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COMPARATIVE ANALYSIS OF YIELD DISTRIBUTION IN FIRST AND SECOND-CLASS QUALITY FIR AND SPRUCE SAWLOGS (*Abies alba* Mill./*Picea abies* L.): A CASE STUDY FROM NORTH MACEDONIA

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ABSTRACT

The efficient utilisation of sawlogs represents a crucial determinant for the operational success of sawmill capacities. Sawlogs serve as the primary raw material in sawmill operations, and their rational use is influenced by several production-related factors. Key determinants impacting sawlog utilisation include wood species, log quality classification, technological capacity of sawmills, and workforce proficiency, among others. Of particular importance to sawlog processing methods are wood species and quality classification. A principal indicator of sawmill performance lies in the quantitative yield of raw material, defined by the volume of lumber produced from log processing. The economic viability of sawmills is grounded in this quantitative utilisation, with wood species and quality classification exerting the most substantial influence.

This paper presents findings from a comparative analysis conducted at a sawmill facility in Berovo, Republic of North Macedonia. It examines the yield from fir/spruce (*Abies alba* Mill./*Picea abies* L.) sawlogs of both first- and second-quality classes. The analysed logs maintain a consistent length of 4.0 meters. The average diameter for first-class logs ranges from 27.0 to 57.0 cm, while for second-class logs, it spans 38.0 to 62.0 cm. The mean yield rate for first-class logs is 68.93%, and for second-class logs, it is 61.55%. A comparative analysis is provided for the coarse and fine waste generated from log processing for both quality classes. Sawing was conducted using a horizontal band saw, and the resulting lumber is designated for construction and structural purposes.

Key words: fir, spruce, quantitative yield, quality class, lumber

1. INTRODUCTION

The utilisation of raw material is a pivotal factor for the operational success of a sawmill facility. It is defined as the conversion of raw logs into sawn lumber. Comprehensive sawlog utilisation encompasses quantitative, qualitative, and value-based aspects. Maximum quantitative yield refers to the volume of sawn assortments derived from the processing of a single or multiple sawlogs. Factors influencing this efficiency include wood species, raw material quality classification, workforce skill level, production costs, energy consumption, and productivity, among others. One of the main elements influencing sawmill's financial success is its quantitative yield. Furthermore, this yield holds significance in terms of sustainable forest resource management and ecological considerations. Achieving success in wood processing requires attention not only to quantitative yield but also to maximising economic returns. The main concerns in wood processing are increasing financial advantages, which are frequently a limiting factor for quantitative yield (Nikolić, 2010). When processing a log, the goal should not necessarily be to extract the maximum quantity of assortments but rather to produce high-quality assortments, sometimes at the expense of a lower quantitative yield.

Sawmill technology in wood processing has a long-standing tradition in the Republic of North Macedonia. The country is rich in forest resources, resulting in large annual volumes of coniferous and deciduous logs of varying lengths, diameters, and classes being processed. The average quantitative yield rate in sawmills varies broadly, ranging from 48.0% to 70.0% (Rabadziski, 2019). The lumber obtained serves numerous applications, with a small portion used for producing rotary cut and plain sliced veneer, while the majority is used in construction and furniture manufacturing. Deciduous species are predominantly used for furniture production, whereas coniferous species are preferred for construction purposes. Among coniferous species, white and black pine (*Pinus strobus*, *Pinus nigra*) and fir and spruce (*Abies alba* Mill, *Picea abies* L.) dominate. Fir and spruce lumber is processed and marketed as a single category (species) known commercially as "čamovo drvo," due to their similar physical and mechanical properties and anatomical structure.

The genus *Abies* comprises approximately 50 species found in temperate mountainous regions of the Northern Hemisphere (Europe, North America, Asia Minor, the Caucasus, Asia, and Central America). In Europe, the predominant species is the silver fir (*Abies alba* Mill.), with trunks reaching heights of 30-40 meters (up to 60 meters in primaeval forests) and diameters of 1.5-2.0 meters. Fir wood is highly durable when submerged in water, and impregnated fir is used for telecommunications poles, power lines, and other applications. In mountainous regions, fir is utilised for shingles and fences and is a valued source for pulp production. The genus *Picea* includes around 45 species distributed across all continents, except Africa. In Europe, the two primary species are *Picea abies* L. and *Picea excelsa* Ling. Spruce trunks are straight with long, clear wood grains and are distinguished by their relatively cylindrical shape, reaching heights of 40-55 meters, diameters of up to 1.5 meters, and lifespans of up to 1,000 years. Spruce wood is soft, lightweight, easy to process, and widely used. It takes stain and polish well but is difficult to impregnate, making it suitable for construction, joinery, structural woodwork, musical instruments, and more. It is highly valued in the pulp industry due to its long cellulose fibres. Fir wood differs from spruce by its lack of resin channels and black-ringed knots (Georgievski, 1994).

In North Macedonia's processing context, the average quantitative yield rate for fir/spruce logs ranges from 64.0% to 74.0% (Rabadziski, 2019). These values are general; specific, precise data on fir/spruce log yield according to quality class is lacking. When processing coniferous logs, yield rates range from 53.0% to 64.0% (Chernev, 1960). While literature provides relatively lower yield values for deciduous species, advances in processing technology and machinery have led to higher yield rates for both deciduous (Rabadziski, 1994; Smajić *et al*., 2023; Stamenkoska *et al*., 2021; Milčovski, 2014) and coniferous species (Rabadziski *et al*., 2013). Log dimensions (diameter particularly) remain a major influence on quantitative yield (Baltrušaitis *et al*., 2001; Smajić *et al*.), and sawing patterns selection is also critical, depending on log diameter and the type of lumber needed.

This study provides a comparative analysis of the quantitative yield of fir/spruce logs from first and second quality classes. The analysis encompasses yield, coarse, and fine waste for each class, with the objective of determining the impact of quality class on quantitative yield.

2. MATERIAL AND METHODS

The study was carried out in a sawmill that processes both coniferous and deciduous wood species in Berovo, Republic of North Macedonia, under production and operational settings. The sawmill has a lot of cutting-edge technological resources. A total of 20 fir/spruce logs were processed—10 from first-class quality and 10 from second-class quality—classified according to the Macedonian standard MKS EN 1316-1:2013. The raw material originated from Borovets, Republic of Bulgaria. All logs had a uniform length of 4 meters, with diameters ranging from 29.0 to 57.0 cm for the first-quality class and from 38.0 to 62.0 cm for the second-quality class. The total processed wood volume amounted to 5.358 m³ for the first class and 8.588 m³ for the second class. Logs were delivered and processed with bark intact (Figure 1-a). The sawing process was tailored for lumber intended for construction and structural purposes, with the sawing pattern strategically selected to maximise lumber quality from each log. During sawing, boards and higher-quality planks were obtained from the peripheral zone of the log, while beams, smaller beams, and lower-quality planks were produced from the core (Rabadziski, 2019). Log preparation before sawing involved washing in a dedicated, covered area adjacent to the sawmill hall. Primary processing was conducted on a horizontal band saw model

"Šumska kraljica" (Figure 1-b), featuring a 3.0 mm kerf width. Secondary processing, including longitudinal cutting, was performed on a longitudinal circular saw model MABA-Maschinen AG LA, with a kerf width of 4.0 mm. The production process for fir/spruce lumber is illustrated in Figure 2.

a b

Figure 1. *a – Fir/spruce sawlogs, b – Primary processing of the chosen sawlogs*

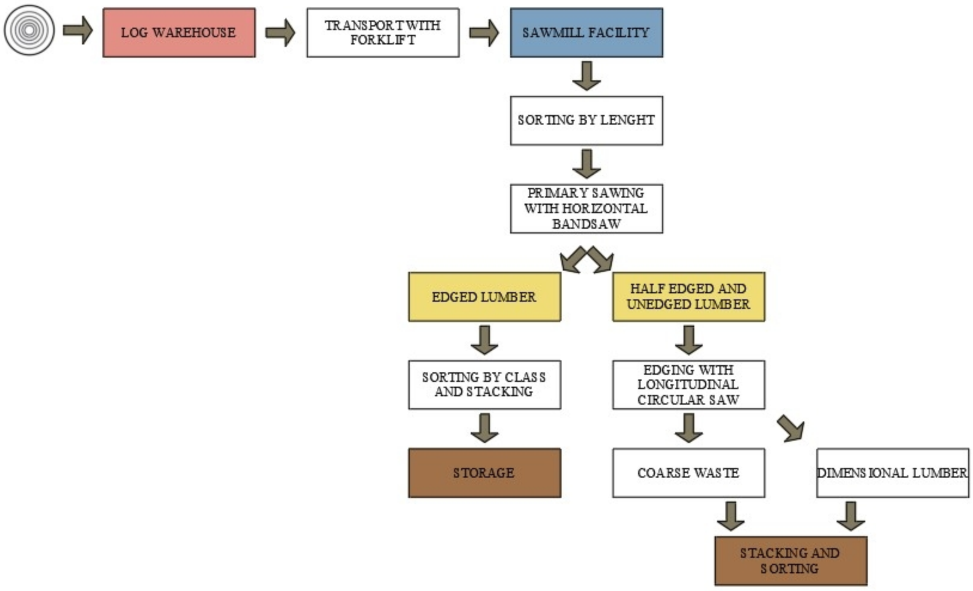

Figure 2. *Sawn lumber production flow*

The following measurements were taken on the logs: diameter at the thin end (d_1), diameter at the thick end (d_2), and length (l). Length was measured using a steel tape, while diameters were measured with a wooden calliper. All measurement values, as well as those derived from calculations, were rounded to the nearest whole centimetre. The measurement data was recorded on standardised forms. Key parameters influencing quantitative yield include the mean diameter (d_{sr}), log volume (V_{sawlog}), and diameter taper (S). These were calculated as follows (according to Rabadziski, 2019):

$$d_{sr} = \frac{d_1 + d_2}{1} \ (cm) \qquad (1)$$

$$V_{sawlog} = \frac{{d_{sr}}^2 \cdot \pi}{4} \cdot l(m^3) \qquad (2)$$

$$S = \frac{d_2 - d_1}{l} (cm/m) \qquad (3)$$

The sawn lumber was measured in terms of length, width, and thickness, with width measured at the mid-length of each piece. Quantitative yield was calculated as the ratio of the volume of sawn lumber (V_{lumber}) to the total log volume (V_{sawlog}), expressed as a percentage (%). Similarly, the volume of coarse waste ($V_{coarsewaste}$) and fine waste ($V_{finewaste}$) was also calculated. Coarse waste includes offcuts and trimmings generated during the dimensional processing of sawn lumber. This waste originates from the primary machine (band saw) but primarily during secondary longitudinal cutting on the circular saw. Fine waste consists of sawdust volume, while wood dust is excluded from the calculations for quantitative yield.

The volumes of lumber, coarse waste, and fine waste were calculated as follows (according to Rabadziski, 2019):

$$V_{lumber} = thickness\ x\ width\ x\ lenght\ (m^3) \quad (4)$$

$$V_{finewaste} = \sum cut\ height\ x\ cut\ lenght\ x\ cut\ width\ (m^3) \quad (5)$$

$$V_{coarsewaste} = V_{sawlog} - \left(V_{lumber} + V_{finewaste}\right)\ (m^3) \quad (6)$$

The obtained data was processed using descriptive statistical methods to facilitate a comparison of yield between the two quality classes.

3. RESULTS AND DISCUSSION

The data for first- and second-class quality logs is presented in Table 1. A total of 20 logs were processed, with 10 logs from each quality class. The length for all logs is constant at 4.0 m. Logs in the first-class exhibit minimal taper (ranging from 0.50 to 0.75 cm/m, with a mean value of 0.56 cm/m), placing them in the group of fully cylindrical logs (according to Mihajlov, 1966). In the first-class logs, the small-end diameter ranges from 26.0 to 56.0 cm, while the large-end diameter varies from 29.0 to 59.0 cm. Since the second-class logs have an average taper of 1.23 cm/m and a range of 1.00 to 1.50 cm/m, they are classified as less cylindrical, which is consistent with their lower quality grade. In this class, the small-end diameters span from 36.0 to 58.0 cm, and the large-end diameters range from 40.0 to 65.0 cm.

Table 1. *First- and second-class quality fir/spruce sawlogs, l = 4.0 m*

Q.c.	N.	d_1 (cm)	d_2 (cm)	d_{sr} (cm)	S (cm/m)	V_{sawlog} (m^3)	Y_{lumber} (%)	$Y_{coarsewaste}$ (%)	$Y_{finewaste}$ (%)	$Y_{central}$ (%)	$Y_{peripheral}$ (%)
I	1	28.0	30.0	29.0	0.50	0.264	65.32	23.68	11.00	34.70	30.62
	2	26.0	29.0	27.0	0.75	0.237	64.32	23.32	12.36	49.96	14.37
	3	32.0	34.0	33.0	0.50	0.342	73.25	15.75	11.00	53.66	19.58
	4	33.0	35.0	34.0	0.50	0.363	67.32	19.53	13.15	25.31	42.02
	5	36.0	38.0	37.0	0.50	0.430	69.99	19.49	10.52	48.08	21.96
	6	37.0	40.0	38.0	0.75	0.466	70.17	18.25	11.58	39.38	30.79
	7	43.0	45.0	44.0	0.50	0.608	71.67	18.70	9.63	45.22	26.44
	8	46.0	48.0	47.0	0.50	0.694	65.02	21.33	13.56	38.53	26.49
	9	53.0	55.0	54.0	0.50	0.916	70.74	14.94	14.32	33.36	37.38
	10	56.0	59.0	57.0	0.75	1.038	71.50	15.25	13.25	51.49	20.01
II	11	36.0	40.0	38.0	1.00	0.045	59.11	26.66	14.23	42.22	16.89
	12	41.0	45.0	43.0	1.00	0.581	61.68	25.54	12.78	23.08	38.00
	13	40.0	46.0	43.0	1.50	0.581	59.35	26.69	13.96	39.57	19.78
	14	47.0	53.0	50.0	1.50	0.785	60.93	25.44	13.63	43.90	17.03
	15	53.0	58.0	55.0	1.25	0.986	64.32	21.63	14.05	17.81	47.50
	16	56.0	61.0	58.0	1.25	1.075	60.40	25.04	14.56	40.56	19.84
	17	53.0	57.0	55.0	1.00	0.950	61.95	25.09	13.96	45.09	16.96
	18	6.0	65.0	62.0	1.25	1.227	63.02	22.42	14.56	44.83	18.20
	19	59.0	65.0	62.0	1.50	1.208	61.01	24.66	14.33	38.05	22.95
	20	58.0	63.0	60.0	1.25	1.150	63.71	21.95	14.34	39.96	23.75

** Q.c. – quality class; d_1 – small end diameter; d_2 – wide end diameter; $d_{sr\_}$ – mean diameter; S – diameter taper; V_{sawlog} – sawlog volume; Y_{lumber} – lumber yield; $Y_{coarsewaste}$ – percentage of coarse waste; $Y_{finewaste}$ – percentage of fine waste; $Y_{central}$ – lumber yield obtained from the central zone of the sawlog; $Y_{peripheral}$ – lumber yield from the peripheral zone of the sawlog.*

The diameters of the second-class logs are larger overall, so the sawing pattern for these logs was designed based on maximising quantitative yield—aiming to produce the largest possible lumber volume from each log, regardless of quality. Conversely, the first-class logs were processed with a focus on producing high-quality lumber, irrespective of diameter. In these cases, the positioning of the lumber within the log influenced the sawing layout. The total quantitative yield, fine and coarse waste, and an analysis of the sawn lumber's position within the logs were calculated. The percentages of quantitative yield, coarse waste, and fine waste for first- and second-class quality are illustrated in Figures 3 and 4.

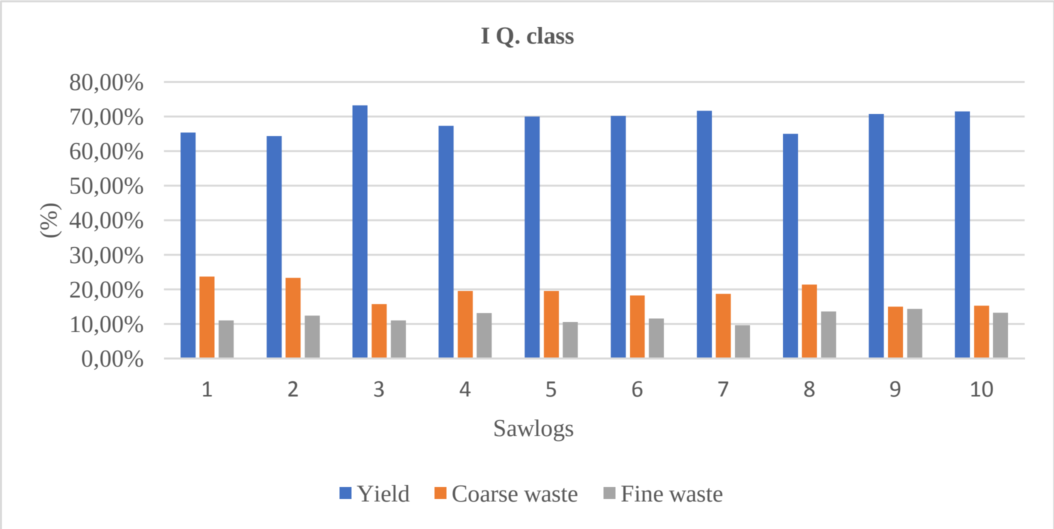

Figure 3. *Ratio of yield, coarse and fine waste in first-class quality sawlogs*

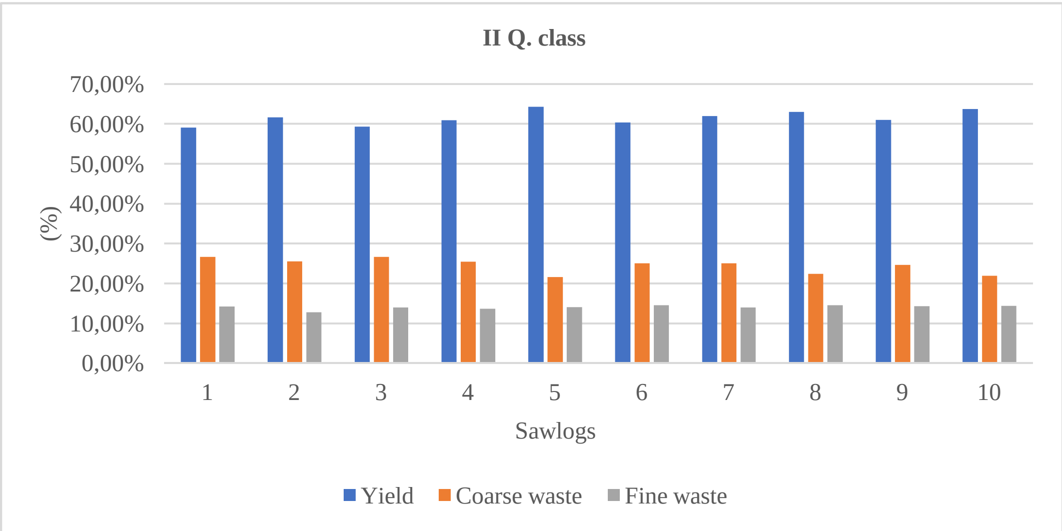

Figure 4. *Ratio of yield, coarse and fine waste in second-class quality sawlogs*

From Table 1 and Figures 3 and 4, it can be observed that the yield for first-class logs is higher than that for second-class logs. The data from both quality classes were analysed using descriptive statistics (shown in Table 2), and the values are represented with histograms (Figure 5). This statistical analysis highlights the difference in yield percentages between the two classes, where first-class logs demonstrate not only higher quantitative yield but also more consistent quality in the resulting lumber. The histograms in Figure 5 provide a clear visual comparison, further emphasising the variance in quantitative utilisation between first and second quality classes.

***Table 2.** Descriptive statistics data for the first- and second-class sawlogs*

	Q. class	Mean (%)	Std. Deviation (%)	Std. Error (%)	95% Confidence Interval for Mean		Min (%)	Max (%)
					Lower Bound	Upper Bound		
Yield	**I**	68,93	3,18	1,00	66,66	71,20	64,32	73,25
	II	61,55	1,75	0,55	60,30	62,80	59,11	64,32
Coarse waste	**I**	19,02	3,13	0,99	16,78	21,26	14,94	23,68
	II	24,51	1,86	0,59	23,18	25,84	21,63	26,69
Fine waste	**I**	12,04	1,52	0,48	10,95	13,12	9,63	14,32
	II	14,04	0,53	0,17	13,66	14,42	12,78	14,56
Yield from central zone	**I**	41,97	9,20	2,91	35,39	48,55	25,31	53,66
	II	37,51	9,37	2,96	30,80	44,21	17,81	45,09
Yield from peripheral zone	**I**	26,97	8,50	2,69	20,89	33,05	14,37	42,02
	II	24,09	10,36	3,28	16,68	31,50	16,89	47,50

***Figure 5.** Comparison of yield (Y_{lumber}, $Y_{central}$, $Y_{peripheral}$), coarse and fine waste in both first- and second-class*

The yield for first-class logs ranges from 64.32% to 73.25%, with an average of 68.93%. For second-class logs, the yield is between 59.11% and 64.32%, with an average yield of 61.55%. The average yield for first-class logs aligns with literature-reported averages (64.0 to 74.0%) according to Rabadziski (2019), while second-class logs show a slight deviation from the documented average. Comparing the mean yields between the two classes, a difference of 7.33% is observed. The lower yield in second-class logs can be attributed to a greater taper (S = 1.23 cm/m), curvature exceeding 3.0% of the log length (per MKS EN 1316-1:2013), and a higher occurrence of knots and anatomical imperfections. The greater taper in second-class logs also increases the volume of slabs and generates a higher proportion of coarse and fine waste. The average coarse waste for first-class logs is 19.02%, whereas for second-class logs, it is 24.51%. This higher amount in second-class logs is dictated by the taper and increased inclusion of additional zones during lengthwise dimensioning (Nikolić, 2010). For fine waste, the difference between the two classes is smaller at 2.00%, with 12.04% for first-class and 14.04% for second-class logs. This minor variance suggests that fine waste is less affected by log quality class. In terms of total yield and the percentage of coarse waste, quality class has a significant influence, with first-class logs showing favourable values compared to second-class logs. The higher percentage of coarse waste in second-class logs could be further utilised for producing small wooden elements, though this approach was not pursued in this study.

This study also analysed yield based on the lumber's origin within the log. Depending on the log zone, there is lumber from the core zone and lumber from the peripheral zone (Rabadziski, 2019). The quality of sawn lumber, relative to the log's location, mainly depends on the wood species. In softwood species, the cross-section is divided into three zones: heartwood with 8-10% participation, mature wood with 50-70% (including the heartwood), and sapwood with approximately 30% (5-7 cm wide, measured from under the bark). The distribution of these zones affects lumber quality, particularly in logs with a larger average diameter. Lumber from the sapwood zone (peripheral lumber) has a higher tangential shrinkage coefficient and is more prone to warping than lumber from the heartwood (core lumber), according to Nikolić (2010). The peripheral zone in logs contains smaller intergrown knots, which are visible on the lumber surface and reduce quality. In first-class logs, lumber from the core zone accounts for 41.97%, while in second-class logs, it represents 37.51%. For lumber sawn from the log periphery, first-class logs yield 26.07%, while second-class logs yield 24.09%. The differences in yield by log zone between the two classes are relatively small, ranging from 1.98% for peripheral lumber to 4.46% for core lumber. It can be concluded that first-class logs produced more lumber from the core zone, thus maximising the quality potential of the logs. Analysing yield by zone origin for each class individually, both classes show higher yield in the log's core zone. In terms of lumber quality based on log zone origin, quality class does not play a significant role, as the values for peripheral and core lumber are close for both classes.

4. CONSLUSIONS

The comparative analysis of quantitative yield for fir/spruce logs of first- and second-class quality shows differences in values between the two classes. Logs classified as first-class yield higher values for quantitative utilisation, averaging 68.83%, while second-class logs show an average yield of 61.55%. This difference illustrates the influence of quality class on the percentage of maximum quantitative yield. First-class logs exhibit favourable taper values, contributing to a higher percentage of quantitative yields and a lower quantity of coarse and fine waste. It can be concluded that quality class significantly impacts the percentage of coarse waste, while its influence on fine waste is negligible.

First-class logs have a greater proportion of lumber obtained from the central zone of the log (41.97%). The higher quality class facilitates a greater yield of the log's central zone, yielding higher-quality lumber suitable for construction and structural purposes with enhanced load-bearing capacities. The lower proportion of lumber from the peripheral zone in first-class logs also indicates greater dimensional stability and reduced deformation and defects during drying. Further research is needed to explore the quality of sawn lumber concerning the log's zone of origin, depending on the log's diameter and sawing pattern.

Practically, the results of this research suggest prioritising first-class logs in practice to maximise yield and profit, especially in the demand for high-quality lumber. For second-class logs, there is potential to increase yield by utilising coarse waste for the production of small wooden elements. First-class logs are suitable for high-quality lumber demand, while optimising the sawing process for second-class logs could meet the demand for lower-quality lumber in larger quantities.

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