Analysis of Qualitative Features of Beech and Oak Trunks as a Determinant of the Quality Assessment

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Abstract: Proper quality assessment of timber requires a certain level of knowledge and overview of technical conditions and correct identification and assessment of the qualitative features of trunks. The ratio of the highest quality classes is decreasing. Therefore, increasing the potential financial resources allocated to forest management could lead to the improvement and increase of this ratio. The objective of the study was to identify the frequency and occurrence of limiting features in the group of non-coniferous beech and oak trunks. A further objective was to classify major factors causing and increasing the frequency of occurrence of such limiting marks. Altogether, 969 beech and oak trunks were assessed in the University Forest Enterprise of the Technical University in Zvolen. The dependences of the size and occurrence of individual qualitative features on the selected factors were statistically assessed using the Pearson correlation coefficient and Cramer’s V; significance was established using \( \chi^2 \) test and a significance level \( \alpha = 0.05 \). The most frequently occurring features were sweep, knots, and heart shakes. The results of the comparative and statistical analysis indicate that the management of forest stands and interventions carried out in the forest stands affect the occurrence of the negative features being analyzed the most. However, the conditions of the given site (soil, subsoil, and slope) also play a certain role and can affect the technological aspect of the harvest. The obtained results are valid for the conditions of the University Forest Enterprise of the Technical University in Zvolen; however, they can also be applied in a wider range of similar conditions of Central European forest stands.

Keywords: forest; trunks; quality assessment; qualitative features; influencing factors; statistical analysis

1. Introduction

Valuation of wood growing in the production forests is the key area for the forest owners, forest enterprises, as well as a starting point for long-term planning in the field of forest management [1,2]. Although forest ecosystem services, their appreciation, and the payment schemes for such services are coming to the fore [3–6], the wood production aspect of production forests will still represent the biggest economic importance for forest owners. The quantitative parameters of harvested trunks limit, to a certain extent, their utilization in the conversion process. However, they do not provide sufficient information on the potential of trunk valuation according to the utilization purpose in individual assortment quality classes [2,7–9]. The optimum assessment and sale of grown and produced timber would not be possible without knowing its qualitative and quantitative features precisely. The criteria for timber quality assessment have to be based on a set of qualitative features. Since we are not capable of assessing the timber following a simple procedure according to positive qualitative features, negative qualitative features are used instead,
i.e., assessment is carried out according to the amount and extent of features (defects) or according to the amount and extent of normal features, abnormalities, tree diseases, and wood defects that degrade its valuation and limit its utilization [10, 11].

Therefore, correct timber assessment requires a certain knowledge level and overview of the technical conditions and correct identification and assessment of the qualitative features of timber. Qualitative features of timber can be classified according to their origin: Features originating during the tree growth (e.g., sweep, knots, and false heartwood), features caused by biotic and abiotic factors (e.g., defects caused by insects, rot, and suffocation), and defects caused by human activities (e.g., shakes and splitting) [12, 13]. The trunk quality can be significantly affected by any of these groups.

The recent optimization has been connected with trends leading towards automation of assessing the qualitative features, which can be seen primarily in wood processing plants [14–16]. Optimization approaches to assessing the qualitative features represented by expensive technologies have been unavailable in forestry field operations so far. Trunk quality assessment is, therefore, usually carried out visually and manually by a respective employee.

When assessing the trunks from the qualitative point of view, the most important aspects cover mainly the knowledge of the limiting qualitative features, their correct assessment, and elimination of factors causing or increasing the occurrence of such features. Timber quality assessment allows for the differentiation of its potential for conversion and further processing [17]. However, within a wider geographical context, this situation is complicated by different terminology, as well as by different technical conditions of timber quality classes [18–21]. The objective of the paper was to identify the occurrence and extent of limiting features of trunks in the non-coniferous assortment groups. A further aim was to classify the main factors causing and increasing the of such features. The results should provide information for the forest owners and forest managers on the selection of strategies for establishing the forest stands and on the forest management interventions in order to eliminate the negative qualitative features as much as possible. The results will also contribute to a better overview and identification of qualitative features and assessment optimization of the available volume of harvested trunks.

2. Materials and Methods

2.1. Research Area Specification

The analyzed trunks were harvested in the area of the University Forest Enterprise of the Technical University in Zvolen. The Enterprise manages forests in three regions—Kremnické vrchy Mts., Štiavnické vrchy Mts. and Javorie Mts., which are divided by the rivers Hron and Slatina in the vicinity of the town of Zvolen. Forestlands currently occupied by the Enterprise represent 9724.06 ha, and 9106 ha thereof are owned by the state. On 1 January 1998, forest lands in the Forest management unit Zvolen and partial lands of the Forest management unit Dobrá Niva were separated from the Stredoslovenské lesy, š. p. Banská Bystrica (state enterprise)—branch Kriváň, and were allotted to the University Forest Enterprise of the Technical University in Zvolen. This fact made the research, in terms of historical analysis, quite complicated, since the forest management plans for the forest stands allotted to the Forest enterprise Krupina were created for different periods than the plans created for other areas. Forest stands were dominated by broad-leaved tree species representing 82% (mostly Beech, Oak, and Hornbeam). In terms of coniferous tree species, the prevailing ones were Spruce and Fir.

The University Forest Enterprise was restructured, and the Forestry Administration Sekier was dissolved. Forest divisions merged and were managed by the Forestry Administration Budča, which now manages eight forest districts. However, the analysis of the qualitative features of trunks was conducted when there were 13 forest districts. Their overview and share of forest stand area are provided in Table 1.
Table 1. Organizational structure of the University Forest Enterprise, forest districts, corresponding area of forest stands, and their numbering at the time of analyzing the qualitative features.

| Forest District No. | Area of State Forests (ha) | Area of Non-State Forests (ha) | Total Area of Forest Stands (ha) | No. of Trunks |
|--------------------|-----------------------------|-------------------------------|---------------------------------|--------------|
| Hákovo—1           | 219.92                      | 221.8                         | 441.20                          | 41           |
| Bieň—2             | 578.02                      | 1.53                          | 579.55                          | 0            |
| Ostrá Lúka—3       | 891.86                      | 8.13                          | 899.99                          | 69           |
| Bukovina—4         | 1046.08                     | 116.05                        | 1162.13                         | 78           |
| Blážová—5          | 761.35                      | 68.68                         | 830.03                          | 33           |
| Mláčik—6           | 554.51                      | -                             | 554.51                          | 49           |
| Třnie—7            | 672.29                      | 63.01                         | 741.3                           | 132          |
| Lúpica—8           | 488.84                      | 31.94                         | 520.78                          | 101          |
| Geberanica—9       | 630.67                      | 163.27                        | 813.94                          | 219          |
| Sekier—10          | 1170.09                     | 22.97                         | 1193.06                         | 34           |
| Čertove kúty—11    | 667.24                      | 45.9                          | 713.14                          | 14           |
| Michalková—12      | 510.35                      | 45.89                         | 556.24                          | 19           |
| Podzámčok—13       | 712.89                      | -                             | 712.89                          | 180          |

The area of the University Forest Enterprise was selected due to its availability and the possibility of carrying out the research activities, also with certain restraints on the production continuity of timber assortments. In addition, the data (also historical) from the forest management plans were available without any obstructions.

2.2. Research Material

The research material included selected trunks of non-coniferous tree species. For the research purposes, the two most frequently occurring broad-leaved species were selected, i.e., beech (covering 33.9% of Slovak forests) and oak (covering 10.5% of Slovak forests) [22].

The sample size (number of assessed trunks, $n$) affects the accuracy of estimating the parameters of the population. The higher the $n$ is, the narrower the confidence level is. Increased sample sizes also decrease the probability of type II error and increase the power of statistical tests. With very small sample sizes, it can often happen that the width of the confidence interval and information value of testing the statistical hypotheses are affected more by the sample size than by the variability of the measured data [23]. Based on experience from similar research studies [11,24], the sample size was determined according to the equation [25]:

$$n = 4 \cdot \left(\frac{\sigma_y \%}{E \%}\right)^2$$  \hspace{1cm} (1)

$\sigma_y \%$ represents the coefficient of variation; it was determined from the available literature [25–27] and according to the results from previous research studies [7,24]. As $\sigma_y \%$ the value of 45% was selected. $E \%$ is the selected error of estimation determined according to similar research studies [7,24] at the level of 5–7%.

Based on the above-mentioned calculation, with the selected significance level of 95%, 165–324 tree trunks of each tree species had to be assessed. This limit was met in the case of both tree species, beech (567 assessed trunks) and oak (402 assessed trunks). Altogether, 969 trunks of non-coniferous tree species (Table 1) were assessed. The identification of individual trunks in terms of the specific forest district or forest stand where they were harvested was carried out using the identification number mark of the corresponding forest district and forest management registry—chapter 2723 harvest according to the districts, stands, harvest types, and tree species. Eighteen oak trunks remained unidentified, either due to an absent or illegible mark or missing record.

In each assortment, the determining qualitative and quantitative features were quantified (tree species, butt end diameter, top diameter, assortment length, knots, heart shakes, frost cracks, seasoning check, ring shakes, sweep, spiral grain, false heartwood, cancer, suffocation, fungi stains, heartwood rot, sap rot, and insect damage). Measuring the qualita-
tive features was conducted in accordance with the STN EN 1309-3 [28]. Following simple statistical calculations, the ratios of individual qualitative features were quantified overall and according to the tree species and individual forest districts. All measurements were carried out in the timber yard Lieskovec (part of the University Forest Enterprise). Each measured assortment was accompanied with corresponding photos (of the entire log and butt end) in order to provide for a retrospective analysis of individual features.

Following the forest districts with the highest and lowest frequency of occurrence of the specific qualitative feature, the individual factors were compared in the stands, where the timber was harvested. The essential factors mentioned in the forest management plans include terrain type, operating group of forest types, forest type, forest category, stand type, rotation, stand age, stand density, regeneration period, aspect, slope, forest area, soil, ground cover, tree species composition, site index, phenotype category, management method, selection cutting, regeneration harvest, the proportion of incidental felling, intervention intensity and applied logging, and transportation technologies.

Studying the dependences between the qualitative features and the above-mentioned factors would be extremely time-consuming and well as extensive. Therefore, only those factors were considered, which are different in individual forest districts in the highest and lowest frequency of occurrence of the feature in question, and a relevant dependence between those factors and qualitative features was proven. The study focused mainly on factors associated with growth conditions (soil, subsoil, aspect, slope, altitude, stand density, species representation, and canopy), silvicultural interventions (selection cutting, regeneration harvest, incidental felling, intervention intensity and concentration, and the amount of harvested timber), logging and transportation methods, and technologies (logging, forwarding, and hauling of timber). Forest districts or stands having the highest or lowest frequency of occurrence of the given qualitative feature with a very low number of assessed trunks were substituted by another forest district or by the following district with the highest or lowest incidence, where the number of studied specimens was sufficient for statistical evaluation.

Assessing the dependence of the false heartwood on the stand age was discussed within several studies [24,29]. Authors of the studies expressed the dependence of the false heartwood forming on the stand age by the Pearson correlation coefficient $r_{xy}$ and the following equation [25]

$$r_{xy} = \frac{1}{n} \sum \frac{x_i - \bar{x}}{s_x} \frac{y_i - \bar{y}}{s_y}$$

where $r_{xy}$ is the Pearson correlation coefficient, and $n$ is the sample size. The numerator expressions $x_i - \bar{x}$; $y_i - \bar{y}$ represent the deviations of quantities from the arithmetic mean, and $s_x$, $s_y$ are standard deviations of the quantities.

Values of $r_{xy}$ vary in the interval $(-1; 1)$, while negative values represent indirect dependence (when one quantity increases and the other one decreases and vice versa), and positive values represent direct dependence (both quantities either increase or decrease simultaneously in the same direction). The correlation coefficient equaling 0, means linear independence; if $r_{xy} = \pm 1$, it is full dependence.

The further coefficient that was used to assess the dependence was Cramer’s V [30], whose value according to Cohen’s size represents a certain degree of dependence (Cohen’s size [31]: Cramer’s V > 0.5—strong dependence, 0.5-0.3 is medium dependence, 0.3–0.1 is weak dependence and <0.1 is trivial dependence). Programs MICROSOFT EXCEL and STATISTICA 12.0 were used for calculations and creating graphical outputs.

Information about individual factors in forest stands, where the assortments were harvested, was adopted from the forest management plans (historically 30 years backward). The credibility of the data was slightly lower since the borders and area of individual forest space units changed. In addition, some forest management plans for forest stands managed by the previous Forest Enterprise Krupina (forest stands allotted to the University Forest Enterprise in 1998) were designed for different decades than the earlier forest management
plans of the University Forest Enterprise. Nevertheless, the collected data were reliable enough and corresponded to the forest stand of interest.

The relevance of individual qualitative features for their classification into quality classes was assessed in terms of technical conditions of the standard STN 48 0056 [32].

The accuracy of the findings was inevitably affected by the number of recorded trunks in individual forest districts, which was influenced by the above-mentioned factors. The results are, nevertheless, a good assumption for drawing general conclusions.

3. Results

Figure 1 illustrates the percentage of occurrence of individual qualitative features in the sample consisting of 969 beech and oak trunks. The highest frequency of occurrence was recorded with the following features: sweep, knots, and heart shakes. The proportion of simple sweeps and multiple sweeps was 51.2% and 22.4%, respectively (differences caused by rounding).

![Figure 1. Percentage occurrence of recorded qualitative features and their average size in the entire sample of non-coniferous trees.](image)

The frequency of occurrence of knots was recorded in forest districts No. 7 (beech 89.8%) and No. 3 (oak 85%). The lowest frequency of occurrence of knots was observed in forest districts No. 5 (52% beech) and No. 7 (56.6% oak).

Regarding the sweep, the highest frequency of occurrence was recorded with beech in district No. 6 (82.4%) and oak in forest district No. 3 (90%). On the other hand, the lowest frequency of occurrence of sweep was recorded in forest district No. 10 (42.3% beech) and No 9 (71.8% oak).

The highest frequency of occurrence of heart shakes was recorded with oak in forest district No. 13 (63.4%) and beech in forest district No. 9 (67.8%). On the contrary, the lowest frequency of occurrence of heart shakes was observed in the forest districts No. 6 and No. 3, 47.1% beech and 35% oak, respectively.

Beech false heartwood showed the highest frequency of occurrence in forest district No. 1 (87.8%) and the lowest frequency of occurrence in forest district No. 7 (38.8%).

Further important limiting factors that were identified in the sample in a relatively higher amount (more than 10%) also included heartwood rot (average size of 11.1 cm) and spiral grain (average size of 3.9 cm/m).

Heartwood rot or sap rot showed the highest frequency of occurrence in the forest district No. 9 (oak 51.3%) and No. 7 (beech 24.5%). The lowest frequency of occurrence was observed in the forest district No. 1 (2.4% beech) and No. 4 (10% oak). The highest frequency of occurrence of spiral grain was seen in forest district No. 10 (42.3% beech) and
No. 7 (14.5% oak), while the lowest frequency of occurrence was recorded in forest district No. 13 (4.3% oak) and No. 8 (7.1% beech).

All relevant features limiting the timber assortment quality were statistically analyzed in terms of factors that could affect the frequency of occurrence and extent of those features. Factors that can be expressed numerically and could have been statistically analyzed using statistical relations included mainly stand density, representation of the particular tree species, slope, terrain type, average stand height, and site index. Other factors that were analyzed only via simple comparative analysis of the highest and lowest frequency of occurrence in the specific forest districts covered soil and subsoil, altitude, used silvicultural interventions, and the frequency of incidental felling.

3.1. Analysis of Factors Affecting the Beech Tree Species

Overview of the factors that could have been expressed numerically (statistically analyzed) and their impact on individual qualitative features of beech in selected forest districts with the highest and lowest frequency of occurrence of the particular feature is illustrated in Table 2. The size of individual quality features and their dependence on factors that can be expressed numerically was statistically evaluated using the Pearson correlation coefficient $r_{xy}$ and Cramer’s $V$, determining its significance via $\chi^2$ test at the significance level $\alpha = 0.05$ (Table 2). Only features with the highest frequency of occurrence and significance in terms of limiting the classification of the log into quality classes were statistically analyzed: knots, sweep, heart shakes, false heartwood, rot, and spiral grain.

The stands of interest in the forest district with the highest frequency of occurrence of sweep (No. 6) were dominated by the brown forest soil, typically rich in humus, and brown colluvial forest soil, typically very rich in humus. Forest district No. 10 with the lowest frequency of occurrence of sweep was typical with mesotrophic soil, typically poor in humus and skeletal soil poor in humus. The soil conditions were almost the same, and soil and its carrying capacity does not affect the occurrence of sweep. The subsoil in both cases was created mostly by andesite. The occurrence of sweep could have also been affected by altitude since the diameter with the highest frequency of occurrence of sweep can be associated with higher altitudes of the fifth and sixth vegetation belt, while the altitude in forest district No. 10 was significantly lower. Forest stands in both forest districts were regenerated stands of approximately the same age, and all were mainly slightly or moderately endangered stands. It can be stated that the clear-cutting method of harvest, carried out in past decades, affected the sweep negatively. Furthermore, sweep can be eliminated by a suitable qualitative selection of trees of low quality and marking of the target trees. Small-scale windthrow in the 1990s did not significantly affect the occurrence of sweep either. As can be seen in Table 2, sweep was most significantly affected by the stand height and according to the highest significance of Cramer’s $V$ by the tree species representation. Both forest districts are mainly of northern aspect; thus, the aspect affects the occurrence and size of sweep only minimally. Sweep can also be eliminated by appropriate production of timber assortments (e.g., for sawmill conversion); appropriate harvest methods focused on obtaining assortments can partially eliminate this negative qualitative feature.
Table 2. Statistical dependence of the size of individual qualitative features of beech trunks on selected factors in individual forest districts.

| Qualitative Feature | Statistical Indicator | Stand Density | Tree Species Composition | Slope | Terrain Type | Stand Height | Site Index |
|---------------------|-----------------------|---------------|--------------------------|-------|--------------|--------------|------------|
| Sweep               | $r_{xy}$              | 0.1           | -0.09                    | -0.15 | -0.1         | 0.14         | -0.16      |
|                     | Cramer’s V            | -             | 0.64                     | 0.67  | 0.57         | 0.67         | 0.69       |
|                     | $\chi^2$              | -             | 64.7                     | 52.8  | 25.2         | 35.2         | 37.1       |
| Knots               | $r_{xy}$              | -0.02         | 0.16                     | 0.12  | 0.12         | 0.12         | 0.25       |
|                     | Cramer’s V            | -             | 0.53                     | 0.54  | 0.58         | 0.56         | 0.56       |
|                     | $\chi^2$              | -             | 115.8                    | 51.1  | 57.6         | 71.3         | 42.3       |
| Heart shakes        | $r_{xy}$              | 0.09          | 0.07                     | -0.01 | 0.02         | 0.01         | -0.02      |
|                     | Cramer’s V            | -             | 0.53                     | 0.53  | 0.57         | 0.55         | 0.54       |
|                     | $\chi^2$              | -             | 359.75                   | 198.69| 90           | 297.2        | 203.7      |
| False heartwood     | $r_{xy}$              | -0.14         | 0.05                     | 0.18  | 0.17         | 0.17         | 0.04       |
|                     | Cramer’s V            | -             | 0.76                     | 0.74  | 0.75         | 0.74         | 0.78       |
|                     | $\chi^2$              | -             | 157.2                    | 120.9 | 91.6         | 92.5         | 100.3      |
| Heartwood/ sap rot  | $r_{xy}$              | 0.24          | -0.05                    | 0.35  | 0.29         | -0.04        | 0.73       |
|                     | Cramer’s V            | -             | 0.9                      | 0.9   | 0.95         | 0.9          | 0.94       |
|                     | $\chi^2$              | -             | 53.8                     | 42    | 35           | 30           | 35         |
| Spiral grain        | $r_{xy}$              | 0.2           | 0.12                     | -0.19 | -0.15        | 0.27         | 0.27       |
|                     | Cramer’s V            | -             | 0.47                     | 0.41  | 0.47         | 0.39         | 0.44       |
|                     | $\chi^2$              | -             | 11.7                     | 9     | 11.7         | 8.3          | 6.9        |

When comparing soil conditions in forest districts with the highest (No. 7) and lowest (No. 5) frequency of occurrence of knots, it can be concluded that slightly acidic and skeletal soil, rocky andosols, and ilimerized soil with pH 4.5–5.0 were associated with a higher probability of knot formation than brown forest soil, rich in humus. In the stands of forest district with the highest frequency of occurrence of knots (No. 7), regeneration was carried out via shelterwood border cutting, while in forest district No. 5, thinning and cleaning were carried out. The intervention intensity was approximately the same; the amount of timber harvested from thinning and cleaning was comparable. Tending can thus affect the forming of large knots, and pruning has to be carried out, too. Table 2 shows that the strongest dependence is between the size of the knots and the site index (higher site index—the lower proportion of knots). According to Cramer’s V, the strongest dependence is on tree species representation. An aspect of forest district No. 5 was mostly eastern and northern in the case of forest district with the highest frequency of occurrence of knots. Therefore, a hypothesis that the eastern aspect was more favorable in terms of limiting the knot formation was formulated. Harvesting and transportation technology had no impact on knot occurrence. In addition, most of the timber logging was carried out using a wheeled tractor.

The stands of interest in the forest district with the lowest frequency of occurrence of heart shakes (No. 6) were dominated by brown forest soil, typically rich in humus, and brown colluvial forest soil, typically very rich in humus. All stands in the forest district with the highest frequency of occurrence of heart shakes (No. 9) were dominated by brown forest soil poor in humus. Since there were no differences in the soil, it can be concluded that soil did not affect the occurrence of heart shakes. The subsoil in both cases consisted of andesite. The forest district with the lowest frequency of occurrence (No. 6) that could have been statistically analyzed (No. 6) was mostly composed of older regenerated stands (moderately endangered), while the forest district No. 9 was composed of stands in the initial stage of regeneration or older regenerated stands (slight to moderate endangering). Therefore, it can be concluded that age did not significantly affect the formation of heart shakes. The method of regeneration and tending was in both forest districts similar.
However, forming of heart shakes can propagate the occurrence of rot, frost cracks, or it can be a result of internal tension in the tree. They can be eliminated by appropriate qualitative selection. The occurrence of heart shakes in forest district No. 9 could have been caused by windthrow, dead tree damage, or natural damage affecting a whole decade when no tending interventions were planned. It means that incidental felling may increase the risk of heart shake occurrence. Table 2 displays that there was only a weak direct dependence between the mentioned factors and heart shake occurrence. Crammer’s V indicated that the strongest dependence was on tree height. It can be stated that western aspects are more favorable in terms of minimizing heart shakes. The occurrence of heart shakes was most significantly affected by harvesting and transportation technologies. In order to minimize the occurrence of heart shakes in harvested timber, the use of cableway technology is the most suitable. The presence of false heartwood can also affect the occurrence of heart shakes since it directly encourages the forming of heart shakes as well as ring shakes due to the gradual wood decomposition. Bark pockets and metal shards that are ingrown inside the trunk can also contribute to heart shake forming.

The stand of interest in the forest district with the highest frequency of occurrence of false hartwood (No. 1) was dominated by brown ranker mull-humus soil and brown forest nutritious andosol. On the other hand, the forest district with the lowest frequency of occurrence of false heartwood (No. 7) was dominated by ranker soil and ilimerized soil (ranker andosol and ilimerized soil); therefore, in this case, it could be stated that nutrient richer soil in the forest district No. 1 affected the lower frequency of occurrence of false heartwood. The subsoil in both forest districts was formed mostly by andesite. Thus, it could be concluded that the subsoil did not affect the occurrence of false heartwood. The forest stand in forest district No. 1 was a 120-year old stand (moderately endangered) in the regeneration phase, while stands in the forest district No. 7 were 75–140-year old stands (moderately endangered). These facts confirm conclusions already proven in previous research studies that long rotations exceeding 130 years affect negatively the occurrence and form of false heartwood [24], which implies that old age in stands has adverse effects on false heartwood formation. The analysis of silvicultural treatments shows that the selection system significantly reduces the occurrence of false heartwood of beech when compared to the understory management method. More intensive tending can also cause negative effects; in addition, it increases the risk of occurrence of other negative qualitative features. Data in Table 2 show that the strongest direct dependence of the size of false heartwood was on the terrain slope; however, the dependence was statistically insignificant. According to Cramer’s V, the strongest dependence was on the tree species representation. High values of the coefficient were caused by the low data variability (only one stand in forest district No. 1); therefore, the dependencies were relatively high.

When eliminating the occurrence of rot, it is important to focus on minimizing the surface damage to tree trunks during harvest and logging. The forest stands of interest in the forest district with the lowest frequency of occurrence of rot (No. 1) were dominated by ranker soil and brown forest soil, mesotrophic soil, typically rich in humus. The soil in the forest district with the highest frequency of occurrence of rot (No. 7) could be classified as brown forest soil, mesotrophic, typically rich in humus and ilimerized, slightly skeletal, humus poor soil. Thus, potentially more favorable conditions for minimizing the occurrence of sap rot are provided by humus-rich, brown forest soil. Andesite subsoil prevailed in both forest districts. The age of stands had no significant effect on the occurrence of beech sap rot. In the forest district with the lowest frequency of occurrence of rot (moderately endangered stand), selection forest management with purposeful selection in combination with no intervention for one decade was conducted. In the stands of forest district with the highest frequency of occurrence of rot (moderately endangered stands), regeneration cutting in the form of shelterwood border cutting in bands (in the width of two stand heights) and small-scale group shelterwood cutting (in the width of two stand heights) was carried out. Tending of the stands was carried out via thinning. Thus, it can be concluded that the selection system, along with purposeful selection, had a high impact regarding
minimizing the sap rot occurrence. Table 2 shows the strongest dependence between rot size and soil quality. According to Cramer’s V, the strongest dependence was on the terrain type. High values of this coefficient were caused by a small sample number and low data variability (a small number of trunks with sap rot in individual forest districts). Aspect, being almost the same in stands of both forest districts, did not have a strong effect on the occurrence of rot. Harvesting and transportation technology can affect the occurrence of heartwood and sap rot while carrying out cutting and logging of trunks. Surface damage to the bark of standing trees can allow the development of fungal diseases, increasing the probability of rot occurrence. Therefore, it is necessary to pay attention to an increased discipline in terms of technology, application of protective agents (treat the damage right after it has been caused), and motivating the employees to carry out the job as well as possible. In this regard, the most suitable technology is provided by forest cableways. In terms of surface damage, bark stripping (need for increased protection in endangered stands) and unprofessional pruning can be dangerous as well.

Forest districts with both the highest (No. 10) and the lowest (No. 8) frequency of occurrence of spiral grain are dominated by brown forest soil, mesotrophic, and humus poor soil; thus, the soil does not affect the occurrence of spiral grain. Mostly andesite subsoil prevails in both forest districts. Stands in both forest districts are at the regeneration age (115–125 years old), so the age does not affect the occurrence of spiral grain either. Stands in forest district No. 8 (moderately endangered stands) were regenerated via border shelterwood cutting in bands with the width of two stand heights and small-scale clear-cutting. In the previous decades, regeneration was carried out via border cutting. In previous decades there was windthrow in these stands. Stands (slightly to moderately endangered) in forest district No. 10 were regenerated via border shelterwood cutting and small-scale shelterwood cutting in a band with a width of two stand heights. In the 1970s, the regeneration was carried out by a combined small-scale clear-cutting. From the above-mentioned facts, it can be concluded that applying a clear-cutting method during the younger stages of regeneration is not desirable in terms of spiral grain occurrence. Windthrows of smaller extent do not have an adverse effect on the occurrence of spiral grain. This negative feature can be eliminated mainly in stages of stand tending by appropriately selected silvicultural interventions and their intensity. Clear cutting in the later stages of regeneration does not have a negative impact on the occurrence of spiral grain. Table 2 indicates that the strongest direct dependence was between the spiral grain size and height and site index; however, the dependence was not statistically significant. Cramer’s V did not indicate any statistically significant dependence. The prevailing aspects in forest district No. 8 were eastern to north-eastern, while forest district No. 10 was dominated by north-western aspects. Thus, it can be stated that the amount of daylight and orientation had a slight impact on the occurrence of spiral grain. Harvesting and transportation technologies did not have a significant impact on spiral grain occurrence. However, this feature can be negatively affected by the browsing of young trees.

3.2. Analysis of Factors Affecting the Oak Tree Species

The overview of quantifiable factors, which could have been statistically analyzed, and their impact on individual qualitative features of oak timber in the selected forest districts with the highest and lowest frequency of occurrence of feature is provided in Table 3. The dependence of the size of individual features on quantifiable factors was statistically evaluated using the Pearson correlation coefficient $r_{xy}$ and Cramer’s V and determining the significance via $\chi^2$ test at the significance level $\alpha = 0.05$ (Table 3). As in the case of beech, only the features with the highest frequency of occurrence and significance in terms of limitation for classifying the log into the quality classes were statistically analyzed: knots, sweep, heart shakes, false heartwood, rot, and spiral grain.
Table 3. Statistical dependence of the size of individual qualitative features of oak trunks on selected factors in individual forest districts.

| Qualitative Feature | Statistical Indicator | Stand Density | Tree Species Composition | Slope | Terrain Type | Stand Height | Site Index |
|---------------------|-----------------------|---------------|-------------------------|-------|--------------|--------------|------------|
| Sweep               | \( r_{xy} \)          | 0.09          | 0.12                    | −0.24 | -            | 0.15         | 0.17       |
|                     | Cramer’s \( V \)      |               | 0.72                    | 0.72  | -            | 0.69         | 0.67       |
|                     | \( \chi^2 \)          |               | 47.7                    | 47.7  | -            | 43.8         | 40.9       |
| Knots               | \( r_{xy} \)          | −0.21         | −0.19                   | 0.14  | 0.21         | −0.2         | −0.07      |
|                     | Cramer’s \( V \)      |               | 0.43                    | 0.46  | 0.52         | 0.47         | 0.43       |
|                     | \( \chi^2 \)          |               | 46.25                   | 40.16 | 17.8         | 43.2         | 35.1       |
| Heart shakes        | \( r_{xy} \)          | −0.06         | −0.01                   | −0.02 | -            | 0.08         | 0.03       |
|                     | Cramer’s \( V \)      |               | 0.52                    | 0.47  | -            | 0.5          | 0.51       |
|                     | \( \chi^2 \)          |               | 87.4                    | 48.5  | -            | 108          | 86.3       |
| Heartwood/sap rot   | \( r_{xy} \)          | 0.22          | 0.08                    | 0     | 0.06         | −0.11        | 0.19       |
|                     | Cramer’s \( V \)      |               | 0.53                    | 0.55  | 0.65         | 0.56         | 0.43       |
|                     | \( \chi^2 \)          |               | 51.1                    | 24.1  | 22.1         | 49.4         | 19.9       |
| Spiral grain        | \( r_{xy} \)          | −0.07         | −0.27                   | 0.11  | 0.13         | −0.37        | −0.28      |
|                     | Cramer’s \( V \)      |               | 0.46                    | 0.43  | 0.53         | 0.46         | 0.4        |
|                     | \( \chi^2 \)          |               | 15.9                    | 10.5  | 5.4          | 7.9          | 7.3        |

The forest stands of interest in the forest district with the lowest frequency of occurrence of sweep (No. 9) were dominated by brown forest soil, mesotrophic, poor in humus, while the stands in the forest district with the highest frequency of occurrence of sweep (No. 3) were dominated by brown ranker forest soil, typically poor in humus and brown forest soil, mesotrophic, typically poor in humus. The soil conditions were almost the same, and thus, the soil and its carrying capacity did not affect the occurrence of sweep. The subsoil in both forest districts was created mostly by andesite. There were no relevant differences in altitude either. Forest stands (moderately endangered) in both forest districts were of approximately the same age (80–90 years). In the forest district with the lowest frequency of occurrence of the initial sweep stage of regeneration begins with border shelterwood cutting combined with small-scale clear-cutting proceeding southwards and north-westward. Previous experience with beech wood has indicated that using a clear-cutting method can negatively affect the occurrence of sweep in the forthcoming decades, which could eventually affect the value of the remaining stand at the rotation age. In the forest district with the highest frequency of occurrence of sweep, only thinning was planned. It can be stated that in terms of oak sweep incidence, less intensive tending was more favorable (one intervention in a decade). In both forest districts, smaller and larger (larger in forest district No. 9) windthrows were recorded, but these had no impact on the occurrence of sweep. Massive dieback of oak in the 1970s in the stands of forest district No. 9 did not have an impact on the occurrence of sweep either. Sweep could be eliminated by a suitable qualitative selection of individual trees of lower quality and marking the target trees. Table 3 shows that the height of trees and site index had the most effect on the occurrence of sweep. According to Cramer’s \( V \), the most significant factor was tree species representation and slope. Assessing the terrain type was not possible since the terrain type was the same in all forest stands. Aspect in both forest districts was mostly northern and north-eastern. Therefore, this aspect had a small impact on the sweep occurrence. Sweep could also be eliminated by suitable procedures in assortment production. In terms of further harmful agents, sweep could have also been affected by browsing.

The forest district with the lowest frequency of occurrence of knots (No. 7) and corresponding stands of interest were dominated by the brown forest soil, mesotrophic, typically poor, or rich in humus. The forest district with the highest frequency of occurrence of knots (No. 3) is dominated by ranker soil, typically poor in humus, and mesotrophic brown soil,
typically rich in humus, so both districts had similar soil composition. Therefore, it can be presumed that soil was not the deciding factor for the occurrence of knots. Subsoil was in both cases composed of andesite. In the forest district with the lowest frequency of occurrence of knots, older stands were located. Most of them were in the regeneration stage, while forest district No. 3 was dominated by 80-year-old stands, where thinning was planned. Stands in forest district No. 7 (moderately endangered) were managed by small-scale shelterwood cutting in bands and border shelterwood cutting without any incidental felling. Tending was carried out by more intensive thinning, similarly to the stands in forest district No. 3. In the stands of forest district No. 3 (moderately endangered), tending was carried out in the form of thinning and cleaning. The stands gradually changed from slightly endangered to moderately endangered. Incidental felling and oak disease, which occurred in the 1970s, represented negative factors. Thus, it can be stated that the occurrence of oak disease and incidental felling, which negatively affected the tending, had an impact of increased knot forming in oak wood that also had less intensive tending. Pruning was of lower significance than in the case of beech due to the ability of oak to get rid of dead branches. As can be seen in Table 3, the terrain type had the highest impact on the occurrence and size of knots; however, the statistical significance of the test was relatively low. In the case of most factors, there was only indirect dependence. Comparing the aspect in both districts predicts a recommendation that oak is more prone to form knots when located in northern aspects.

The stands of interest in the forest district with the lowest frequency of occurrence of heart shakes (No. 3) were dominated by the brown ranker forest soil, typically poor in humus or mesotrophic soil, typically poor in humus. On the other hand, the forest district with the highest frequency of occurrence of heart shakes (No. 13) were characterized by mesotrophic brown forest soil, typically rich in humus and ilimerized soil moderately skeletal, and poor in humus. In contrast to beech, the soil could have had a certain impact on the occurrence of heart shakes. The subsoil in both districts was composed mainly of andesite. Forest stands in both districts were at the age of 80–100 years. While in the forest district No. 3 (moderately endangered stands) tending was being carried out, the stands of forest district No. 13 (slightly endangered stands) had already started to be regenerated. Tending in stands of forest district No. 3 was carried out in the form of thinning with gradual segmentation of stands. The smaller windthrow in the 1970s did not have any impact on the occurrence of heart shakes. However, it affected tending and one complete decade was without any interventions. Incidental felling, as well as clear-cutting regeneration, increased the risk of heart shake occurrence. The occurrence of heart shakes could be eliminated by a suitable qualitative selection during stand tending. As can be seen in Table 3, there was only a small direct dependence of the heart shake size and the above-mentioned factors. According to Cramer’s V, the strongest dependence was in the case of tree height; therefore, the conclusions were similar as in the case of beech. This aspect only had a minimum impact on the occurrence of heart shakes on oak stands. In general, it can be said that the conclusions for oak are the same as in the case of beech. Bark pockets and ingrown metal shards can also cause heart shakes.

The forest stands of interest located in forest district No. 4, where the frequency of occurrence of heartwood rot was the lowest, were dominated by ilimerized soil, moderately skeletal, poor or rich in humus, and brown forest soil, typically poor in humus. The soil in the forest district with the highest frequency of occurrence of heartwood rot (No. 9) was brown forest soil, mesotrophic, typically poor in humus. Therefore, it can be claimed that soil did not have a great impact on the occurrence of heartwood rot. However, ilimerized soil seems to be more favorable for oak than brown forest soil. The subsoil was in all cases almost the same (composed of andesite); therefore, no significant impact on the formation of heartwood rot could be observed. The age of stands was almost the same in all forest districts (80–110 years), so similarly to beech, the age did not have a significant impact on the occurrence of heartwood rot. Forest stands (moderately endangered) in the forest district with the lowest frequency of occurrence of heartwood rot were regenerated.
by small-scale shelterwood cutting in bands with a width of two stand heights or by small-scale group shelterwood cutting. Thinning was less intensive. In the past, the forest stands (moderately endangered) in the forest district No. 9 were regenerated by small-scale clear-cutting in bands with a width of two stand heights, tending in the past three decades was almost without interventions since the stands were regularly affected by windthrows. From the above-mentioned fact, it can be concluded that mostly the small-scale clear-cutting and windthrows (district No. 9) may adversely affect the occurrence of heartwood and sap rot.

The soil in the forest stand of interest in the forest district with the lowest frequency of occurrence of spiral grain (No. 13) was mostly moderately ilimerized, poor in humus, and sometimes skeletal. The soil in the forest district with the highest frequency of occurrence of spiral grain (No. 7) is also ilimerized, moderately skeletal, poor or rich in humus, so the soil did not significantly affect the occurrence of spiral grain. Andesite subsoil was typical for both forest districts. The age of the stands in the forest district No. 7 ranged from 90 to 140 years, while in the forest district No. 13, the age was in the range of 90–110 years. The age, similarly to beech, only had a slight impact on the occurrence of spiral grain. It can be eliminated mainly in the stages when tending was carried out by correctly selected interventions and their intensity. As can be seen in Table 3, the strongest indirect dependence (however statistically insignificant) was in the case of stand height and site index. Cramer’s V did not indicate any statistically significant dependence. The amount of daylight and orientation also had a slight impact on the occurrence of spiral grain. Harvesting and transportation technology (similarly to beech) do not have a deciding impact on the occurrence of spiral grain; however, these can be affected by browsing of young crops.

3.3. Summary of Factors Influencing the Limiting Qualitative Features

Each qualitative feature was affected by several environmental factors in most cases. It is necessary to combine factors for stand quality assessment. If we want to grow specific valuable assortments, it is necessary to focus on an effective combination of these factors with the possibility of influencing the negative features as much as possible, since the combination of the features determines the classification of the log into the quality class.

Suitable sites should be typical with mixed stands without monocultures, which will be managed without a clear-cutting management system. This system was proven as a negative factor, increasing the frequency of occurrence of several qualitative features. The question of harvesting methods should be reconsidered as well since a blanket application of whole-tree logging is not right.

Table 4 provides an overview of the main factors affecting the occurrence of deciding qualitative features and the possibilities of eliminating their size or occurrence.
| Qualitative Feature | Beech | Oak |
|---------------------|-------|-----|
| **Influencing Factors** | **Minimization Options** | **Influencing Factors** | **Minimization Options** |
| Knots | Acidic and skeletal soil, pruning during tending the stands, site index, tree species representation, age, aspect | Pruning, forest soil of higher quality, lower intervention intensity, eastern aspect | Incidental felling, oak disease, aspect, browsing | Stand protection, stable stands, health selection, except northern aspect |
| Sweep | Altitude, clear-cutting in initial stages of tending, representation, browsing | Qualitative selection with marking the target trees, without clear-cutting, appropriate handling, crop protection, assortment method | Clear-cutting, tending, browsing, representation | Qualitative selection, without clear-cutting, tending of lower intensity, stand stability, motivation—maintaining technological procedures, cableway technology |
| Heart shakes | The occurrence of rot, frost cracks, incidental felling, windthrow, tree height, aspect, representation, harvesting, and logging technology | Qualitative selection, western aspect, stand stability, maintaining correct technological procedures—motivation system, cableway technology | Soil, incidental felling, clear-cutting, height, shards, technological procedures | Qualitative selection, without clear-cutting, stand stability, motivation—maintaining technological procedures, cableway technology |
| False heartwood | Soil, subsoil, age, long rotations, forest management style, tending intensity, representation, surface damage to the trunk during tending | Soil richer in nutrients, shorter rotations, selection system, lower intensity tending, treating the damage to trunk surface | - | - |
| Heartwood rot | Same as with false heartwood | Same as with false heartwood | Small-scale clear-cutting, incidental felling, site index and aspect (partially), damage during harvesting and logging, browsing | Ilimerized soil, minimizing clear-cutting, undergrowth system, health selection, treating the surface damage—motivation, cableway technology, stand protection |
| Sapwood rot | soil, forest management style, site index, damage during harvesting and logging, browsing | Brown forest soil of higher quality, selection system, higher site index, treating the surface damage—motivation, cableway technology, stand protection | Same as with heartwood rot | Same as with heartwood rot |
| Spiral grain | Clear cutting during tending, aspect, browsing | Silvicultural interventions, eastern aspect, crop protection | Stand tending, aspect, browsing | Intervention intensity, eastern and southern aspect, crop protection |
4. Discussion

Despite the importance of this issue, similar research has only been dealt with by very few authors leading to a lack of research studies in this sphere. Most studies just quantify the occurrence of the features in question or identify the causing factors [12,33]. Most authors only focus on one specific qualitative feature and ways of affecting the feature, while a complex approach is absent [29,34–38].

It is inevitable to mention that there are certain negative qualitative features (e.g., some types of stains) that are required and very valuable on the market. For instance, some color modifications of oak wood are extremely valuable on the market, as well as some grain patterns caused by false heartwood in beech wood.

A study from 2007 [39] mentions certain ways of eliminating the knot occurrence, e.g., congested canopy cover and spacing when establishing the forest and in young stands, mixed tree species in the stands, or phenotypes with thin branches. Other measures include suitable and timely selected silvicultural interventions (pruning and tending). Also important is stand stability and species diversity. These conclusions were partially in accordance with the findings of the present study in terms of minimizing knot occurrence.

Račko and Čunderlík [29] established that the amount and size of the false heartwood in beech wood was determined mostly by the diameter of the trunk, while the dependence on stand age was weaker. This was partially confirmed also in the present study.

Zeltins et al. [40] analyzed the occurrence of cracks of Norway spruce trunks. As the main possibilities of their elimination, they introduced silvicultural interventions and qualitative selection aimed at increasing the wood density.

Michalec et al. [41] quantified the occurrence of negative qualitative features of wood using 5470 specimens of spruce logs from managed and unmanaged forests. The most often occurring feature was knot representing 70.38% and 67.13% in unmanaged forests and managed forests, respectively. A similar amount of knot occurrence was also identified in the present study in the case of non-coniferous tree species. In addition, the present study also confirmed the fact that suitable management of forest stands can partially eliminate the frequency of occurrence of this qualitative feature.

5. Conclusions

Some conclusions are drawn from the results of a comparative analysis of the influencing factors in two forest districts. These forest districts were selected because they had either the lowest or the highest frequency of occurrence of false heartwood. Therefore, the conclusions may seem only as a general statement; however, they are based on analyzing the factors in both forest districts.

Despite the limited sample size and the above-mentioned problems with the retrospective analysis of meeting the forest management plan, the present results confirmed most causes of the occurrence of some qualitative features that were established by authors in previous studies. In addition, the study introduced new findings concerning new factors affecting the occurrence of the features in non-coniferous tree species. These new findings include mainly the impact of soil, aspect, some harvesting interventions in terms of tending, as well as the impact of applied harvesting and logging technology.

The results of the comparative and statistical analysis show that forest management of the stands and silvicultural interventions affect the formation of the analyzed negative features most significantly. A certain role is also played by the conditions of the site (soil, subsoil, and terrain slope), which affect the technological aspect of the logging process in the second place.

The presented results are valid for the conditions of the University Forest Enterprise of the TU in Zvolen; nevertheless, they can also be applied in a wider context and to conditions similar to forest stands in Central Europe.

In the future, this work will inevitably continue in similar research studies since the ratio of the highest quality classes is decreasing, and new possibilities of its increase have to be researched. It can subsequently bring more finances to forest management [42,43].
Furthermore, it is important to search for a qualified workforce who understand the issue and will carry out the required tasks correctly and precisely, which is associated with creating a system of positive and negative motivation [44,45].

Qualitative use of beech wood in comparison to oak wood is significantly affected and limited by the occurrence of false heartwood. The occurrence and size of knots in oak wood can be significantly limited by appropriate tending interventions.

The present research results could be used in further research studies in this field and contribute to producing timber assortment of higher quality. The obtained results are important for sustainable forest management and the improvement of the quality assessment standards.

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