ANALYSIS OF DIAMETER TAPER IN FIR (*ABIES ALBA* Mill.) AND SPRUCE (*PICEA ABIES* L.) SAWLOGS FROM 1ST AND 2ND QUALITY CLASS

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ABSTRACT

The success of sawmill capacities mainly depends on the rational use of raw materials, specifically the logs for sawing. The rational use of sawmill logs is primarily influenced by quantitative yield. The quantitative yield is a complex matter influenced by several parameters, with the main ones related to the sawmill logs. The key parameters include the diameter of the logs, their length, and the diameter taper. This study focuses on analyzing the diameter taper of fir (*Abies alba* Mill) and spruce (*Picea abies* L.) sawlogs from 1st and 2nd quality class. Taper, which represents the gradual reduction in log diameter from the base to the top. By examining 80 selected logs from the sawmill company in Berovo, Republic of North Macedonia, this study identifies patterns in taper rates across eight diameter groups. The results show the impact of taper on log utilization, highlighting the implications for sawing efficiency and wood quality.

Key words: diameter taper, fir, spruce, log geometry, log volume, mean diameter, quality class, sawmill.

INTRODUCTION

In sawmill processing, the utilization of raw materials is defined as utilization in the form of sawn lumber or as a complex utilization of sawmill logs (Rabadziski and Zlateski 2019). Besides sawn lumber, other products such as parquet blanks, wooden elements, battens, and similar products are obtained during the process of log sawing. The Republic of North Macedonia has a long-standing tradition in sawmill processing. Raw materials from both coniferous and deciduous species dominate. For an optimal sawmill processing operation, planned utilization of raw materials is necessary.

The complex utilization of sawmill raw materials is influenced by many factors, such as the thickness of the saw blade, the diameter and length of the logs, their curvature, the sawing method, utilization of coarse waste, etc.

The diameter of the logs is an important characteristic, considered a significant factor when forming sawing patterns and determining quality classes. The diameter value is taken as the arithmetic mean between the diameters of the thick end and the thin end of the log. The diameter taper represents the gradual decrease in diameter from the thick to the thin end of the sawlog. It is an inevitable phenomenon in sawmill logs, resulting from the tree's geometry. In nature, there is no perfectly cylindrical tree trunk. In fact, the diameter taper is a deviation from the cylindrical shape, approaching the conical form of tree trunks.

Tree trunks usually have a straight longitudinal axis, and the trunks themselves are symmetrically built around that axis. As a result, the cross-sections of the trunks are nearly circular, and the longitudinal section, which passes through the trunk's axis, forms a regular figure bounded by two equal curved lines, symmetrically arranged on both sides of the axis

(Mihajlov 1966). The volume of living trees is a primary factor that strongly affects the utilization of forest resources. When calculating the volume of living trees, it is important to consider the diameter taper (McTague and Weiskittel 2020). The calculation of diameter taper in living trees is of interest in forestry and wood processing due to its importance and impact on the complex utilization of sawmill raw materials (Weiskittel *et al*. 2011).

Generally, if previous research is analyzed, it can be concluded that coniferous wood species show better diameter taper than deciduous species. Beech logs (*Fagus sylvatica* L.) with a constant length of 4.20 m, from 1st, 2ns and 3rd quality class, showed an average diameter taper value of 1.00 cm/m (Rabadziski 1991). For pine logs (*Pinus sylvestris*) with a constant length of 5.00 m, from 1st, 2nd and 3rd quality class, the average diameter taper was 1.00 ± 0.093 cm/m (Rabadziski *et al*. 2017).

In the wood processing industry, maximizing the utilization of raw materials is crucial for both economic and environmental reasons. Understanding how taper varies between logs of different sizes and species can help optimize sawing processes and improve resource efficiency. The taper plays a critical role in classification and quality, directly influencing lumber output (quantity of sawn lumber).

This study focuses on two important coniferous species: fir (*Abies alba* Mill) and spruce (*Picea abies* L.). These species are widely used in the timber industry, and their physical characteristics, including diameter taper, significantly affect the yield of processed logs. By analyzing data from logs processed in the chosen sawmill (researched capacity), this paper provides insights into the diameter taper of fir and spruce logs and its influence on sawmill output. The two species were analyzed together due to their similarity in anatomical structure and identical physical-mechanical properties. In the lumber trade market in the Republic of North Macedonia, these two species are sold as one under the name,,čamovo drvo". The analyzed logs were divided into groups according to their diameter.

MATERIALS AND METHODS

A sawmill capacity in the Maleshevo region of the Republic of North Macedonia was selected as the subject of the research. The research facility is located in Berovo, Republic of North Macedonia. The sawmill processes wood species of both coniferous and deciduous origin and is equipped with good technological resources. The logs for sawing are sourced both domestically and internationally, primarily from the Republic of Bulgaria. The total annual volume of processed logs at the research facility is 3200 m^3/year. The distribution of the annually processed raw material by wood species is as follows: beech (*Fagus sylvatica* L.) 1600 m^3/year, pine (*Pinus sylvestris*, *Pinus nigra*) 1200 m^3/year, fir/spruce (*Abies alba* Mill, *Picea abies* L.) 300 m^3/year, and other wood species 100 m^3/year. At the time of data collection, a large quantity of fir/spruce logs was available at the sawmill, which explains the choice of wood species for the research. The research was conducted under production-exploitation working conditions.

The basic parameters of fir/spruce logs were measured using a wooden caliper and steel tape. The following parameters were recorded for the logs:

- diameter of the thin end (d_1),
- diameter of the thick end (d_2),
- length of the logs (l).

A total of 91 logs were measured, with 80 selected for analysis. Logs were grouped into eight diameter classes.

The taper was calculated as:

$$Taper = \frac{d_2 - d_1}{l} \ (cm/m) \tag{1}$$

where d_2 *(cm)* is the thick-end diameter, d_1 *(cm)* the thin-end diameter, and l *(m)* the log length.

Figure 1 shows the fir and spruce sawlogs.

Figure 1: Fir (left) and spruce (right) sawlogs

The data was processed using statistical analysis, and the mean, standard deviation, and error were calculated.

The logs were classified according to Macedonian standards (MKS EN 1316-1:2013).

Logs were divided into eight diameter groups as followed: 26.0–30.0 cm, 31.0–35.0 cm, 36.0–40.0 cm, 41.0–45.0 cm, 46.0–50.0 cm, 51.0–55.0 cm, 56.0–60.0 cm and 61.0–65.0 cm.

Each group was analyzed for diameter taper, average diameter, and volume.

The taper values were statistically processed, with mean taper, standard deviation, and variation coefficients calculated for each diameter group. These metrics allowed for an assessment of the relationship between diameter group and taper, and how this affects sawmill efficiency.

The length of the logs was with the constant value of 4.0 m.

RESULTS AND DISCUSSION

The parameters for the logs in the first thickness group were as followed: diameter of the logs at the thin end, ranging from 26.0 cm to 30.0 cm, at the thick end from 28.0 cm to 30.0 cm, and the average diameter was between 27.0 cm and 29.0 cm. The diameter taper was from 0.50 cm/m to 1.00 cm/m. In this group, 10 logs were analyzed, each with a length of 4.0 m, with a total log volume of 2.388 m^3. The logs were classified as 1st and 2nd quality class.

According to the data for the logs in the second thickness group shown, it can be noted that the smallest diameter of the logs at the thin end was 31.0 cm, and the largest diameter was 33.0 cm. The values for the diameter of the logs at the thick end ranged from 34.0 cm to 35.0cm. The average diameter ranged from 32.0 cm to 34.0 cm. The values for the diameter taper of the logs were within the range of 0.50 cm/m to 1.00 cm/m. The logs were classified as 1st and 2nd quality class, with a constant length of 4.0 m and a total log volume of 3.372 m³. A total of 10 logs was analyzed.

The data for third thickness group of logs with a diameter from 36.0 cm to 40.0 was the followed: the diameter of the logs at the thin end ranged from 36.0 cm to 38.0 cm, and at the thick end, it ranged from 38.0 cm to 49.0 cm. The logs were 4.0 m long. The values for the diameter taper ranged from 0.50 cm/m to 1.00 cm/m. The total volume of the analyzed logs was 4.485 m³. The logs were of 1st and 2nd quality class, and there were 10 logs in total in this thickness group.

For the forth thickness group, it can be concluded that the diameter of the logs at the thin end ranged from 41.0 cm to 43.0 cm, while at the thick end, it ranged from 44.0 cm to 45.0 cm. The average diameter ranged from 43.0 cm to 44.0 cm. The diameter taper was within the range of 0.50 cm/m to 1.00 cm/m. The logs are 4.0 m long and are of 1st and 2nd quality class. In the analysis, 10 logs were included, with a total volume of 5.828 m³.

For the fifth thicknes group it can be concluded that the diameter of fir/spruce logs at the thin end ranged from 46.0 cm to 47.0 cm. The diameter at the thick end was between 48.0 cm and 50.0 cm. The average diameter ranged from 47.0 cm to 48.0 cm. The logs were 4.0 m long. The diameter taper was within the range of 0.50 cm/m to 1.00 cm/m. A total of 10 logs of 1st and 2nd quality class were analyzed, with a wood volume of 7.243 m³.

For the sixth thickness group, it can be noted that the diameter of the logs at the thin end was from 51.0 cm to 53.0 cm, while the diameter at the thick end was from 53.0 cm to 55.0 cm. The average diameter ranged from 52.0 cm to 54.0 cm, and the diameter taper was from 0.50 cm/m to 1.00 cm/m. The logs were of 1st and 2nd quality class, with a length of 4.0 m and a volume of 8.889 m³.

Based on the data for the seventh thickness group, it can be briefly concluded that 10 fir/spruce logs were analyzed, each with a length of 4.0 m, 1st and 2nd quality class, with a total log volume of 10.490 m³. The diameter of the thin end was from 56.0 cm to 58.0 cm, and at the thick end, it was from 58.0 cm to 60.0 cm, with an average diameter of 57.0 cm to 59.0 cm. The diameter taper of the logs was within the range of 0.50 cm/m to 1.00 cm/m.

For the last, eight thickness group, it can be concluded that the diameter of the thin end of the log’s ranged from 61.0 cm to 63.0 cm. The diameter at the thick end ranged from 63.0 cm to 65.0 cm. The average diameter was from 62.0 cm to 64.0 cm, and the logs were 4.0 m long. In the analysis, 10 logs were included, of 1st and 2nd quality class, with a total log volume of 12.423 m³. The diameter taper varied within the range of 0.50 cm/m to 1.00 cm/m.

The average taper across all logs ranged from 0.675 cm/m to 0.775 cm/m, with the highest taper values occurring in the smaller diameter groups (table 1). The taper generally decreased as log diameter increased, indicating that larger logs tend to have more uniform diameters along their length. This is consistent with previous research, which suggests that larger trees exhibit less taper due to their more cylindrical shape. Figure 2 visualizes the values for the mean diameter taper across the all 8 thickness groups.

Table 1: Statistical data for the mean diameter taper for the fir and spruce sawlogs

Count number	Thickness group	$\bar{x} \pm f\bar{x}$	$\sigma \pm f\sigma$	$v \pm fv$
	D (cm)	*(cm/m)*	*(cm/m)*	*(%)*
1	26.0 – 30.0	0,675 ± 0.051	0.160 ± 0.036	23.715 ± 5.593
2	31.0 -35.0	0.775 ± 0.055	0.175 ± 0.039	22.581 ± 5.300
3	36.0 – 40.0	0.700 ± 0.069	0.218 ± 0.049	31.135 ± 7.607
4	41.0 – 45.0	0.750 ± 0.071	0.224 ± 0.050	29.814 ± 7.235
5	46.0 – 50.0	0.725 ± 0.066	0.208 ± 0.046	28.644 ± 6.910
6	51.0 – 55.0	0.675 ± 0.062	0.195 ± 0.044	28.927 ± 6.989
7	56.0 – 60.0	0.675 ± 0.051	0.160 ± 0.036	23.715 ± 5.593
8	61.0 – 65.0	0.700 ± 0.059	0.187 ± 0.042	26.726 ± 6.389

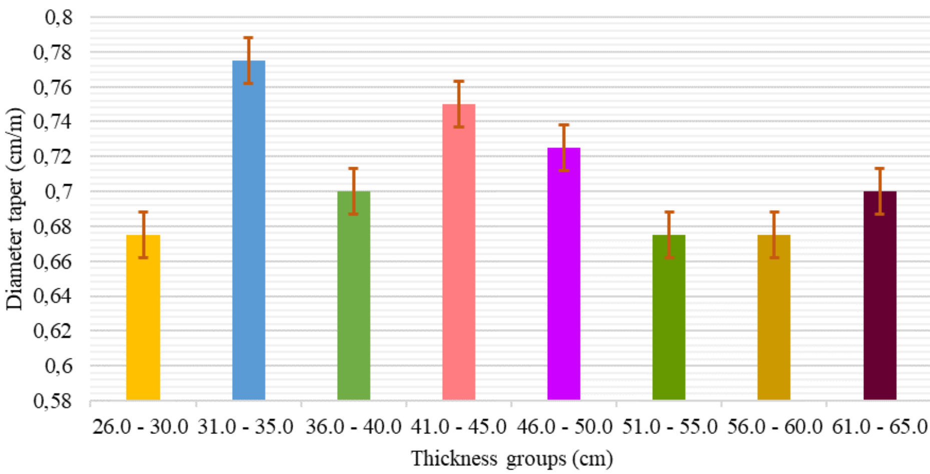

Figure 2: Mean log diameter taper for the thickness groups

The analysis of the diameter taper was carried out to obtain relevant results on how the taper of the logs behaves. The goal is to understand and observe how the quality class of sawmill logs affects the taper as a factor. In this way, the cylindrical shape of the logs and their classification into 1st and 2nd quality classes, according to the standards of MKS EN 1316-1:2013, were confirmed.

Additionally, it is important to note that this serves as a good indicator for expecting higher quantitative yield values due to the smaller proportion of sawn assortments in the additional zone of the logs.

Log volume increased progressively with diameter, as expected. The total volume of logs in the smallest diameter group (26.0-30.0 cm) was 2.388 m^3, while the largest group (61.0–65.0 cm) had a volume of 12.423 m^3. This significant increase in volume is attributable to both the greater diameter and the more cylindrical shape of larger logs, which have a lower taper rate. The log volume according to the thickness groups is shown in table 2 and Figure 3.

Table 2: Sawlogs volume for the fir and spruce sawlogs, according to the thickness group

Count number	Thickness group	Sawlogs volume
	D (cm)	*V* (m^3)
1	26.0 – 30.0	2.388
2	31.0 – 35.0	3.732
3	36.0 – 40.0	4.485
4	41.0 – 45.0	5.828
5	46.0 – 50.0	7.243
6	51.0 – 55.0	8.889
7	56.0 – 60.0	10.490
8	61.0 – 65.0	12.423
9	Sum $_{\Sigma I+...+VIII}$	55.118

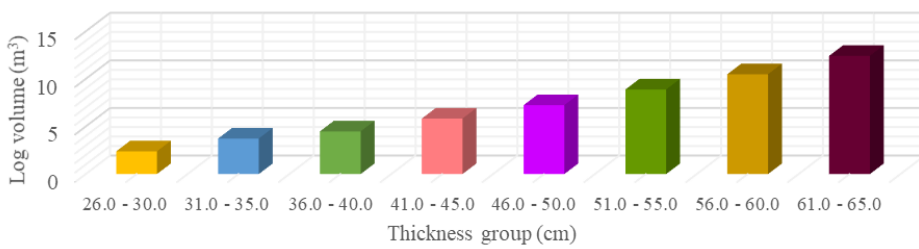

Figure 3: Sawlogs volume distribution according to the thickness groups

The results suggest that logs with lower taper (i.e., larger logs) are more efficient for sawmilling, as less material is wasted. Logs in the higher diameter groups (56.0-65.0 cm) had both higher volumes and lower taper, meaning they are likely to yield more usable timber per unit of raw material. Conversely, logs in the smaller diameter classes exhibited higher taper, which reduces the efficiency of the sawing process and increases the proportion of waste material.

CONCLUSIONS

This study highlights the importance of understanding diameter taper when selecting logs for sawmill processing. Logs with larger diameters tend to have lower taper and thus yield more lumber per unit of raw material. The results of this study can help sawmills optimize their log selection and sawing processes to maximize efficiency and reduce waste.

The taper of fir and spruce logs plays a crucial role in determining lumber yield in sawmills. Our analysis suggests that managing taper through log selection and processing techniques can optimize yield, particularly for longer logs where taper variations are more pronounced.

Further research is recommended to explore the effects of log taper on specific sawing techniques and to examine how taper varies with tree age and forest management practices.

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