Influence of Storage Time and Log Length on the Distribution of Wood Chip Size

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Chip size distribution is important in kraft pulping, as it affects chemical use, quality, and yield in pulp production. *Pinus taeda* logs with two storage periods (0 and 2 weeks) and two log lengths (2.4 and 7.0 m) were processed with a disc chipper. Logs stored for two weeks produced chips with 7% less moisture than logs with no storage period. The storage period significantly influenced the quantities of overthick, accept, pin, and fines classes. Logs stored for two weeks produced 1.7% more overthick, 3.8% more pin, and 1.1% fines than logs with no stocking period. Consequently, the amount of accept produced was 6.2% higher for chips from processing freshly harvested logs. Log length influenced the produced quantities of oversize, overthick, and accept. Logs with a length of 2.4 m produced chips with 1.4% more oversize, 2.5% more overthick, and 4.6% less accept, compared to 7.0 m logs. Thus, it was concluded that *Pinus taeda* logs with shorter storage periods and longer lengths generate more chips in the "accept" class.

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Keywords: Pinus taeda; Log storage period; Log length; Chip size distribution

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INTRODUCTION

In 2020 the planted forest sector in Brazil reached the mark of 9.55 million hectares for industrial crops, representing a growth of 17.6% compared to 2019. The pulp sector is responsible for much of this growth, having in the period between 2009 and 2020, increased production by 57.5% (IBÁ 2021). In 2020, Brazil consolidated itself as the second largest pulp producer in the world, only behind the United States of America (USA), which highlights the importance of this product for the forestry sector and the country's economy (IBÁ 2021).

The industrial transformation of wood into chips is completed in the Wood Yard, from a set of in-line equipment, with the system being fed with materials of different characteristics and quality. The chipping process in the pulp industries in Brazil, most of the time, is completed by disc chippers (Brannvall 2009).

Regarding the chip quality for chemical pulping, the objective is to obtain pulp with high yield, through the formation of chips of uniform size, which are completely impregnated with the cooking liquid (Pulkki 1991). Some other characteristics are considered important, such as: moisture content, species, thickness, basic density, seasonal variation, and bark content (Bergman 1985). Poor wood quality results in more shives in the pulp, yield losses, increased chemical costs, and increased variability of the mill processes (Timmerfos *et al.* 2019). For the purposes of this study, chip quality refers to size distribution, *i.e.*, percentage of oversize, overthick, large accept, small accept, pin, and fines.

Freshly harvested logs lose moisture while in storage either in the plantation, at roadside, or at the mill (Röser *et al.* 2011). However, it is important to point out that moisture content is strongly affected by seasonality, air temperature, and humidity, which vary from place to place, and between time of the year. Stack geometry, orientation to sun and wind, locality, and individual log exposure will either accelerate or inhibit the rate of log drying (Salin and Gjerdrum 2009; Defo and Brunette 2007; Persson *et al.* 2002). Previous studies have investigated the impact of moisture content (MC) on chip size distribution. Van Der Merwe *et al.* (2016), investigated the influence of two pulp log drying periods (1 and 2 weeks) on moisture content and chip size distribution when chipping eucalyptus pulp logs. As result, it was observed that moisture content was lower for chips produced from logs dried for 2 weeks than chips produced from logs dried for 1 week. The results also show that the drying period had a significant impact on the chip size distribution. Thus, logs dried for 1 week produced less overthick and accepts chips than logs dried for 2 weeks.

Log length also has an effect in chip size distribution, Twaddle (1997), when analyzing wood characteristics that affect chip thickness, under laboratory conditions, demonstrated that orientation of wood growth rings in relation to chipper knife influenced chip thickness. Chips formed with knife tip oriented tangentially to wood growth rings were thicker than those where the growth rings were oriented radially to the knife. This demonstrates that log orientation, when entering the chipper, affects chip quality, leading to the implication that this is due to the frequency that the knives find a zone of weakness in wood.

Considering the importance of chip quality for pulping in the kraft industries, which are part of an increasingly strong productive sector at the national and international level, and knowing that most of the studies carried out in this area are on laboratory scale, it is very important to conduct studies demonstrating factors that affect this parameter on industrial scale. Thus, under the hypothesis that the raw materials characteristics alter the chips final quality, it is possible to perform analysis for chip size to analyze how these variations influence the final product quality.

EXPERIMENTAL

Materials

For the experiment, approximately 148 tons of *Pinus taeda* logs were chipped, corresponding to four trucks. Logs were harvested at the age of 10, during the winter, in the region of Três Barras, Santa Catarina, Brazil. The chip samples were collected on the company's chipping line, shortly after leaving the chipper, before passing through the classifying sieves. For each load, three samples with the approximate weight of 3 kg for each were collected at three different processing moments: one at the beginning, one in the middle, and one at the end of the load. This ensured that the repetitions were completed inside the loads.

The samples were divided into green - without storage time - and dry - with storage time. Samples without storage time were collected from loads that came directly from the forest to the processing line. The loads with storage period were chosen from piles that had already been stored for two weeks. The stored logs were kept in an open yard, with good ventilation, for two weeks in July (winter). The weather was cold, with temperatures ranging between 2 and 24 °C. The average precipitation for the month of July is 130 mm, with winter being the driest time of year.

During the processing, chipping parameters were kept constant (Table 1).

Table 1. Basic Parameters of Chipping Process

Knife Processing Time	0 to 3 h
Number of Knives	18
Sharpness Angle	35°
Chipper Rotation Speed	277 rpm
Feeding Speed	1.7 m/s
Capacity	300 to 500 m^3 sub / h

The study tested four treatments, mixing two lengths of wood with two storage times (Table 2).

Table 2. Treatments Tested in the Study

Treatment	Storage Time	Log Length
1	0 Weeks	2.4 m
2		7.0 m
3	2 Weeks	2.4 m
4		7.0 m

Chip Classification

The chip classification was made following the SCAN-CM 40:01 (2001) standard, which is a Scandinavian method for the distribution of wood chip sizes for pulp production. The equipment used was the Chip Classifier (TCLT; Tecnomeca, Caieiras, SP, Brazil), which separates the sample into six classes, described on the left in the figure below:

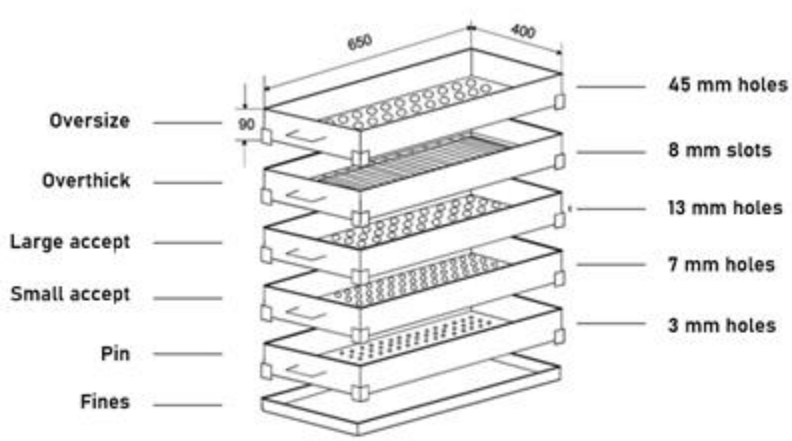

Fig. 1. Chip classifier and chips classes

Moisture Content

Moisture content was referenced based on its wet weight. For determination of chip moisture, samples of 300 g were collected from each repetition of the study. These samples were then dried in an oven at a temperature of 110 ± 5 °C until reaching a constant weight (minimum 15 h), following the methodology used by the company.

After drying, the samples were weighed again, and the moisture content (MC) was calculated using Eq. 1,

$$U\ (\%) = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

where U (%) is moisture content on a wet basis, M_i is initial mass (g) of the wet sample, and M_f is final mass of the dry sample (g).

Statistical Analysis

An analysis of variance (ANOVA), at 5% significance, was performed for each of the response variables obtained. That is (i) moisture content; (ii) percentage of oversize; (iii) percentage of overthick; (iv) percentage of large + small accept; (v) percentage of pin; and (vi) percentage of fines. To facilitate the analysis of the results, the classes Small Accept and Large Accept were combined and named "Accept".

The objective was to analyze if there was any significant variation between samples of different treatments, *i.e.*, to demonstrate how log length and storage time influence chip size distribution after chipping. The data were analyzed in Excel software (Microsoft, Version 2209, Redmond, WA, USA).

RESULTS AND DISCUSSION

Moisture Content

The storage time influenced the moisture content of the chips. Logs with no storage time obtained an average moisture content 7% higher than the average for logs stored for two weeks (Table 4).

Table 3. Variance Analysis for Chip Moisture

Source Variation	GL	QM	F
Storage time	1	147.7008	43.83 *
Length	1	8.8408	2.62 ns
Storage time × Length	1	7.2075	2.14 ns
Waste	8	3.3700	
Total	11	-	
Average (%)	59.3		
CV (%)	7.02		
GL = degree of freedom, QM = average square, F = calculated F-value, * = significant at 5% probability, ns = not significant			

In addition, it was observed that the moisture content variation for the period of two weeks was greater than at zero weeks (Fig. 1). This indicates that moisture is influenced by several factors, and, over time, the interaction of these factors, such as variation in rainfall, wind, pile arrangement, results in greater variations in logs moisture.

Elloumi *et al.* (2021) concludes that the moisture content significantly affects the size distribution of chips.

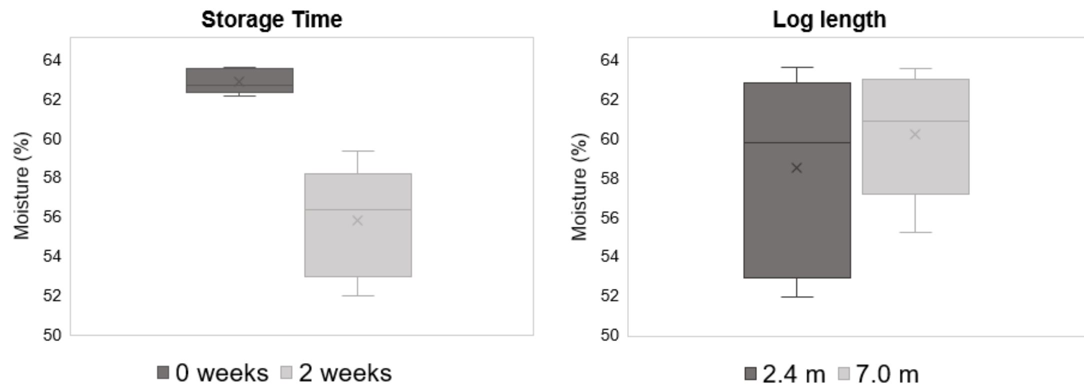

Fig. 2. Chip moisture averages for storage time and log length

In contrast, log length, with a value p = 0.14 and F less than critical F, did not influence the moisture content of the chips (Table 3). Despite this, there was a behavior to be analyzed. For wood without storage time, there were no significant differences in moisture content between the treatments of short size wood and long size wood (variation of 0.2%). However, for wood stored for two weeks, it was observed that short wood lost 3.2% more moisture than long wood (Table 4). This may be an indication that short wood will show higher drying rates when there is a significant storage period, which is in accordance with studies that demonstrate that drying rates increase with decreasing log size (Connel 2003; Defo and Brunette 2007), because there is more relative surface area for drying in logs with shorter length.

Table 4. Moisture Content Averages for Different Treatments

Storage Time	Length (m)	Moisture content (%)
0 weeks	2.4	62.7 (0.78)
	7.0	62.9 (0.56)
2 weeks	2.4	54.2 (2.87)
	7.0	57.4 (2.07)

Chip Classification

For the class oversize, it was observed that only log length significantly affected the amount of chip generated, and short logs produced 1.3% more oversize than long wood (Table 5). This behavior can be explained based on previous studies, which show that gravity feed chippers produce higher amounts of large chips, compared to horizontal feed chippers (Twaddle and Watson 1992a,b; Nati *et al.* 2014). The authors suggest that this occurs because the logs have highly variable orientations during chipping in chippers with gravity feeding. The same effect explains the greater generation of oversize on horizontal feed chippers fed with short wood. The short wood has a smaller support surface and tends to cross during feeding, meeting the chipper knives in highly varied angles, with produces chips with larger sizes.

Table 5. ANOVA F-Values for Chip Size Distribution

Source Variation	Oversize	Overthick	Accept	Pin	Fines
Storage time	1.88 ns	23.03 *	39.41 *	50.25 *	11.98 *
Length	16.13 *	48.93 *	21.75 *	0.65 ns	0.56 ns
Storage time × Length	2.12 ns	2.78 ns	1.28 ns	1.76 ns	0.87 ns
Average (%)	1.85	5.92	84.41	5.55	2.26
CV (%)	51.4%	29.1%	5.1%	39.2%	34.3%
* = Significant at 5% probability, ns = not significant					

The individual effects of both length and storage time resulted in significant differences in the amount of overthick (Table 5). Logs stocked for two weeks generated 1.7% more overthick than logs without a storage period (Table 6). Similar results were found by Elloumi *et al.* (2021), in which conditions of lower moisture content resulted in thicker chips, especially at higher sub-zero temperature. The same behavior was observed by Watson and Stevenson (2007) in a study that analyzed the influence of wood moisture on the size of chips produced from both hardwood and softwood. In this study, the authors observed that when the moisture content of wood is high, it will be less rigid and more plastic and malleable. The friction between the wood and the cutting tool is a crucial factor for chip formation, and deformations in the vicinity of the cut lead to thicker chips because of the damage to the log surface. In wetter wood, mechanical forces are better distributed during chipping, which leads to less damage to the log surface. Thus, when it meets the cutting tool, there is less chance of cracks occurring in the log outside the cutting area, which would generate thicker chips.

The length of the wood, among the two variation factors analyzed, was the one that most influenced the amount of overthick chips generated. Longer logs generated 2.5% less overthick than shorter logs (Table 7). It can be said that the 2.4 m wood class consists mainly of top wood from the trees, as the base wood (with larger diameters) is sold for other purposes such as sawmills and lamination. This particularity should be observed because studies suggest that chip production with higher thicknesses is related to wood quality defects, such as irregular grain and knots (Bjurulf 2006; Cáceres *et al.* 2016). Along with this particularity, it should be noted that studies conducted with softwoods have proven that the portions of the log with smaller diameters (top of the trees) have greater amounts of knots (Cáceres *et al.* 2016a,b; Zolotarev *et al.* 2020). Therefore, it can be said that the knot content increases proportionally with the height of the tree, which would explain the greater production of thicker chips for top logs.

Logs stored for two weeks produced significantly more pins compared to logs without a storage period (7.5% and 3.7%, respectively), as well as fines (2.8% and 1.7%, respectively) (Table 6). This result agrees with the observation made by Brännvall (2009) and Timmerfors *et al.* (2021) that woods with a high dry matter content produce higher percentages of pins and fines. Because the surface wood dries faster than the innermost portions of the logs, as the surface/volume ratio increases (which can be observed in shorter logs), the amount of surface portions with higher drying rates increases, which leads to larger portions of excessive dry wood and, consequently, greater amount of pin and fines produced. This occurs in the shorter logs, as they correspond to the apical portions of the tree, which have smaller diameters.

As for the accepts, it can be said that the percentage of chips produced for this class during chipping is a function of the percentage of the undesirable size fractions produced. A higher percentage of chips in the oversize, overthick, pin, and fines classes resulted in a lower amount of accepts. Logs stored for a longer period produced higher percentages of overthick, pin, and fines (Table 6), which resulted in a 6.2% lower production of accepts; the only class that did not present such behavior was oversize, on which the variable storage time had no significant effect.

The same trend was observed when the classification results for the log length parameter individually (Table 7) were analyzed. Short logs produced chips with a higher amount of oversize and overthick, which resulted in a significantly lower amount of chips produced on the accept class compared to the amount of the same class produced from long logs.

Table 6. Averages of Each Class of Chips Produced from Logs with Different Storage Periods

Log Storage Time	Variable				
	Oversize (%)	Overthick (%)	Accept (%)	Pin (%)	Fines (%)
0 weeks	2.1 (1.06) a	5.1 (1.09) a	87.5 (2.23) a	3.7 (0.90) a	1.7 (0.35) a
2 weeks	1.6 (0.85) a	6.8 (1.88) b	81.3 (3.62) b	7.5 (0.99) b	2.8 (0.68) b

Values in parentheses correspond to the standard deviation;
Average values followed by different letters in the same column indicate significant differences at the 5% probability level.

Table 7. Averages of Each Class of Chips Produced from Logs With Different Lengths

Log length (m)	Variable				
	Oversize (%)	Overthick (%)	Accept (%)	Pin (%)	Fines (%)
2.4	2.5 (0.61) a	7.2 (1.49) a	82.1 (4.44) a	5.8 (2.62) a	2.4 (0.95) a
7.0	1.2 (0.69) b	4.7 (0.68) b	86.7 (2.92) b	5.3 (1.86) a	2.1 (0.62) a

Values in parentheses correspond to the standard deviation;
Average values followed by different letters in the same column indicate significant differences at the 5% probability level.

CONCLUSIONS

1. The variable storage time significantly influenced the results of moisture content and percentage of all chip classes (except the amount of oversize).
2. The log length influenced only the classes of oversize, overthick, and accepts, not resulting in significant differences for percentage of pin and fines.
3. No significant interactions were observed between storage time and log length for any of the variables analyzed.

4. *Pinus taeda* logs with shorter storage time (higher moisture content) and longer length generated better quality chips, considering good quality chips that have a higher percentage of weight in the accept class and a lower percentage in the oversize, overthick, pin, and fine classes.

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