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Differences in Some Physical and Chemical Properties of Beechwood with False Heartwood, Mature Wood and Sapwood

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Abstract: The article presents the differences in some physical and chemical properties of wood with false heartwood, mature wood, and sapwood of *Fagus sylvatica* L.: density of wood in the dry state, color in the color space CIE L*a*b* on the tangential surface and the planed surface at w = 10 ± 0.5%, as well as moisture and acidity of wet wood. As part of chemical analyses, the relative proportion of cellulose, hemicelluloses, lignin, and extractive substances in individual zones of beechwood in trunks with false heartwood was determined. From the carried out analyses, it follows that the biggest difference between the wood of false heartwood, mature wood, and sapwood is the color of the wood. The red-brown color of the wood with false heartwood in the color space CIE L*a*b* is described by the following coordinate values: L* = 64.9 ± 4.9; a* = 12.9 ± 1.4; b* = 19.6 ± 1.7. The most significant differences between the values of the color space are on the lightness coordinate, where the light ochre-white of mature wood shows a decrease of ΔL* = −14.0 compared with the color of false heartwood, and the white—pale grey color of sapwood shows a decrease of ΔL* = −17.5. The density of dry beechwood with false heartwood is higher by $\Delta\rho_0$ = 4.7% than the density of mature wood, and the density of sapwood is $\Delta\rho_0$ = 12.3% lower than the density of wood with false heartwood. The exact opposite applies to the acidity of wet beechwood. The results of wet wood acidity measurements also point to certain differences. While the acidity of the wet wood of false heartwood is pH = 5.32 ± 0.13, the acidity of the sapwood is 5.1% lower. The higher acidity of beech heartwood is attributed to the presence of organic acids in polyphenols during heartwood formation. From the comparison of the representation of cellulose, hemicellulose, lignin, and extractive substances, it follows that the relative content of lignin and hemicelluloses is higher in false heartwood than in mature wood and sapwood. On the contrary, the content of holocellulose and cellulose is highest in sapwood. The presented divisions in the physical and chemical properties of beechwood with false heartwood do not limit the use of beechwood in industrial applications, except for a change in color; the definition of color boundaries in the color space CIE L*a*b* creates space for sorting beechwood according to color and can be used to increase the color variety of compositions of construction-carpentry products.

Keywords: beechwood; sapwood; mature wood; false heartwood; physical and chemical properties of wood

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1. Introduction

Beech is a native tree of European forests, in which it is widely represented. There are two types of beech on the European continent: *Fagus sylvatica* L. (from England and Sweden through western-central-southern-southeastern Europe to the Balkans) and *Fagus orientalis* (from the eastern part of the Balkan Peninsula through the Caucasus to Asia Minor) with very similar characteristics.

European forests are an important source of beechwood, which is still in demand on the market, either as natural wood or color modified for its positive properties [1].

Beech forest (*Fagus sylvatica* L.) belongs to scattered-porous woods. Beechwood is medium-heavy, flexible, and easy to split. It has good mechanical properties, it is plasticized, bent, and machined very well. Thanks to its high permeability, sapwood is well impregnated, stained, and dyed [2–5]. Dry sapwood and mature beechwood are light white-grey in color with a yellow or red tinge [6–8].

In older trees, there may be red-brown wood in the middle of the trunk, so-called false heartwood. False heartwood is a growth defect that arises in the zone of mature wood due to the reactions of atmospheric oxygen with wood [4,9,10]. The primary cause of false heartwood is the penetration of air into the tree trunk through wounded areas of the trunk or tree branches and the subsequent oxidation of soluble carbohydrates and starch in living or partially dead parenchymal cells in mature wood. In extreme frosts lasting several consecutive days with temperatures below -30 °C, the parenchyma begins to die in the growing tree, and conditions are created for the emergence of so-called frost false heartwood [4]. By oxidation of carbohydrates and starch, polyphenolic compounds are formed, which penetrate neighboring tissues and color them red-brown [9,10].

According to the appearance of false heartwood in the tree trunk, it is divided into the following types: round, star, mosaic, and flame (eccentric, centric) [11]. The wood of false heartwood, compared with greenwood, has a lower moisture content in the growing tree and, according to the work of [12], a lower permeability for liquids. The color difference in the wood of false heartwood from the sapwood and mature wood is the reason for the removal of sawmill assortments from the production of bent furniture, sports tools, and some construction and carpentry products.

After cross-sectioning the trunk, the differences in the physical and chemical properties of beechwood due to the uneven distribution of wood moisture, wood permeability, the presence of reaction wood, or the proportion of rectified core are pointed out in the works of the authors of [2,10,12–17]. So far, less attention has been paid to the issues of differences in physical and chemical properties, such as density, color, acidity, and chemical composition of sapwood, mature beechwood, and false heartwood after cross-sectioning the trunk.

The aim of this paper is to determine the differences in the physical properties of wood with false heartwood compared with mature wood and sapwood, such as wood density, wood color, wood acidity, and differences in the chemical composition of beechwood, from the aspect of influence on technological processes. The difference in the color of false heartwood beech is an incentive to expand the use of false heartwood beech in industrial applications for the creation of color compositions.

2. Material and Methods

2.1. Material

Measurements of the physical and chemical properties of beechwood with false heartwood, mature wood, and sapwood were performed on beechwood from Štiavnické vrchy locality (Slovakia). For research, 35 cutouts from different trees with healthy round false heartwood were selected. Lumber was produced by sharp cutting. Blanks with dimensions of $32 \times 50 \times 800$ mm were produced by spreading the central lumber with a thickness of h = 50 mm and transverse handling.

The results of the measured values—wood density ρ_0, lightness L*, red color a*, yellow color b* on the coordinates of the color space CIE L*a*b*, chroma C*, and wood acidity (pH)—are presented in the form of writing the average measured value $\overline{x}$ and standard deviation s_x.

$$x = \overline{x} \pm s_x \tag{1}$$

The degree of dispersion of the measured values is evaluated through the coefficient of variation:

$$v_x = \frac{s_x}{\overline{x}} \cdot 100 \ \ [\%] \tag{2}$$

2.2. Determination of the Density of Dry Beechwood

The density of wood in an absolutely dry state was determined according to [18] *Wood—Determination of density.* For the production of samples to determine the density of false heartwood, mature wood, and sapwood of beechwood, 2 blanks of false heartwood, 2 blanks of mature beechwood, and 2 blanks of sapwood were selected from the zone close to the boundary line dividing false heartwood from mature wood. From the blanks, test bodies were made with the following dimensions: thickness h = 15 mm; width w = 40 mm; length l = 100 mm. The produced test bodies were dried in a laboratory oven (MEMMERT UM110m Niedersachsen, Germany) at a temperature of t = 103 ± 2 °C to a constant weight. After drying, the samples were placed in a desiccator, and then, after cooling, the wood density was measured. The measurements of the density of samples of sapwood, mature wood, and false heartwood in an absolutely dry state were carried out using a digital density meter, KIT 128 from the company (RADWAG, Kraków, Poland), working on the principle of Archimedes' law and set for determining the density of solid substances. The density of sapwood, mature wood, and false heartwood samples was calculated from the equation:

$$\rho_0 = \frac{m_0}{V_0} = \frac{m_0}{\frac{m_0 - m_0^*}{\rho_{H_2O} \cdot g}} = \left(\frac{m_0}{m_0 - m_0^*} \right) \cdot (\rho_{H_2O} \cdot g) \quad \left[kg \cdot m^{-3} \right] \tag{3}$$

where: m_0—mass of dry sample [kg]; V_0—volume of dry sample [m^3]; m_0^*—mass of dry sample immersed in distilled water [kg]; ρ_{H_2O}—density of distilled water at atmospheric pressure and temperature t = 14.5 °C; g—9.81 $m \cdot s^{-2}$, the gravitational acceleration of Earth.

2.3. Determining the Color of Beechwood in the Color Space CIE L*a*b*

Color measurements were made on 5 false heartwood blanks, 5 mature wood blanks, and 5 sapwood blanks selected randomly from each central board. The locations of wood color measurements on individual blanks were chosen randomly on the loading surfaces of the blanks. To measure the color, the blanks were dried in an air-conditioned room at a temperature of t = 20 °C and a relative humidity of φ = 60% to a moisture content of w = 10 ± 0.5% in order to preserve the original color of the wood. The bedding surfaces of dry blanks of false heartwood, mature wood, and sapwood were machined on a horizontal plane milling machine FS 200.

The color of the wood of the beech blanks in the color space CIE L*a*b* was measured with a colorimeter, Color Reader CR-10 Plus (Konica Minolta, Osaka, Japan). A D65 light source was used and the diameter of the optical sensing aperture was 8 mm.

The difference in the color of the wood of false heartwood from the color of the mature wood and the sapwood of beech was evaluated through the total color difference ΔE*:

$$\Delta E^* = \sqrt{\left(\overline{L_1} - \overline{L_2}\right)^2 + \left(\overline{a_1} - \overline{a_2}\right)^2 + \left(\overline{b_1} - \overline{b_2}\right)^2} \tag{4}$$

where: $\overline{L_1}$, $\overline{a_1}$, $\overline{b_1}$—average values on the coordinates of the lightness, red and yellow color of the wood of false heartwood; $\overline{L_2}$, $\overline{a_2}$, $\overline{b_2}$— average values on the coordinates of lightness, red and yellow color of mature wood or sapwood of beech.

2.4. Determination of Acidity and Moisture Content of Beechwood

Acidity was measured on wet blanks made from a central board. By random selection, blanks of false heartwood, mature wood, and sapwood were taken one piece at a time from each tree. For the measurement of wood moisture content, a sample with dimensions of 32 × 50 × 50 mm was taken from each blank. Moisture was determined according to [19].

The acidity of wet beechwood (sapwood, mature wood, and false heartwood) was measured on the planed surface using a pH-meter pH7110 from the company XYLEM (Weilheim, Germany) with a SenTix Sur surface electrode. The measurement was performed by placing the SenTix Sur surface electrode on the surface of beechwood. The acidity value was read after the value stabilized on the pH-meter display.

2.5. Determination of Chemical Composition of Wood

The beechwood samples (false heartwood, mature wood, and sapwood) were disintegrated into sawdust. The fraction of sawdust from 0.5 to 1.0 mm was used for the chemical analyses. Wood sawdust was extracted in the Soxhlet apparatus by a mixture of ethanol and toluene according to [20]. The content of lignin was determined according to [21]. The content of holocellulose was determined using the method by [22]. The content of cellulose was determined according to the method by [23]. Hemicellulose content was calculated as the difference between the content of holocellulose and cellulose. All measurements were performed in triplicate per sample. Data are presented as percentages of oven-dry mass per unextracted wood.

2.6. Changes in Lignin-Cellulose Matrix of Wood by ATR-FTIR

Fourier-transform infrared spectroscopy (FTIR) was used to follow chemical changes in false heartwood, sapwood, and mature beechwood. The measurements were carried out using a Nicolet iS10 spectrometer (Thermo Fisher Scientific, Madison, WI, USA) equipped with the Smart iTR ATR accessory. The spectra were collected in an absorbance mode between 4000 and 650 cm^{-1} by accumulating 32 scans at a resolution of 4 cm^{-1} using diamond crystal. All analyses were repeated four times. The spectra were evaluated using the OMNIC 8.0 software.

3. Results and Discussion

3.1. Density of Beechwood

Wood density is one of the basic physical properties of wood. The mentioned property is commonly used to determine the dependence of the physical and chemical properties of wood in technological processes caused by changes in humidity, heat, or energy. We measured the distribution of wood density along the cross section of the trunk in the zones of false heartwood, mature wood, and sapwood in an absolutely dry state as shown in Table 1.

Table 1. Density values of false heartwood, mature wood, and sapwood.

Zones of Wood	Number of Measurements	Density of Wood	Variation Coefficient
False heartwood	70	$\rho_0 = 704.2 \pm 28.4$ kg·m^{-3}	4.03%
Mature wood	70	$\rho_0 = 670.8 \pm 30.1$ kg·m^{-3}	4.49%
Sapwood	70	$\rho_0 = 617.4 \pm 35.4$ kg·m^{-3}	5.73%

The density of wood decreases from the center to the edge along the cross section of the trunk. The difference between the density in the absolutely dry state of the false heartwood and mature wood is $\Delta\rho_0$ = 33.4 kg·m^{-3} ($\Delta\rho_0$ = 4.7%), and between the wood of false heartwood and sapwood, it is $\Delta\rho_0$ = 87.8 kg·m^{-3} ($\Delta\rho_0$ = 12.3%).

The higher density of false heartwood and mature wood than that of sapwood is due to factors such as:

lignification of cell walls, as reported by [2] and confirmed by measurements performed on the faculty of wood in Zvolen;
filling of vessel lumens with tulles [12–14,24];
and in the wood of false heartwood, also by the presence of organic acids in the polyphenols of the parenchyma cells [2,9,25].

The increase in the density of false heartwood compared with mature wood is not large, and in absolute value, it is at the level of the values of the standard deviations of the analyzed samples. It is attributed to biochemical processes during the formation.

The lower density of sapwood compared with the density of mature wood is attributed to free spaces of lumens without filling them with gills and non-lignified cell walls.

A comparison of the measured densities of mature beechwood samples with data on the density of beechwood from Central Europe reported in the professional literature [2,10,22] shows that the presented values of the densities of the analyzed beechwood samples are within the tolerance of the natural variability of the density.

3.2. The Color of Beechwood

The color of the wood is created by chromophores, i.e., functional groups of the type >C=O, -CH=CH-CH=CH-, -CH=CH-, aromatic nuclei found in the chemical components of wood (lignin and extractive substances, such as dyes, tannins, and resins), which absorb electromagnetic radiation in the UV-VIS area of daylight.

Reflected electromagnetic radiation from the monitored surface entering the eye creates psychophysiological sensations in the human mind, manifested by the variety of perceived colors of the monitored object.

The color of the analyzed samples of beechwood from trees with false heartwood is presented in Figures 1 and 2. The wood of the false heartwood is the darkest in color shades from brown-yellow to red-brown, while mature wood has a light-ocher-white to pale pink color. The lightest is sapwood with a light white-grey-yellow color.

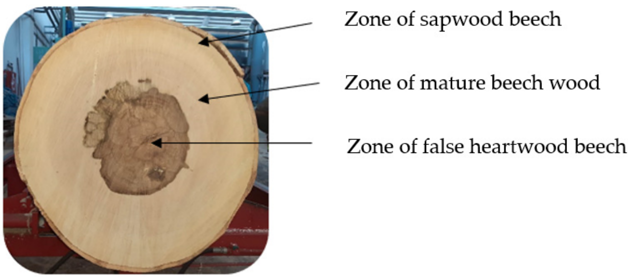

Figure 1. Cross-sectional view of a beech cutout with round false heartwood.

Figure 2. Color of beech sapwood (a); color of mature beechwood (b); color of false heartwood (c).

The results of the statistical processing of the measured values of the color of sapwood, mature wood, and wood with false heartwood on the individual coordinates of the color space CIE L*a*b* and chroma C* are shown in Tables 2–4.

Table 2. Coordinate values of the color space CIE L*a*b* describing the color of dry false heartwood beech.

Beechwood, False Heartwood	**Color Coordinates**			**Chrome**
	L*	**a***	**b***	**C***
Number of measurements [-]	150	150	150	150
Measured value	64.9 ± 4.9	12.9 ± 2.1	19.6 ± 1.7	23.5 ± 1.8
Value of variation coefficient [%]	7.5	16.2	8.6	8.1

Table 3. Coordinate values of the color space CIE L*a*b* describing the color of dry mature beechwood.

Beechwood, Mature Wood	**Color Coordinates**			**Chrome**
	L*	**a***	**b***	**C***
Number of measurements [-]	150	150	150	150
Measured value	78.9 ± 2.4	7.6 ± 1.7	18.9 ± 1.9	20.4 ± 1.9
Value of variation coefficient [%]	3.0	22.3	10.0	9.3

Table 4. Coordinate values of the color space CIE L*a*b* describing the color of dry beech sapwood.

Beechwood, Sapwood	**Color Coordinates**			**Chrome**
	L*	**a***	**b***	**C***
Number of measurements [-]	150	150	150	150
Measured value	82.4 ± 1.9	8.1 ± 1.5	19.1 ± 1.6	20.7 ± 1.7
Value of variation coefficient [%]	2.3	18.5	8.3	8.2

The color differences between beech sapwood, mature wood, and false heartwood on the coordinates of the color space CIE L*a*b* are presented in the bar diagram in Figure 3.

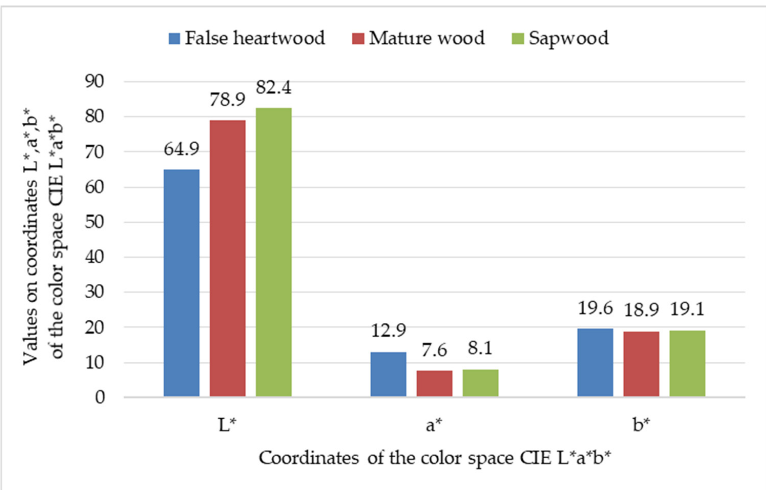

Figure 3. Mean values on the coordinates of the color space CIE L*a*b* of beechwood colors.

The bar diagram in Figure 3 presents mean values of lightness L*, red color a*, and yellow color b* of beech sapwood, mature wood, and false heartwood on the coordinates of the color space CIE L*a*b*.

Visual differences between the colors of beechwood with false heartwood and the color of mature wood, the color of wood with false heartwood and sapwood, or the mature wood and sapwood, numerically expressed in the form of the total color difference ΔE*, are shown in Figure 4.

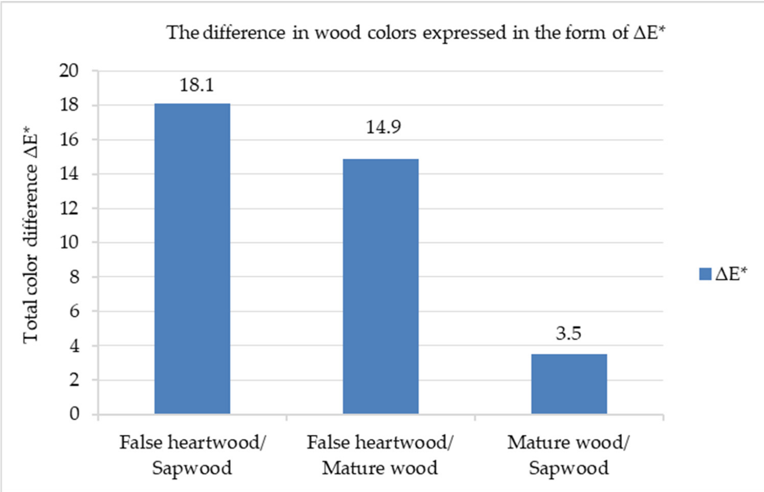

Figure 4. Values of the total color difference ΔE* of the color of beechwood with false heartwood, mature wood, and sapwood.

The color of the false heartwood is identified in the color space CIE L*a*b* by the average value on the lightness coordinate L* = 64.9 ± 4.9 and by the average values on the chromatic coordinates: the red color a* = 12.9 ± 2.1 and yellow color b* = 19.6 ± 1.9. The variety of yellow-brown-red color shades and the darkness of the false heartwood numerically characterize the size of the dispersion of standard deviations, such as lightness s_x = 4.9, red color s_x = 2.1, yellow color s_x = 1.7, as well as the value of the variation coefficient of red color v_x = 16.2%. The colorful variety of the false heartwood is caused by the increased number of chromophores in polyphenolic compounds created by the oxidation processes of soluble carbohydrates and starch contained in the lumens of parenchymal cells. Changes in the chromophoric system of the false heartwood compared with the chromophoric system of the mature wood are manifested by a decrease in the absorption of electromagnetic radiation of wavelengths from 570 to 750 nm, i.e., of red, orange, and yellow colors, which, after being reflected from the surface of the wood, create a dispersion of shades of the color of the wood of the false heartwood perceived by the human eye. The color variety is influenced to a no small extent by the biochemical processes of the length of time of formation of the false heartwood.

The color of mature beechwood is indicated in the color space CIE L*a*b* by the values on the lightness coordinate L* = 78.9 ± 2.4, red color a* = 7.6 ± 1.7, and yellow color b*= 18.9 ± 1.9. The given values of lightness L*, red color a*, and yellow color b* coincide with the values on the coordinates of the color space CIE L*a*b* for beechwood provided in the professional literature [26–30]. The slight darkening of mature wood compared with sapwood causes lignification of the cell walls mentioned in the works of [2,14] and as Figure 3 proves, according to our measurements, an increase in the proportion of lignin in mature wood compared with sapwood by 2.95%.

The lightest color is sapwood. In the color space CIE L*a*b*, it is given by the values on the lightness coordinate L* = 82.4 ± 1.9, red color a* = 8.1 ± 1.5, and yellow color b* = 19.1 ± 1.6. Light shades of white-grey color are attributed to the increased carbohydrate content of sapwood at the expense of the lignin content.

Visually perceived differences between the color of beechwood with false heartwood, mature wood, and sapwood are numerically declared in the color space CIE L*a*b* (Figure 3) by a decrease in the lightness of the false heartwood compared with the mature wood by $\Delta L^* = -14.0$ and compared with sapwood by $\Delta L^* = -17.5$ (the wood is darker), an increase in the values on the red color coordinate for mature wood by $\Delta a^* + 5.3$ and for sapwood by $\Delta a^* + 4.8$, and a slight increase in the values on the yellow color coordinate for mature wood by $\Delta b^* = + 0.7$ and for sapwood by $\Delta b^* + 0.5$. With the mentioned changes in the coordinates of the color space CIE L*a*b*, it is possible to numerically declare the change in the color of the wood from the individual zones through the values of the total color difference ΔE^*. The value of the total color difference between the colors of the wood of the false heartwood and mature wood is $\Delta E^* = 14.9$ and between the false heartwood and sapwood colors is $\Delta E^* = 18.1$. Within the categorization of color differences, the mentioned color differences of wood belong to the category $\Delta E^* > 12$, i.e., which indicates very significant color changes.

The color differences between mature beechwood and sapwood in the color space CIE L*a*b* are on the lightness coordinate $\Delta L^* = -3.4$ and the chromatic coordinates: the red color $\Delta a^* = -0.5$ and yellow color $\Delta b^* = -0.2$. The total color difference between the colors of mature beechwood and sapwood is $\Delta E^* = 3.5$. The difference between the color of mature wood and the color of sapwood is in the category of visible color changes. Numerically, this is declared by the differences between the color of mature wood and the color of sapwood, which can be used to increase the color variety of compositions of construction-carpentry products, floors, or decorative walls.

3.3. Acidity and Moisture Content of Beechwood

Acidity expressing the concentration of H^+ ions determine the acidity or alkalinity of the environment in chemical reactions. In production, acidity is used to control technological processes. In wood steaming technologies for the purpose of modifying the grain of the wood, the acidity of the wood controls the process of modifying the color of sapwood into darker and reddish-brown shades [31,32].

The results of measuring the acidity and moisture of beechwood with false heartwood, mature beechwood, and beech sapwood in the fresh state are shown in Table 5.

Table 5. Measured values of moisture content and acidity of wet beechwood with false heartwood, mature beechwood, and beech sapwood.

Wood of Beech Blanks	Moisture Contentof Wood	Acidity of Wood
False heartwood	w = 59.87 ± 2.95%	5.32 ± 0.13
Mature wood	w = 63.17 ± 3.05%	5.46 ± 0.16
Sapwood	w = 82.87 ± 5.31%	5.59 ± 0.18

The measured values of the acidity of the beechwood of the sapwood zone are similar to those reported by [33,34] for wet coreless beechwood. It is caused by the presence of a diluted aqueous solution of sugars, organic acids, salts of calcium, magnesium, potassium, sodium, and inorganic acids, which are found in the lumens of beechwood tissue [35–38].

The lower value of the acidity of wet false heartwood compared with beech sapwood by $\Delta pH = 5.1\%$ can be attributed to the presence of oxidized extractives in the mass of beech false heartwood.

The moisture content values of wet beechwood point to the fact that the genuine false heartwood of beech has a lower moisture content than mature beechwood below the boundary line. The stated finding is in accordance with studies carried out in the past by [11,15,39,40] as well as the theory of the penetration of atmospheric air into the zones of mature beechwood and subsequent chemical processes of false heartwood formation [2].

3.4. Chemical Composition and FTIR Analysis of Beechwood

The chemical composition of the false heartwood, mature wood, and sapwood of beech is shown in Figure 5. The relative content of lignin and hemicelluloses was highest in the false heartwood and lowest in the sapwood. On the contrary, the relative content of holocellulose and cellulose was the lowest in the false heartwood and the highest in the sapwood. The relative content of extractive substances was higher in the sapwood than in the false heartwood. Authors of [41] found that the content of holocellulose and α-cellulose in the true false heartwood and sapwood of Oriental beech was 81.45% and 83.84%, while the content of α-cellulose was 44.70% and 45.94%. Authors of [42] determined 1.04% lipophilic (extraction in cyclohexane) and 3.71% hydrophilic (extraction in methanol/water mixture, 95:5, v/v) extractives in beechwood. The content of lipophilic extractive substances was comparable in the sapwood and the false heartwood. Saturated fatty acids, fatty alcohols, and free sterols dominated the false heartwood. The sap contained a greater amount of total hydrophilic extractive substances. Mono and oligosaccharides, sugar acids and alcohols, carboxylic acids, simple phenols, and flavonoids were identified as predominant hydrophilic soluble substances in the sapwood, while the concentration of sugar alcohols was higher in the false heartwood.

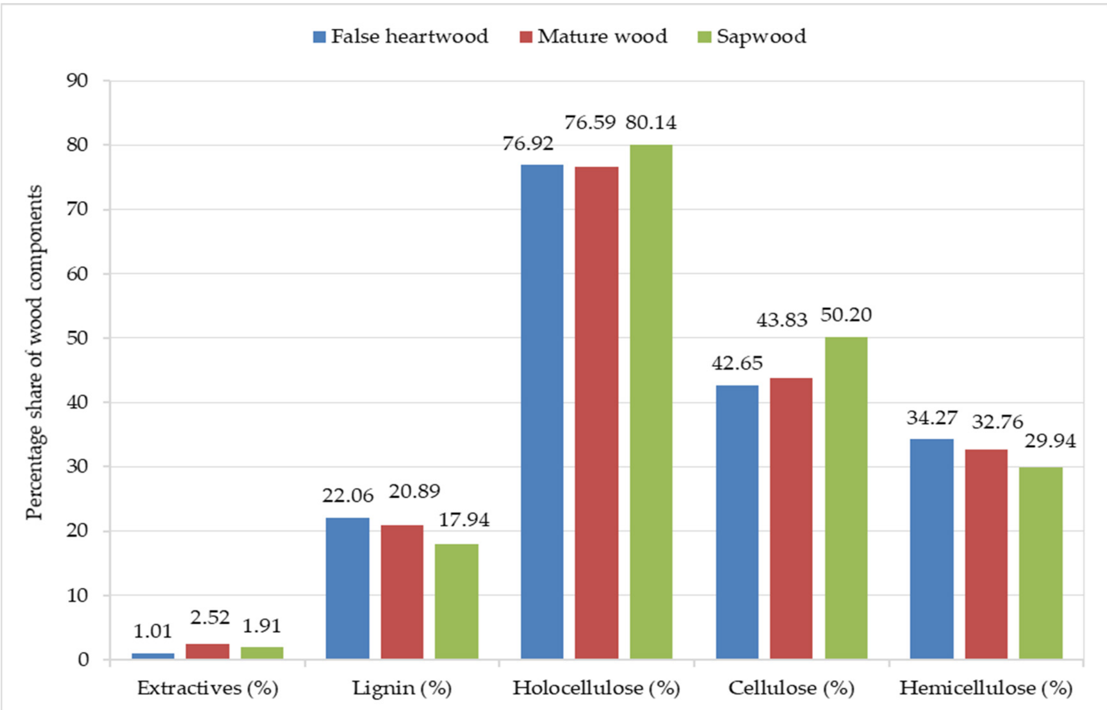

Figure 5. Chemical composition of beech heartwood, mature wood, and sapwood.

Authors of [43] monitored the change in color due to the chemical composition of the wood. They found that the excitation purity is affected by at least two-color chromophores of lignin and at least one chromophore of extractive substances. In our experiment, the excitation purity of the false heartwood increased compared with mature wood, which can be explained by the formation of additional compounds with a colored chromophore. In sapwood, the cellulose content increased, while the lignin content decreased. Lignin is dark in color; on the other hand, cellulose is pale, which could affect the lightness of sapwood. The lightness of the sapwood increased compared with the lightness of the false heartwood.

The chemical composition on the surface of the false heartwood, mature wood, and sapwood in beech was monitored by ATR-FTIR spectroscopy. The entire spectrum can be generally divided into two regions—namely, the functional region located in the range 2700–3800 cm^{-1}, with two main absorption peaks at 2900 cm^{-1} and 3345 cm^{-1}, which correspond to the absorption of the C–H bond stretching and stretching of the O–H bond, respectively, and the fingerprint region located in the range of 800–1800 cm^{-1}, assigned to rocking, stretching, or bending vibrations of various functional groups of wood components. Lignin and carbohydrates containing C-H and O-H functional groups have absorption bands in this area. Therefore, it is difficult to distinguish between the components that caused the variation of the absorption bands in this region. For this reason, we paid attention to the bands in the area of fingerprints (Figure 6). The spectra of beechwood samples are compared in the order of false heartwood, mature wood, and sapwood.

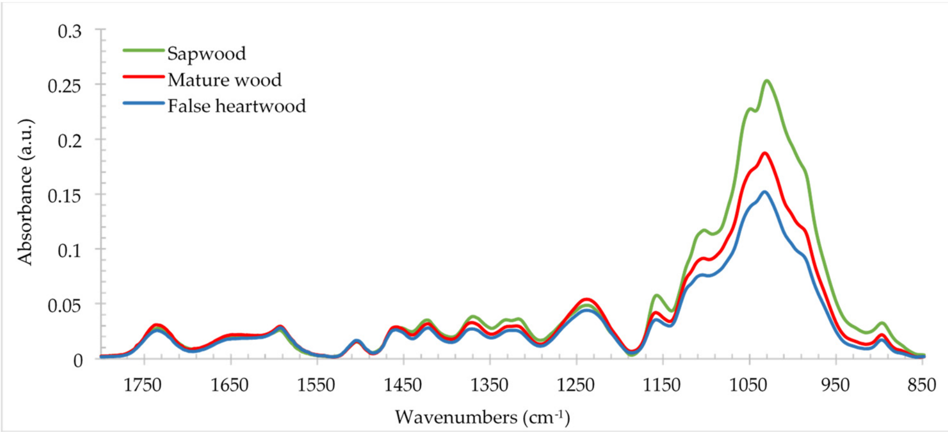

Figure 6. FTIR spectra of false heartwood, mature wood, and sapwood of beech.

Absorption bands at 1593 cm^{-1} (belonging to aromatic skeletal vibration in lignin, and –C=O stretching, and 1504 cm^{-1} (C=C stretching of the aromatic skeletal vibrations in lignin, [44])) are assigned to lignin macromolecules. The intensity of these absorption bands did not change in the false heartwood and mature wood. In sapwood, we observed a decrease in both absorption bands.

At the band of 1421 cm^{-1} (aromatic ring vibration in lignin combined with C−H deformation in carbohydrates), the absorbance from the false heartwood through the mature wood to the sapwood increased by only 9.7%. We observed the same trend in the 1370 cm^{-1} band (C−H deformations in carbohydrates)—the increase was 42.2%. A slight increase in absorbance was again observed at the band of 1328 cm^{-1} (C−O vibration in syringyl plus guaiacyl derivatives is characteristic for condensed structures in lignin) between the false heartwood and sapwood. Increasing bands (false heartwood to sapwood) located in the region of 1159 cm^{-1} (asymmetric stretching of C-O-C), 1053 cm^{-1} (stretching vibrations of C-O and C-C), 1030 cm^{-1} (stretching vibrations of C-O), and 897 cm^{-1} (in-plane symmetric vibration of C-H) indicate differences in the carbohydrate part of the wood.

To compare the chemical composition on the surface of the wood samples used for the experiment, the absorbance ratios of A1506/A1370 and A1730/A1370 were calculated (Table 6). We noticed a decrease in both ratios from the false core to the white due to the increasing intensity of the band at 1370 cm^{-1} (C−H deformations in carbohydrates).

Table 6. Ratios of absorption bands.

Zones of Wood	Nonconjugated Carbonyl/Carbohydrates 1730/1370	Lignin/Carbohydrates 1506/1370	TCI 1370/2900	LOI 1423/894
False heartwood	2.088	1.265	1.085	1.189
Mature wood	2.163	0.969	1.092	1.102
Sapwood	1.497	0.772	0.960	0.886

The crystallinity of cellulose in the samples was monitored by the band ratio of 1423/897 cm^{-1}, which is referred to as the lateral order index (LOI), and the band ratio 1370/2900, which is considered the total crystallinity index (the total crystalline index—TCI). The results show that the value of TCI in the sapwood is lower by 11.5%, and the value of LOI is lower by 25.5% compared with false heartwood (Table 6).

4. Conclusions

From the analyses of the physical and chemical properties of beechwood with false heartwood, mature wood, and sapwood, it follows that the biggest difference is the color of the wood. Color differences result from chemical changes in beechwood during tree growth: the browning of mature wood and false heartwood is attributed to lignification of the cell walls of mature wood and false heartwood, and in the case of false heartwood, to a decrease in the cellulose content and the formation of polyphenolic compounds, which produce red-brown color.

In the color space CIE L*a*b*, the color of the false heartwood is described by the values on the coordinates L* = 64.9 ± 4.9; a* = 12.9 ± 1.4; b* = 19.6 ± 1.7: light ocher-white color of mature wood with values L* = 78.9 ± 2.4; a* = 7.6 ± 1.7; b*= 18.9 ± 1.9 and the white—pale grey color of the sapwood with values of L* = 82.4 ± 1.9; a* = 8.1 ± 1.5; b*= 19.1 ± 1.6. By defining the boundaries of the color of beech sapwood, mature wood, and the wood of false heartwood, space is created for sorting beechwood according to customer requirements for wood color and also for designers when applying beechwood to create color compositions depending on darkness and color shades.

The density of dry false heartwood ρ_0 = 704.2 ± 28.4 kg.m^{-3} is $\Delta\rho_0$ = 4.7% higher than the density of mature wood and $\Delta\rho_0$ = 12.3% than the density of sapwood.

Based on the comparison of the measured values of the acidity of wet wood, it can be concluded that the acidity of wet beechwood with false heartwood pH = 5.32 ± 0.13 is 5.1% lower than the acidity of wet sapwood. The higher acidity of beech false heartwood is attributed to the presence of organic acids in polyphenols during false heartwood formation.

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