The Impact of Resin Harvest History on Properties of Scots Pine Wood Tissue

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This study was conducted in Central Europe (Poland) in pine forests that were subjected to the process of resin harvesting in the 1970s. Forty trees were designated for the study, which had one or two resin blazes. The objectives of the experiment were to determine the effect of resin tapping on the changes in annual growth, wood density, and mechanical strength of wood in the damaged trees. Resin tapping affected the development dynamics, especially in trees with a single resin blaze. In addition, bark cutting affected wood density over the cross-section. However, no significant variation was found in terms of the mechanical properties of wood, which may support the theory of adaptive tree growth and optimization of tree's structure to its functions.

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Keywords: Scots pine; Resin tapping; Adaptive tree growth; Annual growth; Early wood; Wood density; Wood strength

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INTRODUCTION

Forest ecosystems are constantly subjected to adverse environmental conditions. Resin production in coniferous trees is a common response to external abiotic and biotic stress factors. Tree resin consists mainly of organic compounds, such as terpenoids, flavonoids, and fatty acids, which prevent herbivores from feeding on trees. This fragrant secretion is known to be an effective mechanical and chemical barrier against insects, such as bark beetles, which pose a great threat to forests around the world (Hood and Sala 2015). Antibacterial and antioxidant properties of resin are also well studied (Savluchinske-Feio *et al.* 2006; Tillah *et al.* 2016; Aloui *et al.* 2022). Trees produce resin for their protective properties. Resin also protects plants against fungal pathogens. At the same time, volatile phenolic compounds can also be beneficial, as they can attract parasitoids or predators which prey on herbivores that attack the plant (War *et al.* 2012).

Tree resin is widely used in many industrial sectors, predominantly for chemical and pharmaceutical purposes. Raw resin obtained directly from the tree stem must be converted to by-products, such as rosin or turpentine, which then can be used subsequently in the production of cleaners, inks, oils, detergents, solvents, pesticides, adhesives, and many other products (Tomusiak and Magnuszewski 2009; Demko and Machava 2022). Additionally, recent studies suggest a potential function of resin as a natural energy source, which might emit less CO_2 to the atmosphere than other commonly used sources (*e.g.*, Demko and Machava 2022). Overcoming difficulties that may appear in this approach will be a great challenge for the next generations.

RESIN TAPPING

In European countries, resin tapping was carried out for almost 80 years, until the 1980s when cheaper resin from China began to be imported to Europe (Liu 2001). In addition, the major source of wood resins today is as a byproduct from the kraft pulping process (Aro and Fatehhi 2017). Furthermore, synthetic substitutes have replaced natural resins due to lower cost and easier production, and therefore the tapping procedure was abandoned (Coppen *et al.* 1995; Tomusiak and Magnuszewski 2009; Soliño *et al.* 2018; Zaluma *et al.* 2022).

Resin tapping was performed during the vegetation season. The procedure, applied frequently in European forests, consisted of scratching off the outer bark, and then two 5-cm-wide and 5-cm-deep scars were cut on the stem surface. The procedure was repeated several times every week, leading to the formation of parallel scars located 1 to 1.5 cm away from each other. Resin harvesting was performed for several years in the chosen trees and then, following the formal forestry regulations, the tree had to be cut down (Zaluma *et al.* 2022). However, in European forests a large number of such trees have remained uncut through many years after the procedure.

There is a large body of work on the topic of economic value of resin (Wang *et al.* 2026; Le Bouder and Yau 2019; Neis *et al.* 2019; Pavon *et al.* 2021) and technical aspects of resin tapping (Nanos *et al.* 2001; Cunningham 2012) as well as on how environmental factors affect resin yield. However, the influence of this procedure on tree growth and its health still remains to be thoroughly investigated. Considering Portugal and Spain are the most important countries in European resin yield (Cunningham 2012), most of the research in this area was conducted using pines from southern or seaside regions, such as maritime pine (*Pinus pinaster*). Some of the existing sources present contrasting opinions. There are studies that have shown that tree physiology and defense mechanisms might be altered to a certain extent in the stands used for natural product acquisition (*e.g.*, Rodríguez-García *et al.* 2014). However, other authors demonstrate that there is little or no influence of resin tapping on tree growth and development (Velkov and Kaludin 1970; Zaluma *et al.* 2022). These discrepancies may be due to difficulties linked with field studies and the fact that even individual trees in particular stand may not be subjected to equal conditions. Moreover, the results of the studies performed on different species and using different tapping methods may not be easily comparable.

Undoubtedly, some physiological responses may occur when plants are exposed to mechanical interference in living tissues. Systematic resin harvesting results in an extensive injury on the tree stem. This may induce a systemic response to wounding, including new resin canal formation, as observed in tapped *Pinus pinaster* trees. After three years of following the tapping procedure, an increase in axial canal frequency and area was found (Rodríguez-García *et al.* 2014). Some species appear to be less sensitive to tapping than others. In Chinese pine (*Pinus tabuliformis*), short-term resin tapping had no significant effect on the climatic sensitivity and only slightly increased stomatal conductance (Zeng *et al.* 2021a; Zeng et al. 2021b). In Scots pine, tapping did not affect the number of cones, and seeds, viability, or germination (Velkov and Kaludin 1970). Moreover, a recent study on Latvian overmature *Pinus sylvestris* trees showed that injuries caused by resin tapping did not affect health and vitality of these trees even after a few decades (Zaluma *et al.* 2022).

Considering how resin harvesting can affect tree growth, the study results are also inconsistent. Resin tapping negatively affected tree annual growth in *Pinus brutia*

(Zevgolis *et al.* 2022). In *Pinus halepensis*, *Pinus massoniana*, and *Pinus pinaster*, tapped trees manifested narrower annual rings (Papadopoulos 2013; Chen *et al.* 2015; Génova *et al.* 2014). However, in *Pinus sylvestris* an increase in radial increments at breast height occurred as a result of tapping (Tomusiak and Magnuszewski 2009; van der Maaten *et al.* 2017). The scar had no increment due to the lack of cambium and the uncut tissue in wound area was called the 'life belt' (Tomusiak and Magnuszewski 2009; van der Maaten *et al.* 2017). Williams *et al.* (2017) and Du *et al.* (2022) found no changes in the tree ring width in *P. massoniana* and *P. elliotti* trees subjected to tapping. The effect on tree growth may depend on a variety of factors, including age. For example, younger trees are more susceptible to the negative impact of tapping (Moura *et al.* 2022). Another recent study reported that the influence of resin tapping on radial growth is likely to depend also on the stand site and environmental conditions (Garcia-Forner *et al.* 2021).

The question of how resin harvesting affects wood properties is even less understood. Nevertheless, there are reports that indicate the presence of anomalies in wood such as deformations, increased density, callous tissues, and discoloration (Frolov *et al.* 2010; Papadopoulos 2013; Wu *et al.* 2022). It was also found that tapped Scots pine trees after 40 years are less stable than the control trees, and the wood material derived from such trees represent significantly lower technical properties (Tomusiak and Magnuszewski 2009). Nevertheless, Glowacki and Paschalis (1991) reported no significant changes in wood properties derived from tapped pine trees. Overall, the problem is certainly complex - both in terms of long-term study difficulties and in terms of understanding the impact of all co-existing factors that may have an influence on the final results. This topic needs further investigation and there is still a great amount of research to be done in this area.

EXPERIMENTAL

Materials

The study was conducted in 2019 in Central Poland (Fig. 1). The stand was subjected to resin harvesting at the age of 75, *i.e.*, in 1963. The material for the study was collected from 40 trees in 2019 (Table 1). The material for laboratory testing came from resin resources (Fig. 2). Forty trees, with an average DBH of 42 cm ± 5.1 cm and height 28 m ± 1.4 m were selected for the experiment.

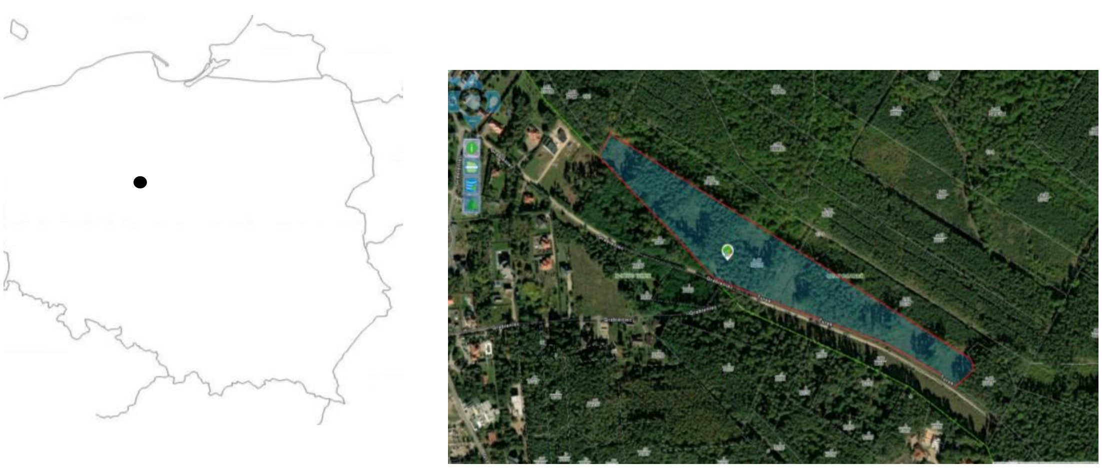

Fig. 1. The area of study (N 18.4696, E 52.0431)

Table 1. Tree Stand Description in Which the Experiment was Conducted

Coordinates	Year	Division Section	Forest Site Type	Age	Index of Stoking	Site Class	Growing Stock (m^3/ha)
N 18.4696, E 52.0431	2019	139h (4.96 ha)	FMC*	131	0.5	II	215

**FMC - Fresh Mixed Coniferous Forest*

Twenty trees were subjected to single-side resin tapping (a single resin blaze) and 20 trees endured both-side resin tapping (double resin blaze). The trees with two resin blazes had, on average, 7 cm larger DBH than the trees with just one resin blaze. This is because thicker pines were deliberately selected in the resinous stand to make two resin blazes. The selected pines were felled and 20-cm-thick discs were collected from the mid-section of the resin blaze. The discs were then divided into two parts. The first one was 3 cm thick and it was used to measure the width of the annual thickness increment. The second part was used to determine the basic density of the wood and its compression strength along the grain. For trees with just single resin blaze the analysis of the wood properties was conducted in R (resin) zone, TZ (transition zone, the so-called "life zone") and in NW (normal wood) zone. For trees with two resin blazes the material was collected from both R zones (from both blazes) and from TZ zones (Fig. 2).

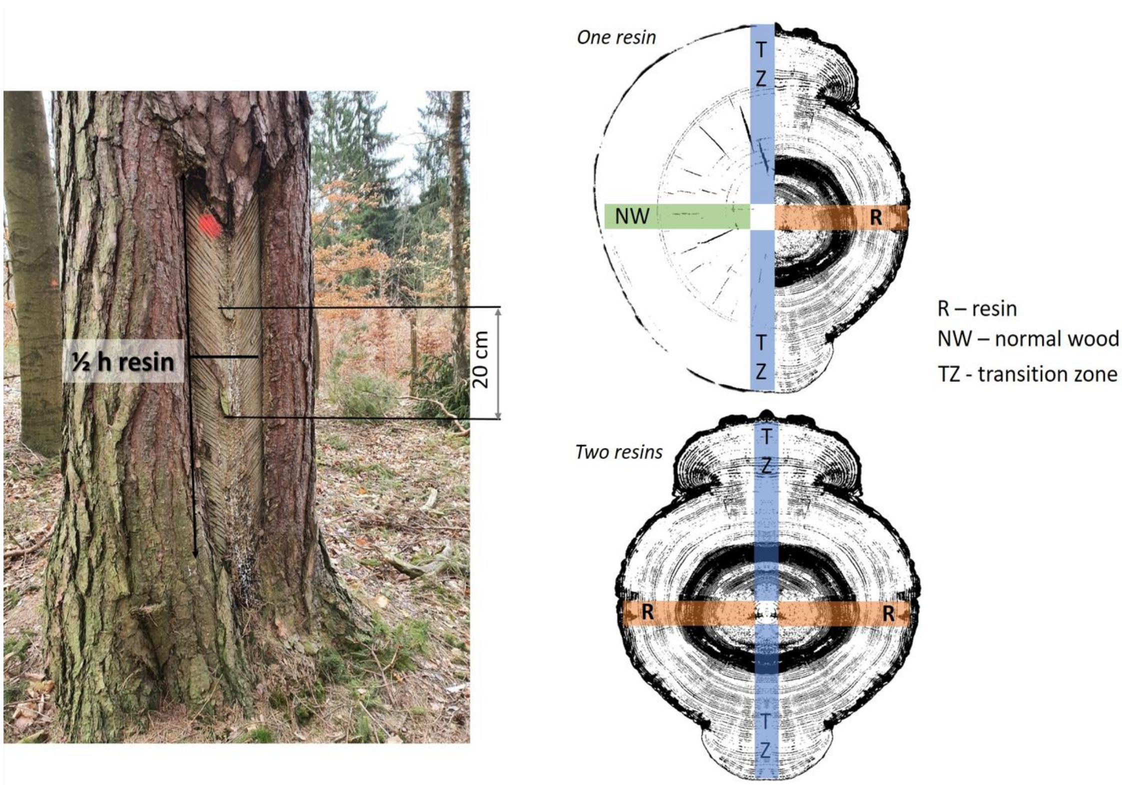

Fig. 2. Diagram presenting samples for laboratory analysis. Left: image of tapped side of a tree; Right top: Cross-section of tree tapped on the right side and normal wood on the left; Right bottom: Cross-section of tree tapped on opposite sides with no normal wood designated.

Methods

Annual increment

The annual increment was measured with a scanner with programmed software designed for the analysis of the annual increment (WinDENDRO). The measurement was completed for each disc in the R and NW directions. The mean annual increment for early wood, late wood, and for the entire annual ring was determined in the area or areas of the resin blaze (in the trees with a double blaze – double R) and beyond the resin blaze (NW), only for the trees with just one resin blaze (single R). In addition, the mean width of early wood and late wood as well as annual rings in the time until resin tapping (RT) and after resin tapping (ART) were measured (Fig. 2).

Wood density

The collected discs were also used to determine basic wood density (Q_u) in accordance with the PN-77 and D-4101 norms. Wood density was determined separately for the radius with the resin blaze (R), transition zones (TZ), and for trees with just one resin blaze, for the area without the blaze (NW) (Fig. 2).

Based on the obtained data, the density was calculated using Eq. 1,

$$Q_u = m_0 / V_{max} \tag{1}$$

where m_0 is the mass of the sample in an absolutely dry state, V_{max} is the volume of the sample in the maximal saturation state.

Mechanical properties of wood

Compression strength along the grain was measured in accordance with the PN-79/D-04102 norms with the accuracy up to 0.01 MPa. The compression strength along the grain (R_c) was calculated similarly to wood density (Q_u), as shown in Eq. 2,

$$R_c = \frac{P_{max}}{A}\ (MPa) \tag{2}$$

where P_{max} is the maximal (destructive) compression strength (N) and A is the cross-sectional area of the sample (cm^2).

Statistical analyses

At first, the distribution of the population was determined following Kolmogorov-Smirnov tests, because the collected data indicated normal distribution at level $p > 0.05$. Further analysis was performed by describing a mean standard deviation and *post hoc* tests. Statistical analyses were conducted adopting STATISTICA 13 set (StatSoft, Inc., Tulsa, OK, USA).

RESULTS

Wood Properties

First, the properties of wood tissue in the model trees before (RT) and after resin tapping (ART) were analysed. The mean width of the annual rings in the trees with a single resin blaze was 1.74 mm in the time before resin harvesting and 1.31 mm afterwards. The differences were statistically significant. The mean width of the annual rings in trees with two resin blazes were respectively 2.03 mm (RT) and 1.99 (ART) mm, and they were not statistically significant (Fig. 3).

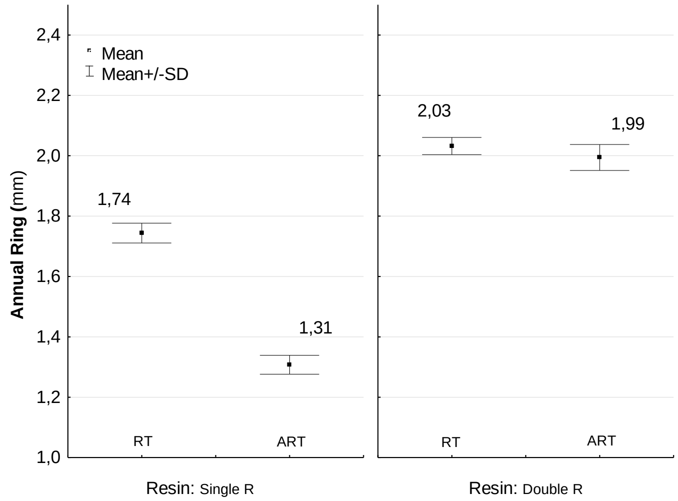

Fig. 3. Mean widths of the annual rings in trees with single and double resin blaze in the time before (RT) and after (ART) resin tapping

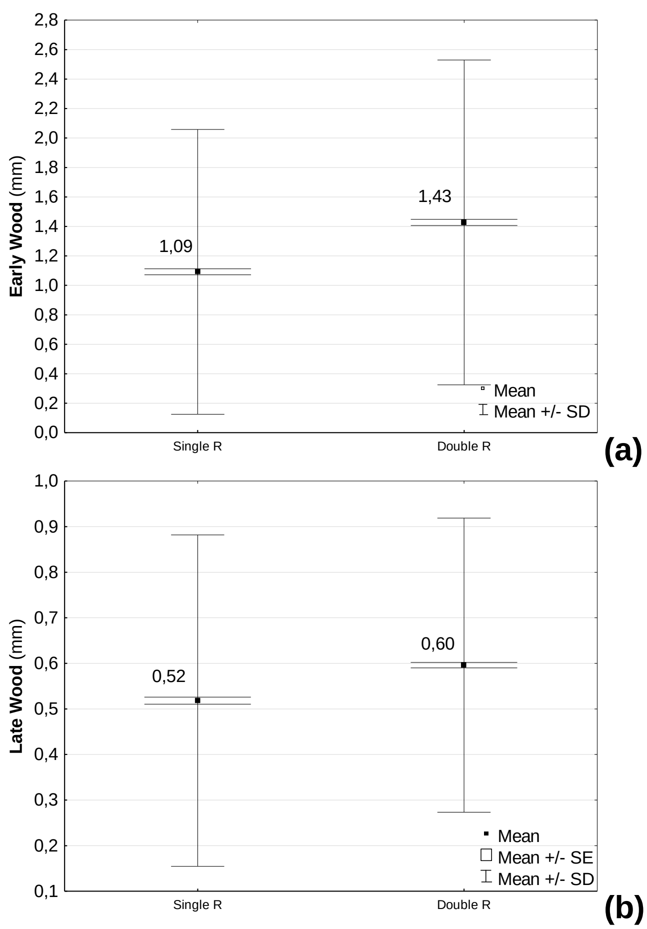

Fig. 4. Statistical characteristics of the width of a) early and b) late wood in trees with a single and a double resin blaze indicate statistically significant differences at the level of $p \leq 0.05$

The mean width of early wood was 1.28 mm and late wood was 0.56 mm, and the standard deviation for these variables was respectively 1.06 mm and 0.34 mm. In the trees with a double resin blaze, the mean width of early wood and late wood was respectively 1.43 mm and 0.60 mm, while for the trees with a single resin blaze it was 1.09 mm (early wood) and 0.52 mm (late wood). The differences in the width of the early wood between the trees with single and double resin blaze were statistically significant ($p \leq 0.05$) (Fig. 4)

The results for the annual ring analysis were atypical, as far as the time before and after resin collection is concerned. In the trees with a single resin blaze, the difference of the mean width of early wood was much higher than in trees with a double resin blaze. In the time after tapping in trees with a single blaze the width of early wood decreased considerably from 1.23 mm to 0.79 mm and the difference was statistically significant ($p \leq 0.05$), while in trees with a double resin blaze the decrease was only 0.16 mm and was not statistically significant. However, for late wood, the differences concerning the time before and after tapping were only observed in trees with a double resin blaze. There was an increase in the mean width of late wood of the ring from 0.57 mm to 0.69 mm, but it was not statistically significant (Table 2).

Table 2. Statistical Characteristics of the Width Variability of Early and Late Wood in Tapped Trees

Variable	Early Wood (mm)			Late Wood (mm)		
	Mean (mm)	SD (mm]	Median (mm)	Mean (mm)	SD (mm)	Median (mm)
Single R	1.092	0.967		0.518	0.364	
RT	1.226	1.083	0.840	0.518	0.358	0.450
ART	0.789	0.513	0.660	0.518	0.376	0.440
Double R	1.427	1.102		0.596	0.323	
RT	1.465	1.176	1.130	0.567	0.286	0.530
ART	1.306	0.813	1.150	0.688	0.406	0.630
Total	1.279	1.057		0.562	0.344	
R	1.441	1.166		0.562	0.298	
Single R	1.313	1.103	0.930	0.508	0.292	0.460
Double R	1.487	1.184	1.120	0.582	0.298	0.530
NW	1.210	1.001		0.561	0.361	
Single R	1.045	0.929	0.760	0.520	0.377	0.440
Double R	1.389	1.045	1.140	0.605	0.337	0.550
Total	1.279	1.057		0.562	0.344	

RT – ART., Single R, Double R, R – NW -

Another property that was analysed was the variation in the width of the annual ring zone depending on its position in the mid-section of cross-section of the resin blaze. To conduct the comparison, two zones were taken into account, *i.e.*, the resin zone (R) and the zone with normal wood without the blaze (NW) (Fig. 2). The width of the annual ring, both in the resin zone and without it, was statistically higher in trees with double resin blaze than in trees with a single blaze (Fig. 5). Moreover, the area with the blaze was characterized by a slightly larger width of the annual rings in both groups. However, statistical differences were noticed only in trees with a single resin blaze (Fig. 5).

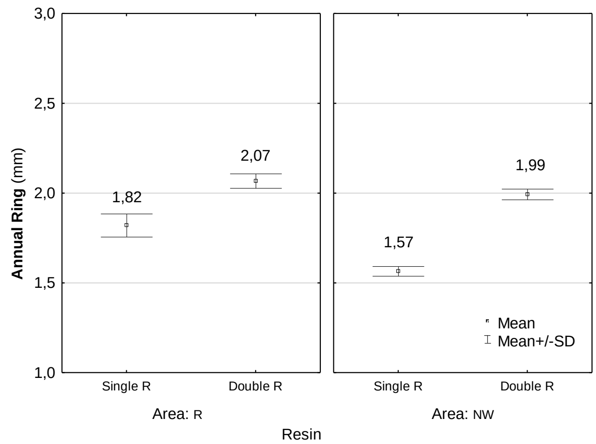

Fig. 5. Mean widths of the annual rings in trees with single or double resin blaze in the resin zone (R) and in the normal wood zone (NW)

The mean width of the early wood in the resin zone (R) was 1.44 mm, and in the normal wood (NW) 1.21 mm. There were no statistically significant differences in the width of the annual ring of late wood in the resin zone (R) and in the normal wood without the blaze (NW). In the resin blaze area, the mean width of the annual ring of the early wood was lower in trees with a single resin blaze than in trees with double blaze (1.31 mm and 1.49 mm, respectively). Significant differences in the width of early wood with single and double resin blaze were observed in the normal wood zone (NW). The difference was 0.34 mm and was statistically significant ($p \leq 0.05$). In the trees with a double resin blaze there was also a greater width of late wood in the normal wood zone (NW) and in the resin blaze zone (R).

Wood Properties

In the three zones, *i.e.*, TZ – transition zone, NW – normal wood without the resin blaze, and R – resin blaze zone (Fig. 2), the analysis of the basic wood density and compression strength along the grain (R_C) were calculated.

The mean density of the analysed wood was 450 kg/m^3, while the mean compression strength of the wood was 42 MPa. The highest density was observed in the normal wood without the blaze zone (NW), it was 490 km/m^3 and it was statistically higher than the density in resin blaze zone (R), which was 434 kg/m^3 (Table 3, Fig. 6). Moreover, high differentiation of wood density in the resin blaze zone was observed. The standard error was 122 kg/m^3. The median value of the basic wood density in the normal wood zone without the blaze (NW) was much higher, *i.e.*, 450 kg/m^3. This is because in some trees there was an increase in the maximum density of wood tissue, particularly in the zone where the tree tissue was similar to reaction wood.

The analysis of the compressive strength did not reveal statistical differences between the compared zones. The mean compressive strength of the analysed wood was 41.8 MPa and fluctuated between 10.6 and 72.3 MPa (Table 3, Fig. 6). At the same time, it was observed that the R zone (resin blaze zone) was characterized by the highest dispersion of compression strength along the grain (Fig. 5).

Table 3. Measurement of Location and Distribution of the Basic Density and Compressive Strength in Tapped Trees According to Zone

	Zone	Mean	SD	Min.	Max.	Median
Basic Density (kg/m^3)	TZ	451	82	318	852	438
	NW	490	122	361	871	451
	R	434	82	246	612	434
	Total	450	88	246	871	437
Compressive Strength, R_c (Pa)	TZ	42	11	12	70	43
	NW	42	11	14	64	40
	R	41	14	11	72	42
	Total	42	12	11	72	42

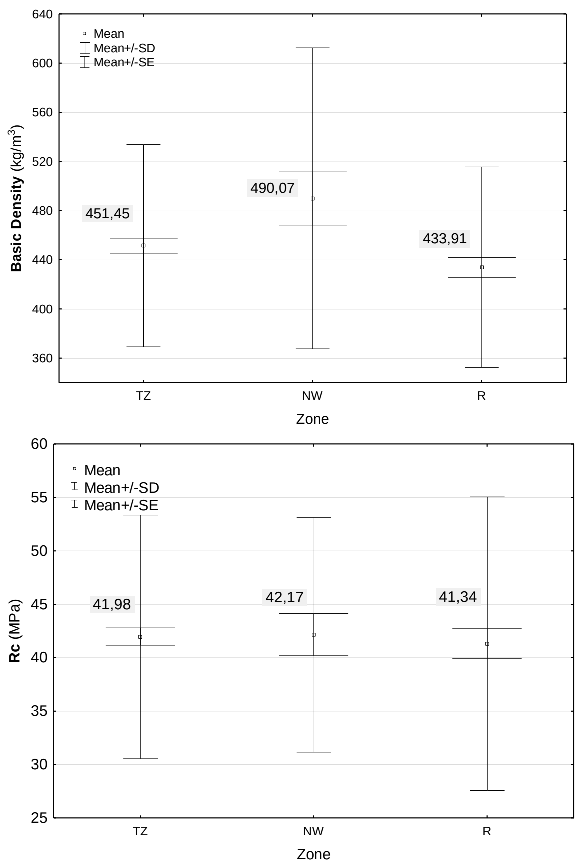

Fig. 6. The measure of location and distribution of the basic density and compressive strength (R_c) in tapped trees depending on the zone: TZ - transition zone, NW – normal wood without the resin blaze, R – resin blaze zone (Fig. 2)

SUMMARY AND DISCUSSION

The history of collecting resin from a tree can be established based on the information when the resin tapping scar was made (Schweingruber 1996). The growth of the trees used for resin tapping is a great opportunity to conduct research and reconstruct the impact of resin tapping on the growth and the survival strategy of the tree. In the literature of the subject matter there are a number of studies concerning resin tapping and how resin tapping scars occur. However, the studies mainly refer to the increment and growth reaction of the tree, particularly in the context of climate change (Magnuszewski and Tomusiak 2013; Génova *et al.* 2014; Chen *et al.* 2015; Zaluma *et al.* 2022; Jakubowski and Dobroczyński 2023). There are no studies that comprehensively discuss the impact of resin blaze not only on the thickness increment, but also on physical and mechanical properties of wood in the resin blaze zone. Resin blazes impact the deformation of the stem (van der Maaten *et al.* 2017). From this perspective, a negative aspect of resin tapping on wood quality is the asymmetrical growth of the stem, which considerably hurts its most valuable attributes, from a commercial viewpoint (Auzins 1995). In the experiment, the main focus was on the influence of resin tapping in the long-term perspective on the qualitative and quantitative changes of the tree tissue in the zone of the resin tapping scar. The variables in the width of the annual increment, the density variables, as well as variables of compressive strength in various areas of the cross-section of the pine in the resin blaze were studied and analysed.

It was noticed that the resin blaze lowers the dynamics of the thickness increment in the annual ring, particularly in the early wood, and it concerns mainly trees with a single resin blaze. In the time after resin tapping with a single resin blaze trees, the width of the annual ring was lowered by 25% and the early wood by 40%, and the difference was statistically significant. In trees with a double resin blaze, there was also a decrease in the width of early wood, but it was not so apparent and was not statistically significant.

Two resin blazes were made on somewhat thicker trees, which most probably were dominating trees in the tree stand; hence, they were physiologically stronger with big and well developed crowns. It is possible that the wound caused by resin tapping scar did not weaken these trees as much as it did the tress from lower biosocial classes, on which only a single resin blaze was made. At the same time, it is worth remembering that the tree aims at achieving balance between the size of assimilation apparatus, availability of water in the soil, and the vascular (conductive) part of the stem. Hence, it may react by widening or contracting of the early wood in sapwood. The tree that protects itself against cavitation (Jackson *et al.* 1995; Boisvenue and Running 2006) lowers the width of the early wood of the annual ring in such a way that there is no disruption of the water column in the tracheids.

The trees with double resin blaze, so the ones dominating in the stand, have enough potential to preserve continuity of conducting by means of the stem’s surface, and their reaction is not as visible as in the trees with a single blaze but from lower biosocial classes. The decreased width of the early wood in trees in the time after resin tapping can stem from a temporary decrease in vitality, as carbohydrates are not invested in the tree growth, but in the excessive production of resin, which has been confirmed by studies done in Greece, Spain, and China (Papadopoulos 2013; Génova *et al.* 2014; Chen *et al.* 2015). Ballesteros *et al.* (2010) reached similar conclusions while analysing scars on *Pinus pinaster* trees caused by a car crash. They also noticed considerable decrease in the width of annual rings, particularly in the areas of cambial damage.

The results of the present work are not completely consistent with those collected by Magnuszewski and Tomusiak (2013). They noticed that the radial increments were bigger, up to 1.3 m, after resin tapping rather than before. Similar conclusions were reached by van der Maaten *et al.* (2017). Zaluma *et al.* (2022) in the studies focusing on the width of the annual rings, they indicated that the radial increment of the tapped trees was clearly higher than the non-tapped trees. Similarly, higher radial increment in tapped trees was observed in the studies conducted in Germany (van der Maaten *et al.* 2017). They provided an explanation that during wood formation is concentrated on the living part of the stem because after resin tapping and scaring the tree there is no increment in the uncovered sapwood after removing the cambium. This can be justified with adaptive tree growth theory (Mattheck 1991), and particularly in this case of optimizing vascular zone (sapwood) in relation to the size of the crown, which did not change. According to Pipe model theory (Shinozaki *et al.* 1964; Rennolls 1994; Lehnebach *et al.* 2018), there is a relation between the size of vascular zone and the size of assimilation apparatus. The resin blaze significantly influences the width of the early zone of the annual ring, which is physiologically active. The tree, while striving to achieve a balance between the assimilation apparatus and the vascular part of the stem, may react by widening the early zone of the annual ring in the undamaged area, *i.e.*, the transition zone (TZ, the so-called "life zone"). The increment reaction of the tree in the earlywood zone allows to preserve the continuity of conducting water and minerals in the stem and protects the tree against cavitation. Damaging the pine at approximately 70% of its circumference has to provoke an increment reaction in the remaining 30% of the undamaged stem. Not only does it seem logical, but it has also been demonstrated in Latvia (Zaluma *et al.* 2022).

The research study also determined wood density and its mechanical compression strength in the resin blaze zone (R), in the normal wood zone (NW), and in the transition zone (TZ). Some interesting results were collected that indicate a link between resin tapping and wood density; however, no such relation was observed between resin tapping and compression strength (R_c). The tree stem performs simultaneously vascular (conductive) and mechanical functions; hence, most probably the changes in wood density are caused by a considerably lower share of early wood in this particular part of the tree with a single resin blaze. Nevertheless, it did not translate directly to an increase in wood strength, which indicates optimization of the tree growth to its function. This refers to the mechanical functions of the tree which strives for optimal distribution of bending stresses in the stem. In order to prevent mechanical damage of the stem, the trees optimize their increment by distributing the stresses evenly and by multiple modifications to the tree tissue. One of the basic protective mechanisms against stress stemming from dynamic loading is preserving the appropriate stiffness of the stem. The key role here is to preserve the proportions between the height, stem diameter, and the right allocation of the biomass, which is reflected in the variability of the tree tissue (Mattheck *et al.* 1998; Kim 2000).

CONCLUSIONS

On the basis of the research it is possible to draw the following conclusions:

1. The process of harvesting wood resin, carried out by the creation of a wound in the form of a resin layer, is a stress factor for trees. It manifests itself in reduced annual growth, mainly in the earlywood zone. From the point of view of the tree's stability, it seems reasonable to perform two tappings on opposite sides of the thickest, dominating trees.
2. Trees with a single resin blaze react much more strongly to the tapping than trees with a double resin blaze; the tree reacts with a change in the annual increment.

3. In trees where resin tapping was conducted, the zone without the resin blaze, *i.e.*, normal wood (NW), was characterised with a lower width of the annual ring, while early wood zone was larger in the resin blaze zone (R), and late wood was larger in normal wood (NW). This is particularly evident in the earlywood zone. It is possible that these changes were due to the fact that these were trees of lower biosocial classes, somewhat physiologically weaker than the trees on which the two resins were made, which may have caused more stress and a stronger tree response.
4. The increase in wood density of normal wood (NW) in trees with a single resin blaze did not result in the increase in the compression strength. This effect may stem from the optimization of the tree growth to fulfil both mechanical and physiological functions of the stem, which is consistent with adaptive tree growth theory.
5. There was no significant effect of the resin spars impacting wood strength. Only a large dispersion of the tissue compressive strength in the resin zone was observed, which is probably connected to the increase in the proportion of earlywood, especially in trees with a single resin tapping area.
6. No relationship was found between basic wood density and compressive strength, demonstrating that the common view concerning a strong relationship between wood density and mechanical properties in coniferous species is not the rule.

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