

Efficient utilization of pine logs in northern Mexico through training

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Abstract

The timber industry and other sectors that rely on forest management, would benefit from a deeper understanding of the extraction work carried out by properly trained workers. The objective of this research was to evaluate the effect of training operational personnel on the efficient utilization of harvested pine logs in the southern region of the state of Chihuahua, in northern Mexico. Two samplings of the logging present in the cutting area of the ejido Basihuare (communal land) were carried out, taking into consideration the diameter with and without bark, visual quality, length, and use for reinforcement. The sampling involved recording 116 logs prior to a directional felling and log dimensioning training process, and 336 logs divided into three sampling blocks after the training. The data was analysed with tests for variance homogeneity, and ANOVA analyses were performed at a significance level of 0.05. It was found that training forestry harvest personnel allows for an improvement in the process of classifying logs destined for industrial use according to their dimension and visual quality. Additionally, the training allowed for the proper adjustment of reinforcements applied in the log dimensioning process, and as a result, it was possible to efficiently utilize available resources, significantly reducing the generation of waste after resizing of the wood products. For the advancement of the forestry sector, it is necessary to prioritize training as a driving element of quality to raise operational efficiency parameters of production and, consequently, promote the evolution of the production process.

Keywords: ejido Basihuare; log grade; log destination; log reinforcement; training

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Introduction

The forest products industry has entered a state of transition due to multiple factors, including global trade, changes in product demand, and advancements in processing technology (Woodall *et al.*, 2011). Modern forest industries are characterized by their production processes being able to run continuously with very large volumes that flow constantly, forcing companies to use their equipment and raw materials in the most efficient way to achieve high productivity, and therefore better economic returns (Lundahl and Grönlund, 2010). Additionally, the quality of properly sizing the raw material, the type of products demanded by the market, and the experience of the personnel are factors that add complexity to this forestry activity (Lähtinen *et al.*, 2008; Han and Hansen, 2016).

It is a fact that the demand for forest raw materials used as inputs in the industrial sector for the production of various products continues to increase (França *et al.*, 2019; Vititnev *et al.*, 2021; Borz *et al.*, 2021). In this regard, during the processing of lumber, large volumes of fibers are produced in the form of byproducts and solid waste derived from the transformation. However, the growing interest in bioenergy, bioproducts, and carbon sequestration raises questions about the proper disposal of these timber volumes (Blatner *et al.*, 2012) and according to Carvalho *et al.* (2019), some fundamental factors for obtaining the best timber yield from logs are found in intrinsic factors such as species and growth tensions, as well as extrinsic factors like the taper and curvature of the log.

Along the same lines, Cesar *et al.* (2015) mention that the logs from native forests are difficult to size due to the incidence of defects, as well as taper and tortuosity. This dimensional heterogeneity is also caused by the operational capacity of field personnel, as each log must receive an individual treatment in the cutting model, which can prolong and increase the cost of the transformation process. The forestry industry and other sectors that depend on forest harvesting would benefit from a deeper understanding of the extraction work performed by properly trained workers (Xu *et al.*, 2014). For this reason, researchers have used tools to assess to what extent the skills of the workforce match the needs of the industry, as these assessments can help guide training programs by identifying current gaps between industry needs and worker preparedness (Bernsen *et al.*, 2020).

Considering training as a response to the need for companies to have qualified and productive personnel while also improving workers' skills, attitudes, and knowledge, the economic benefits of operational training are highlighted, as well as the benefits of proper conceptualization of the timber-based forest production system (Meza and Solano, 2004). Therefore, training is one of the multiple tools that the forestry industry has to combat incidents and increase productivity (Cabezas and Elgueta, 2018).

For the advancement of the forestry sector, it is necessary to apply methods to improve the parameters of operational production efficiency that can define unconsidered factors that determine the evolution of the production process. Therefore, the objective of this study was to evaluate the effect of operational personnel training on the efficient utilization of harvested pine logs in the southern state of Chihuahua, in northern Mexico.

Materials and Methods

Location of the study area

The study was carried out in the ejido Basihuare (communal land), located in the Central-Western region of the state of Chihuahua, Mexico in the north of the municipality of Guachochi, in the physiographic subprovince of Gran Meseta y Cañones Chihuahuenses of the Sierra Madre Occidental province. The area corresponds to a mixed forest with various species of commercial trees such as *Pinus durangensis* Martínez, *Pinus arizonica* Engelm., *Pinus leiophylla* Schiede ex Schltdl. & Cham., *Pinus strobiformis* Engelm., *Juniperus*

depeana Steud. and *Quercus sideroxyla* Bonpl. (Rascón-Solano *et al.*, 2022). The soils are Chromic Luvisol, Litosol, and Eutric Regosol, with medium to fine texture, the climate is Cb'(w2)x', which corresponds to a semi-cold temperate with an annual average temperature between 10 °C and 13 °C and an annual average precipitation of 586.75 to 673.02 mm (INEGI, 2014).

Characteristics of the logs and sample size

From the cutting areas of the 2021 annual cycle of the ejido Basihuare, 448 randomly selected logs were included in this research, with a fixed initial length of 4.88 meters plus reinforcement (the reinforcement refers to an additional section of the logs that allows protecting the integrity of the wood that will be obtained after the transformation process; in Mexico, the reinforcement is up to 15.2 cm additional in the length of the log); regarding the diameter of the log, most of the logs were intended to have a diameter of 35 cm at the smaller end. It was sought to have a certain some proportionality in the number of logs among the species involved to avoid biases.

The 448 pine logs were divided into two samples: the first consisting of 116 logs measured prior to the training process, and the second composed of 332 logs measured after training the field staff, which were distributed into three sampling blocks (112, 108, and 112 logs, respectively) (Table 1). The sample size was estimated at 87 logs through a pre-sampling of 45 logs of the species *Pinus arizonica*, *P. durangensis*, and *P. leiophylla*. For this purpose, the standard deviation of the length of the sampled logs (0.2382) was used as an estimator of the number of logs needed to achieve a sampling error of 5.00% and a reliability of 95.00% (Barnes, 1968).

Table 1. Characteristics of the observed logs by sampling block

Observation	Group	Species	N	MDwb (cm)		mdwb (cm)		Conicity (cm)		Length (m)		Volwb (m ³)	
				Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Before training	X	<i>P. arizonica</i>	45	38.7	10.1	32.9	8.0	0.58	0.36	5.03	0.07	0.5827	0.32
		<i>P. durangensis</i>	35	41.4	10.1	33.6	7.8	0.43	0.37	5.04	0.07	0.6160	0.33
		<i>P. leiophylla</i>	36	37.2	10.0	31.1	7.8	0.51	0.37	5.01	0.07	0.5051	0.33
After training	A	<i>P. arizonica</i>	30	44.4	10.5	39.0	9.9	0.65	0.35	4.97	0.07	0.8126	0.37
		<i>P. durangensis</i>	43	39.6	10.3	33.6	9.9	0.48	0.33	4.98	0.07	0.5933	0.37
		<i>P. leiophylla</i>	39	39.9	10.2	32.6	9.7	0.49	0.32	4.99	0.07	0.5624	0.37
	B	<i>P. arizonica</i>	50	42.9	10.9	35.6	9.0	0.63	0.37	4.96	0.06	0.6721	0.33
		<i>P. durangensis</i>	38	45.2	11.3	37.6	9.5	0.67	0.37	4.95	0.06	0.7616	0.32
		<i>P. leiophylla</i>	20	40.7	10.8	33.8	9.0	0.63	0.36	4.97	0.06	0.6072	0.32
	C	<i>P. arizonica</i>	24	42.0	10.3	38.9	9.3	0.49	0.36	4.97	0.06	0.7628	0.34
		<i>P. durangensis</i>	36	42.3	10.2	38.2	9.1	0.61	0.35	4.96	0.06	0.7397	0.35
		<i>P. leiophylla</i>	52	46.5	10.3	41.7	9.1	0.73	0.35	4.96	0.06	0.8811	0.35

*Number of observations; MDwb: Major diameter with bark; mdwb: Minor diameter with bark; Volwb: Volume with bark; Sd: Standard deviation.

Methods

Two weeks prior to the training process, the measurement of 116 logs in the felling area was carried out before being loaded and transported to the ejido Aboreachi (neighbouring communal land) sawmill. Previously established parameters by the Dirección General de Normas [DGN] (1988) and Orozco *et al.* (2016) were taken into consideration, those who determine the visual quality of pine logs at least 2.44 meters long, which can range from high quality to class five for logs with a large number of defects. These parameters include the shape of the cross-sectional section of the trunk, eccentricity of the pith, curvature and taper of the trunk, cracks, bulges, tree knots, burns, and insect attacks. Additionally, the logs were classified according to their final

industrial destination, in the case of this analysis, logs intended for sawing of thick diameters. Finally, the parameters used in studies such as those developed by Nájera *et al.* (2011) and Ortiz *et al.* (2016) were also considered, those who recorded the diameters with and without bark and the length of each log. Subsequently, the volume of each log was estimated with and without bark using a software in a desktop analysis. The conicity of the logs was calculated, and the volume and percentage of reinforcement with respect to the log's dimensions were determined. For the latter parameter, logs of 2.44 meters or more were considered, with at least 5.1 cm and a maximum of 10.2 cm of reinforcement, as indicated by Barrera and Cuervo (2010).

Training was provided to 12 members of the ejido, aged between 24 and 49 years old. All participants belong to the indigenous ethnic group "Tarahumara" (also known as Rarámuri). During the training process for personnel who cut and dimension the lumber products, a 30-hour course/workshop was conducted, consisting of six hours of theory where the elements of felling and cutting techniques, the destination of the lumber based on its dimensions, and the procedures for classifying pine logs according to the NMX-C-359-1988 were explained (Dirección General de Normas, 1988). Subsequently, field practices were carried out for a total of 24 hours, in order to apply directional felling techniques, dimensioning, and classification of the logs.

During the sizing practice, correct length sizing of the lumber and proper handling of rollwood reinforcements were considered as the main focus. Two weeks after the course/workshop, data from three sampling groups were recorded, with a total of 112, 108, and 112 pieces respectively. The same parameters from the first analysis were considered to compare both samples and measure the efficiency of the training and skill development of the field personnel from the ejido.

Statistical procedure

The statistical package IBM-SPSS version 25 was used to conduct data analysis and determine results (IBM Corp., 2017). The homogeneity of the variances of the analysed variables was evaluated using Levene's tests at a significance level of $p \leq 0.05$. Subsequently, the data were treated with the Shapiro-Wilk test to determine the normality of the observations ($p \leq 0.05$), when finding normality in the data, an analysis of variance was performed at a significance level of 0.05. The included variables were treated with the Duncan test to compare the means of the levels of a factor at a significance level ≤ 0.05 . The effect of training was taken into account in the classification of the log according to its smaller diameter (for primary sawing purposes), the classification of the trunk based on its visual quality, the adjustment of the reinforcement within a range of 5.1 to 10.2 cm, and the efficiency of the wood dimensioning with respect to the volume of reinforcement.

Results and Discussion

Diameter classification

Based on the analysis of the diameter of the logs, it was estimated that prior to the training process (group X), the average diameter was 32.6 cm, this indicates that the field personnel mix raw materials of varying diameters without adequately considering the size of the logs, this can directly affect the performance of the forestry industries, as stated by Murara *et al.* (2005), the yield is affected by the diameter of the logs as the larger the diameter of the log, the greater the sawing yield. However, studies such as the one developed by Zavala and Hernández (2000) do not attribute a significant increase in sawing yield based on the diameter of the roundwood being larger, in this regard, Robson *et al.* (2021) mention that this phenomenon is mainly associated with the lack of linear increases in the thickness of the studied logs.

After the training process, an increase in the average diameter of the logs selected for primary sawing purposes was achieved, to an average of 36.8 cm, the sampling group A presented an average of 35.1 cm, group B presented 35.7 cm, and group C presented 39.6 cm. Based on the above, the diameter increased by 4.2 cm compared to the first stage of analysis, representing a 12.88% increase in dimensional efficiency. In this regard,

Borz *et al.* (2021) found that increasing the diameters of *Picea abies* and *Abies alba* logs allowed for increased productivity in the industries of Harghita County, Romania, with results ranging from a yield of 38.80% to a maximum utilization (95.00%) for logs with diameters greater than 70.0 cm. According to studies such as that developed by Wang *et al.* (2003), the diameter and quality of the logs are important factors to consider regarding the final destination of the raw material. Meanwhile, Haro *et al.* (2015) indicate that logs with diameters below 35.0 cm can have yields higher than expected in the industry of long dimension wood when used in the industry that manufactures wooden pallets, used for transporting or supporting specific loads. Additionally, Braz *et al.* (2014) and Villela-Suárez *et al.* (2018) state that logs with smaller diameters and residues from wood utilization are potential raw materials for generating bioenergy from biomass, renewable energy sources that have not been considered of interest in northern Mexico.

As shown in Figure 1, the analysed diameters range from 15.0 to 65.0 cm. In general, the bulk of the logs are concentrated between 25.0 to 40.0 cm in diameter. The results show that the training had a significant effect on nine out of the 11 diameter categories recorded in the samplings ($p < 0.05$). Furthermore, it was found that after the field staff training, the smaller diameter logs tended to decrease, indicating that it was possible to classify and distribute the raw material more efficiently towards the sawing process of larger diameters. On the other hand, the logs with diameters of 35 and 45.0 cm did not show significant differences in the percentage proportion of the sample ($p > 0.05$); however, these categories do not pose a specific problem since they are within an acceptable range for the aforementioned purposes.

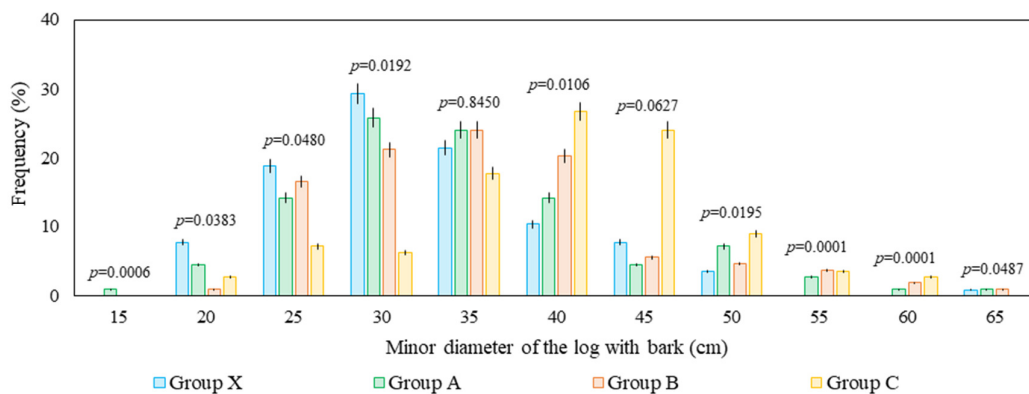


Figure 1. Frequency of the percentage distribution of the smaller diameter with bark of the timber for the pre- and post-training analysis. The upper part of the bars indicates the statistical significance in relation to the analysis of variance test

Visual quality classification of the logs

The visual quality of the roundwood is mainly affected by the conditions of the forest stand since the cutting area of the ejido Basihuare corresponds to a mixed forest in the process of regeneration. Silvicultural, the application of selective cutting to the stand and the absence of tree pruning result in an increase in physical defects in the wood, which leads to diverse visual quality of the raw material.

In this regard, Wang *et al.* (2003) found that heavy thinning in *Taiwania cryptomerioides* plantations results in more and larger knots compared to moderate or no thinning; moreover, pruning allows for a lower number of knots than no pruning. Additionally, Locho *et al.* (2000) indicated that the number and size of timber defects are mainly related to tree pruning and the degree of thinning applied to the forest stand, and these factors have a direct effect on promoting the grade of sawn timber quality in Taiwanese industries.

On the other hand, Monserud *et al.* (2004) argue that curvature and twisting also lead to a greater number of visual defects in roundwood that cause a decrease in sawing yield. Gorges *et al.* (2021), for their part,

attribute the variability of visual quality to the cutting speed of softwoods and the type, quantity, and location of defects present in the logs.

In this study, the number of knots, pith eccentricity, taper of the log, and curvature of the timber were taken into account to analyse the quality of the pieces. It is believed that these intrinsic factors are complemented by extrinsic factors, such as the operator's ability to decide on the longitudinal location for making cuts on the log, thus increasing the volume of higher quality wood destined for primary sawing.

Based on the above, it was found that training for forestry personnel has a significant effect on four of the six classes of 4.88 m long roundwood. Primarily, it was possible to increase the volume of high-quality wood and class 1 wood by up to 60.06% ($p \leq 0.05$), which would represent an increase in the production of high-grade sawn wood (Figure 2); on the other hand, the proportion of lower classes of logs (quality 4 and 5) was significantly reduced, with a reduction of 37.12 and 29.95% respectively, which allows for a reduction in volumes of low-quality sawn wood. The results are similar to those described by Orozco *et al.* (2016), who found that the highest sawing yield for select class wood was recorded for high-quality logs, and high volumes of low-quality sawn wood are associated with a greater number of defects in the logs.

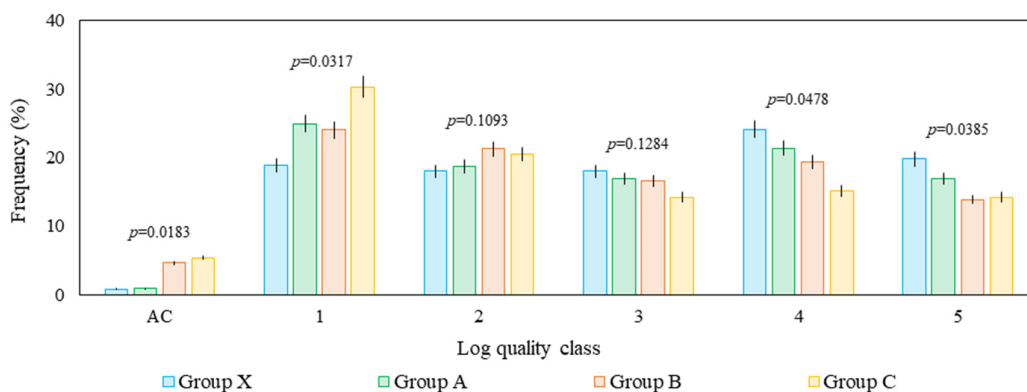


Figure 2. Frequency of the percentage distribution of visual quality classes of roundwood for the pre-training and post-training analysis. The upper part of the bars indicates the statistical significance in relation to the analysis of variance test

Efficient reinforcement adjustment in roundwood

The average length of logs prior to training was 5.03 m (group X), which was found to be higher than the average length after training by 7.1 cm, equivalent to 1.42%. This indicates that the reinforcement applied to the logs was higher in the first sample, possibly due to lack of information required by the personnel. This condition represents an inefficient use of raw materials due to an excess of reinforcement in the sawn pieces.

According to Wade *et al.* (1992) and Lin *et al.* (2011), the yield of logs in the sawing process is affected by length. Therefore, one way to increase the volumetric yield is by optimizing the dimensioning of the pieces, producing sawn wood of required dimensions (Fernando-Egas *et al.*, 2001). According to Sessions (1988) and Garland *et al.* (1989), the use of optimization programs for log cutting allows for logs with favourable characteristics to be obtained, which can increase the primary wood processing efficiency in sawmills.

Erber *et al.* (2020) state that chainsaw dimensioning does not have technological support, and therefore, volume recovery depends on the competency of the chainsaw operator; for this reason, the use of mobile devices such as the "T4E Bucking App" can help maximize cutting accuracy, as the application was found to have superior accuracy compared to experienced operators. However, Wang *et al.* (2009) and Akay *et al.* (2010) mention that the use of technological equipment may not necessarily surpass the skills of a properly trained operator. Therefore, it is necessary to explore available alternatives to increase efficiency in log cutting.

The results on the evaluation of reinforcement and its proportion with respect to log length showed a significant decrease ($p = 0.0001$) based on the increase in chainsaw operator capabilities. Prior to training, the excess reinforcement had an average of 2.40% (11.7 cm) above the maximum acceptable range. However, the maximum value was up to 7.92% higher (38.8 cm), which means that the logs could produce pieces of approximately 5.18 m in length, a dimension that has not been recorded in other Mexican research studies.

On the other hand, the minimum values reached up to 3.68% (17.9 cm) below the nominal dimension, a result that indicates that the sawn wood would have to be reduced to 4.27 meters (14 feet) in length, mainly due to the absence of markets for odd dimensions, as indicated by Rascón-Solano *et al.* (2020) and Rascón-Solano *et al.* (2022).

Furthermore, it was demonstrated that training the forest harvesting personnel allows for proper adjustment of the reinforcements applied in the longitudinal cuts of the sawlogs (Figure 3), since the average reinforcement values were within an acceptable range (5.1 to 10.2 cm). This result indicates that the loss of raw material during the transformation process will be minimized and the activity will be more efficient. These results are consistent with what is described by Wang *et al.* (2004), who indicate that experienced chainsaw operators or those from a professional training background can achieve optimal cutting patterns. In this context, Olsen *et al.* (1991) emphasize the importance of developing the competencies of field personnel, at least with knowledge of the rules for grading and dimensioning round wood.

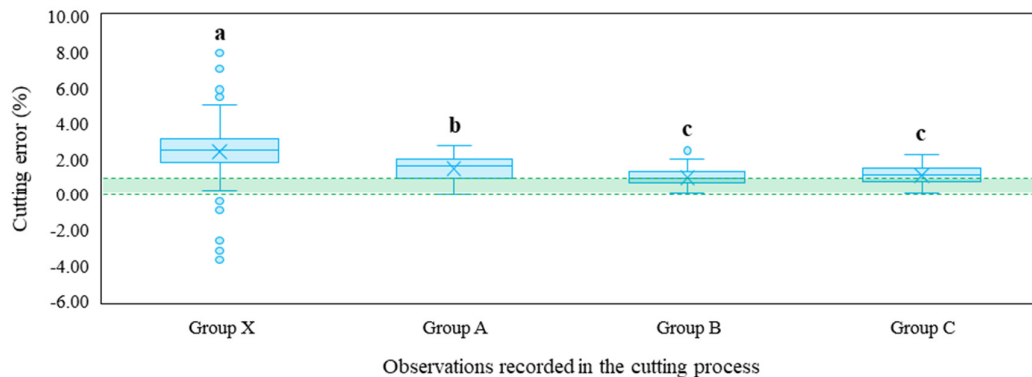


Figure 3. Percentage of reinforcement with respect to log length in pre- and post-training analysis. The green band indicates the range of acceptable cutting error in relation to the reinforcement of the logs, groups with the same letters are not significantly different ($p > 0.05$) in relation to Duncan's mean separation test

Volumetric proportion of reinforcement with respect to log volume

Sawmills and other manufacturers of wood products produce large amounts of woody biomass in the form of cut-offs, wood chips, sawdust, shavings, and bark, collectively referred to as industry waste or solid waste (Kim *et al.*, 2015).

According to the findings of this study, excessive reinforcement of log length prior to the training process resulted in up to 6.08% of the total log volume being generated in the form of solid waste or debris. Additionally, negative results were obtained, indicating that some logs and their corresponding wood products did not meet the expected nominal dimension of 4.88 m, with values ranging from -3.04 to -0.32% outside an acceptable range in relation to the desired log length, as previously mentioned, this leads to volumetric loss, which causes a reduction in industrial productivity, as noted by Caldera and Amarasekera (2015), who attribute these wastes to the inefficiency in the utilization of wood resources, which have been identified as one of the primary factors affecting low profitability and productivity.

On the other hand, Himandi *et al.* (2021) have highlighted that inefficiency and waste in timber production can be addressed through training interventions in the areas of harvesting and industry. In this sense, the effect of training the field personnel in the ejido Basihuare allows for a mean reduction in volume that will be transformed into solid waste by 0.90%, with a maximum value of 2.13% relative to the total volume of the log.

This result coincides with what was found by Olandoski *et al.* (1997) and Barbosa *et al.* (2014), who indicate that the proportion of waste resulting from longitudinal excess cutting of the log is approximately 3.00% of the total volume without considering the bark. Figure 4 shows that through training and technical preparation of personnel who carry out the felling and dimensioning of the timber, it is possible to reduce the volume of waste that will be wasted in the processing of raw material in a significant proportion ($p = 0.0001$).

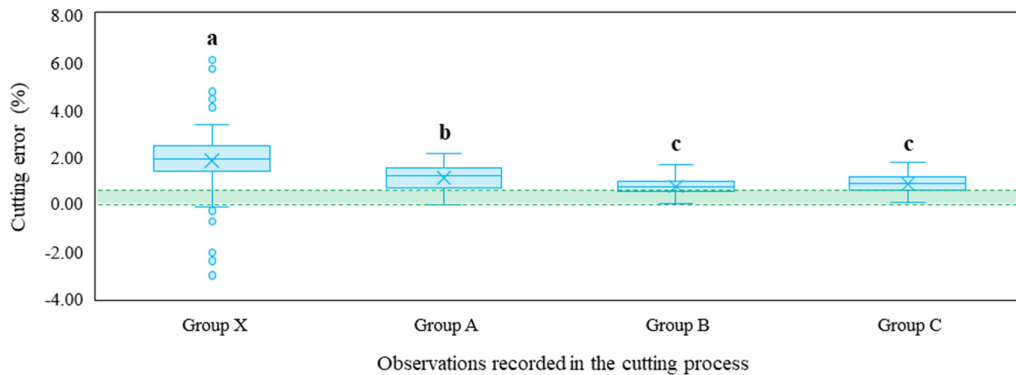


Figure 4. Reinforcement volume relative to total log volume in the pre- and post-training analysis. The green band indicates the range of acceptable cutting error in relation to the reinforcement of the logs. groups with the same letters are not significantly different ($p > 0.05$) in relation to Duncan's mean separation test

Finally, it is necessary to conduct analyses where it is possible to identify if the factor of reducing and adjusting reinforcements in pine lumber significantly increases the productivity of timber industries. Additionally, it is imperative to direct forest industrial activity towards sustainability, with the recovery of raw materials that can be directed to other industrial destinations such as cellulose generation, fiberboards, and bioenergy (Barbosa *et al.*, 2014; Braz *et al.*, 2014; de Araújo *et al.*, 2021).

Conclusions

The results show that the training had a direct effect on a large part of the diameter categories recorded in the samplings. Likewise, it was found that after the field personnel training, the logs of smaller diameters tended to decrease; therefore, it was possible to classify and distribute the raw material more efficiently for the sawing process of larger diameters. It was found that the training of the forest extraction personnel has a significant effect on four out of the six classes of 16-foot log wood. It was also possible to increase the volume of high-quality and class 1 wood and decrease the proportion of lower-class trunks, factors that, together, allow the reduction of volumes of low-quality sawn wood.

Training of forest harvesting personnel was demonstrated to enable the appropriate adjustment of reinforcements applied in the dimensional cuts of timber. This result indicates that the loss of raw material during the transformation process will be minimized, and the activity will be more efficient. By training and technically preparing personnel who carry out felling and sizing activities of timber, it is possible to reduce the volume of waste that will be discarded during the processing of the raw material significantly.

To advance the timber industry, it is necessary to apply methods to increase operational efficiency parameters of production and, consequently, promote the evolution of the production process. Additionally, it is imperative to direct forest industrial activity towards sustainability, with the recovery of raw materials and waste that can be directed towards other industrial destinations.

Authors' Contributions

Conceptualization of the research idea, designing the experiment, and writing-original draft preparation, J.R.S.; formal analysis, validation and discussion, O.A.A.C. and J.A.N.L.; resources, data curation and writing-review and editing, E.A.R., J.J.P. and E.J.T.G.; supervision, J.R.S. and J.A.N.L. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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