigra affect the duration of storage in the warm period of year.

In the further analysis considering various wood surface damages and the storage period duration, the changes of discoloration proportion in sapwood part in the direction from the edge of the plane to middle, will be assessed. In general, it can be observed that the proportion of sapwood discoloration tends to decrease from the end of roundwood towards the middle part. This can be explained by the fact that most of the moisture is released from the endings of the timber, where there are favorable conditions for the development of blue stain. For conifers water transpiration occurs only in the sapwood part, while in the core it has stopped.

The same as for roundwood with different kind of surface damages, also for control roundwood without any visible damages we can observe smaller proportion of discoloration in the direction from the end plane to the middle part (Fig. 4).

When analysing discoloration proportion changes in the sapwood part in the direction from the end plane to the middle, it can be observed that the most important discoloration proportion reduction is from the end plane (5 mm) to 50 mm. Further, with increasing distance from the end plane, discoloration proportion decrease is not significant or even remains unchanged.

Storing pine logs for 25 days with a variety of side surface damages, the following discoloration proportion changes in sapwood part in the direction from the end plane to the middle can be observed:

- control timber at 5 mm – 16%, 50 mm – 9%, 200 mm – 6%;
- timber with bark damages at 5 mm – 28%, 50 mm – 15%, 200 mm – 9%;
- timber with harvester spike roller damages at 5 mm – 39%, 50 mm – 21%, 200 mm – 18%;

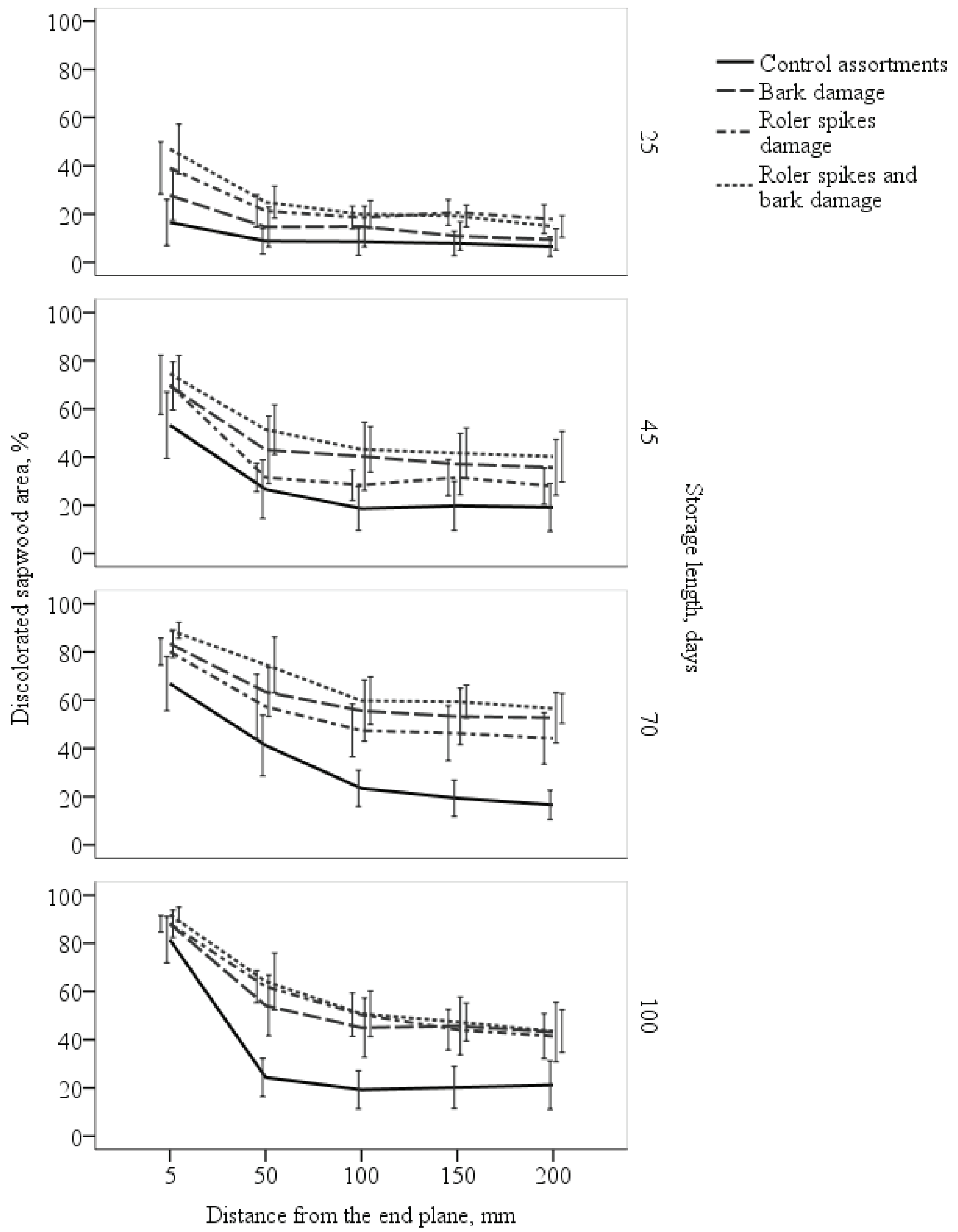

Figure 4. Sapwood discoloration ratio changes depending on the storage duration (± 2 standard errors).

- timber with harvester spike roller damages and bark damages at 5 mm – 47%, 50 mm – 25%, 200 mm – 15%.

Storing pine logs for 45 days, the following discoloration proportion changes in sapwood part in the direction from the end plane to the middle can be observed:

- control timber at 5 mm – 53%, 50 mm – 27%, 200 mm – 19%;
- timber with bark damages at 5 mm – 70%, 50 mm – 43%, 200 mm – 36%;
- timber with harvester spike roller damages at 5 mm – 70%, 50 mm – 32%, 200 mm – 28%;
- timber with harvester spike roller damages and bark damages at 5 mm – 71%, 50 mm – 51%, 200 mm – 40%.

In turn, after the 100-day storage of pine logs, the following changes in discoloration proportion were observed in sapwood part in direction from the end plane to the middle:

- control timber at 5 mm – 81%, 50 mm – 24%, 200 mm – 21%;
- timber with bark damages at 5 mm – 88%, 50 mm – 54%, 200 mm – 43%;
- timber with harvester spike roller damages at 5 mm – 88%, 50 mm – 62%, 200 mm – 41%;

Table 1

Meteorological parameters during the storage

Parameter	Storage period			
	Day 1. – 25.	Day 26. – 45.	Day 46. – 70.	Day 71. – 100.
Sum of positive temperature, °C	472	314	330	134
Sum of precipitation, mm	37	94	25	3

Table 2

Results of multiple factor linear regression

Parameters	Unstandardized Coefficients		t	p - value
	B	Standart. Error		
Constant	-4.688	4.767	-0.983	0.032
Roundwood surface damages	7.374	0.919	8.023	0.000
Distance from the end plane, mm	-0.478	0.046	-10.473	0.000
Precipitation sum, mm	0.162	0.061	2.667	0.008
Positive temperatures sum, °C	0.039	0.012	3.305	0.001

- timber with harvester spike roller damages and bark damages at 5 mm – 92%, 50 mm – 64%, 200 mm - 44%.

According to these results, the summer-autumn period in Latvia is favourable for the development of sapwood fungus. Acquainted with the various authors' studies, we can conclude that the temperature (minimum, maximum and optimum) for the growth of fungus differs slightly. This could be due to other changing circumstances, such as differences in humidity. S. Hubbard *et al*. (2005) claims that optimum temperature for fungus is 20-30 °C, but the fungus may still occur in a temperature range of 4-55 °C. According to S. Olaf (2006), the minimum temperature for the development of fungus depends on the species; it may be from 0-3 °C. The optimum temperature is 18-29 °C and the maximum is 40 °C.

In our situation, for regression analyses the sum of positive temperature and precipitation was used. At the end of storage period the average temperature and precipitation dropped (Table 1) and it caused a slight decrease of fungal damage

To more fully characterize the changes of discoloration proportion in summer-autumn period in sapwood part, multiple factor linear regression was used for analysis in order to assess the wider effect of different factors. The main task of regression analysis is to study the connection between the performance characteristic (discoloration) and factorial signs (side surface damages, storage duration till the 45th day, sum of the positive temperatures, the distance from the end plane up to 50 mm, the sum of precipitation and relative air humidity) and evaluate the function of this correlation. When conducting multiple factor linear analysis, roundwood side surface damages are recoded in digital form (1- control; 2 - bark damages; 3 - harvester spike roller damages; 4 - harvester spike roller damages and bark damages).

After performance of multiple factor linear regression, it can be concluded that damages of the roundwood surface, distance from the end plane (5-50 mm), the amount of precipitation and the sum of positive temperatures significantly affect the roundwood discoloration proportion changes in the sapwood part (Table 2). Linear regression determination coefficient R2 = 0.57, while the correlation coefficient r = 752.

Conclusions

1. The most significant factors influencing the proportion of sapwood discoloration in pine roundwood are side surface damages, the distance from the end plane, precipitation sum and the sum of positive daily temperatures in the storage period.
2. Depending on the roundwood side surface damages, the first signs of discoloration appear from 9th to 16th day of storage, while on all of the logs in timber storage discoloration can be observed in 9 – 13 days after the first signs of discoloration are detected.
3. Analyzing the proportion of discoloration and its changes depending on the duration of storage, it can be observed that between the control timber and timber with harvester spike roller and bark damages there are significant differences in the proportion of discoloration, so it can be concluded

that wood products processed by harvesters are faster infected by fungus, not only because of bruised bark, but also because of damages caused by harvester spike roller.

4. Analyzing the changes in proportion of discoloration in sapwood in the direction from the end plane of log to the middle, the most significant reduction of discoloration proportion can be observed from the end plane (5 mm) to 50 mm.
5. The most rapid discoloration development in sapwood continued until the 45th day of storage, which can be explained by the fact that during this period there was a high average air temperature which is one of the statistically significant factor (p=0.001). After this period there was a decrease in the average air temperature, resulting in decrease of discoloration development intensity.

Acknowledgments

The data for this research was collected in the framework of national research program no. 2014/VPP2014-2017, sub-project 'Studies of timber processing, forest products logistics and planning'.

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