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Original Article

Quality analysis of tropical wood sawing in Cabinda, Angola

Análisis de la calidad del aserrado de maderas tropicales en Cabinda, Angola

Análise da qualidade do serrado de madeiras tropicais em Cabinda, Angola

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ABSTRACT

The work has been carried out in the Amorim sawmill, located in the city of Cabinda, province of Cabinda, Angola; having as objective the application of statistical control during the mechanical processing of the wood to increase the quality and the yields of sawn wood of the species *Baillonela toxisperma, Erythrophleum ivorense, Entandrophragma angolense and Sarcocephalus diderrichii* de Wild e Th. Dur. Defects present in 100 logs per species are determined to define the quality and strategy to improve the use of wood as a raw material. The Control program is applied to increase the dimensional quality of the sawn timber based on the analysis of the average dimensions obtained and the variation of cut in the sawmill. Eccentricity and ovality are the two defects that present the greatest magnitudes in the analyzed logs, being the Entandrophragma angolense logs the ones that present the lowest quality levels. According to the average thickness values for the pieces represented, values are shown for the three species, above the established final dimension (25 mm), with variations greater than 1.5 mm, representing a considerable loss of sawn wood, which implies the need to develop the statistical control process in the sawmill. It is established that the use of the Control program to determine the optimal dimensions of sawn wood, as well as the construction of control charts, constitutes an adequate tool to take decisions aimed at increasing the quality of sawn wood.

Keywords: quality; logs; defects; timber.

RESUMEN

El trabajo se ha realizado en el aserradero Amorim, ubicado en la ciudad de Cabinda, provincia de Cabinda, Angola; teniendo como objetivo la aplicación del control estadístico durante el procesamiento mecánico de la madera para elevar la calidad y los rendimientos de madera aserrada de las especies *Baillonela toxisperma*, *Erythrophleum ivorense*, *Entandrophragma angolen*se y *Sarcocephalus diderrichii de Wild e Th. Dur.* Se determinan los defectos presentes en 100 trozas por especie para definir la calidad y la estrategia para mejorar el uso de la madera como materia prima. Se aplica el programa Control para incrementar la calidad dimensional de la madera aserrada a partir del análisis de las dimensiones promedio obtenidas y la variación de corte en el aserrío. La excentricidad y la ovalidad son los dos defectos que presentan las mayores magnitudes en las trozas analizadas, siendo las trozas de *Entandrophragma angolense* las que presentan los menores niveles de calidad. De acuerdo con los valores medios de grosor para las piezas representadas se muestran valores para las tres especies, por encima de lo establecido como dimensión final (25 mm), con variaciones mayores a 1,5 mm, representando una considerable pérdida de madera aserrada, lo cual implica la necesidad de desarrollar en el aserrío el proceso de control estadístico. Se establece que el empleo del programa Control para la determinación de las dimensiones óptimas de madera aserradas, así como la construcción de gráficos de control, constituye una herramienta adecuada para tomar decisiones dirigidas a aumentar la calidad de la madera aserrada.

Palabras clave: calidad; trozas; defectos; madera aserrada.

SÍNTESE

O trabalho foi realizado na serração Amorim, localizada na cidade de Cabinda, província de Cabinda, Angola; tendo como objectivo a aplicação de controlo estatístico durante o processamento mecânico da madeira para aumentar a qualidade e o rendimento da madeira serrada das espécies Baillonela toxisperma, Erythrophleum ivorense, Entandrophragma angolense e Sarcocephalus diderrichii de Wild e Th. Dur. Os defeitos presentes em 100 toras por espécie são determinados para definir a qualidade e a estratégia para melhorar a utilização da madeira como matéria-prima. O programa de Controle é aplicado para aumentar a qualidade dimensional da madeira serrada com base na análise das dimensões médias obtidas e da variação de corte na serraria. Excentricidade e ovalidade são os dois defeitos que apresentam as maiores magnitudes nos toros analisados, sendo os toros Entandrophragma angolense os que apresentam os menores níveis de qualidade. De acordo com os valores médios de espessura das peças representadas, são apresentados valores para as três espécies, acima da dimensão final estabelecida (25 mm), com variações superiores a 1,5 mm, representando uma perda considerável de madeira serrada, o que implica a necessidade de desenvolver o processo de controlo estatístico na serração. Está estabelecido que a utilização do programa de Controlo para determinar as dimensões óptimas da madeira serrada, assim como a construção

de cartas de controlo, constitui uma ferramenta adequada para a tomada de decisões destinadas a aumentar a qualidade da madeira serrada.

Palavras-chave: qualidade; toros; defeitos; madeira serrada.

INTRODUCTION

The forest sector, both in Angola and the rest of the world, is obliged to modernize and diversify the forest industry in order to contribute to the development of indispensable services that constitute the rights of all society as a whole. Therefore, the application or implementation of statistical control of the sawing process is an effective tool, coinciding in this sense with the work developed by Ãlvarez *et al.,* (2017); Hernández and Da Silva-Porto filipe, (2016) and Mulat *et al.,* (2017).

The control of the quality of the wood is a problem in Angola, which determines the importance of carrying out research that improves the management of the wood and the acquisition of new sawing technologies.

Quality control is defined as the system of production methods that economically generates quality goods or services, in accordance with consumer requirements. Modern quality control uses statistical methods and is often referred to as statistical quality control (Denig, 1990).

To practice quality control is to develop, design, manufacture and maintain a quality product that is capable of satisfying the consumer. To achieve this goal, everyone in the company must promote and participate in quality control. On the other hand, quality control refers to a process or a set of operational activities and techniques that are used to meet quality requirements (Mulat *et al.,* 2017); Nassur *et al.,* (2013), considering the development of a strategy in the sawmill that takes into account the quality of the logs used, as well as the implementation of quality control models for sawn timber, with the possibility of increasing the efficiency of the production process.

Taking into consideration the above mentioned elements, the aim of the present work is to apply statistical control during the mechanical processing of wood in order to increase the quality and yield of sawn timber.

MATERIALS AND METHODS

Working conditions

The work was carried out at the Amorim Sawmill, located in the city of Cabinda, in the province of Cabinda, located in the north of the territory of the Republic of Angola (Figure 1).

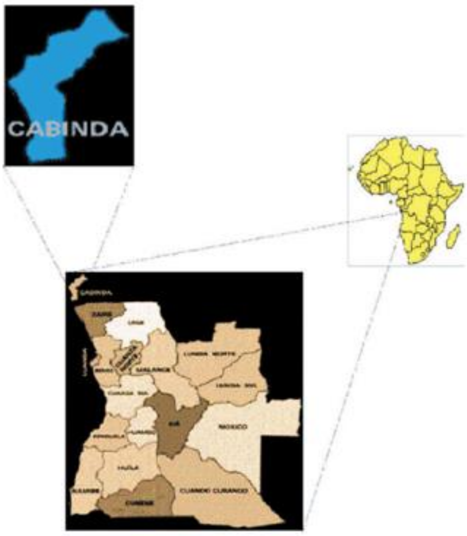

Figure 1. - Location of Cabinda in Angola
Source: Bauza *et al.,* (2006)

Determination of sample size and sampling intensity

Data were taken from a population of 100 logs for the species *Baillonella toxisperma* (Moabi), *Erythrophleum ivorense A. Chev (N'Kassa), Entandrophragma angolense (Tiama*) and *Sarcocephalus diderrichii* de Wild e Th. Dur (Ngulo Mazi) from the Maiombe forest, to determine the number of representative units for the study, having as a variable of interest the diameter at the base of the logs; to determine the number of representative units for the study, from the equation exposed by Chacko, (1965), Freese (1967) and Dovie, (1972), cited by Zavala and Hernández, (2000) (Equation 1).

$$n = \frac{t_{\alpha}^{2} * S^{2}}{E^{2}} \quad (1)$$

In which:

n- sample size;
$t^2 \alpha$- tabular value of t with (n-1) degrees of freedom;
S^2-estimated variance;
E^2- permissible error.

Therefore, the final result, according to the above mathematical expression, is defined as 40 logs, so the 100 used in the test are maintained, which can be seen in Figure 2, at the Amorim sawmill in the city of Cabinda; this represents a higher sample value than that set out in the research carried out by Garcia *et al.,* (2012), using only three samples per species (Figure 2).

Figure - 2. Log storage at Amorim sawmill in Cabinda, Angola

Determination of log defects

a) Conicity

To determine the conicity of the logs, the formula used by Riesco *et al.,* (2013), Missanjo and Magodi (2015), Ortiz *et al.,* (2016) and Kozakiewicz *et al.,* (2018) was applied (Equation 2).

$$Con = (D_2 - D_1)/L \qquad (2)$$

Where:

Taper, cm /m;
D_1-lesser diameter of the log, (cm);
D_2- largest diameter of the log, (cm);
L - length of the log, (m)

b) Eccentricity

To determine the eccentricity of the pith, the geometric center was located in the final cross section of each log and the distance from the pith to the center of the same cross section was measured (Figure 3).

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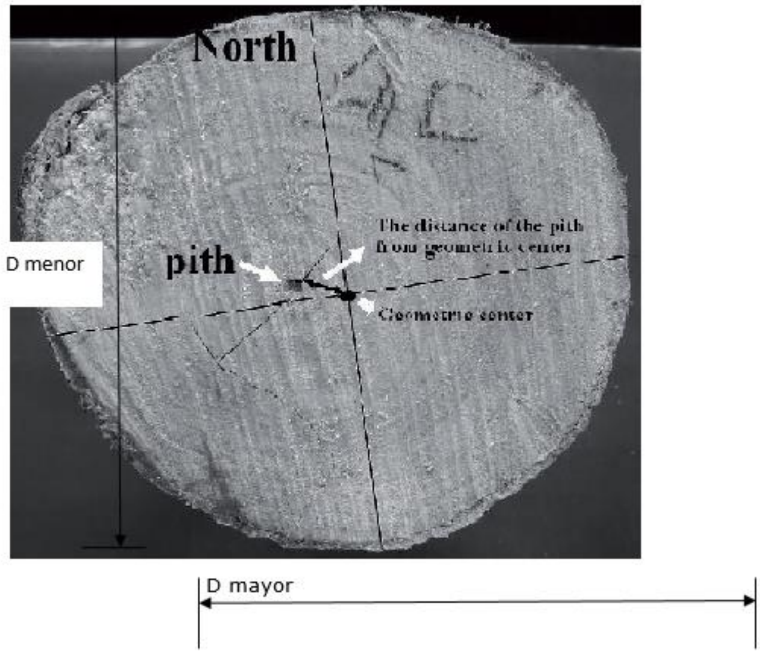

Figure - 3. Cross section of the log to determine the geometric center
Source: Moya *et al.,* (2008)

La excentricidad de la médula fue calculada mediante la ecuación expuesta a continuación según Blanco *et al.*, (2014) (Equation 3).

$$E_x = \left(\frac{(Lc)}{dm}\right) x\ 100 \qquad (3)$$

Where:

Ex-eccentricity, *L*
c- distance between the geometric center and the actual position of the pith, *m*;
dm- mean diameter of the log, *m*.

c) Ovality

The determination of the ovality of logs can be determined from the following mathematical expression used by Álvarez *et al.,* (2013) and Riesco *et al.,* (2014) (Equation 4).

$$O_v = (D_{max} / D_{min}) * 100 \qquad (4)$$

Where:

Ov- ovality, %;
d_{max}- maximum log diameter, m;
d_{min}- minimum log diameter, m.

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The SPSS.15 program is used for statistical processing of the data obtained, in order to obtain the average values, as well as the main statistics that characterize the results obtained. In this way, it will be possible to define the quality of the logs according to the Brazilian standard for the classification of foliage wood logs of 1984.

Determination of sawing variation from the implementation of statistical control of the sawing process

To carry out the relevant analysis, at the Amorin sawmill, 100 sawn pieces were taken for each of the Muabi, N'Kassa and Tiama species, with the same nominal dimensions, taking into consideration the methodology used by Leyva *et al*., (2017).

Six measurements were taken on each piece of sawn wood, three on each edge, equidistantly along the edges, taking care to establish a permanent sequence of measurements with respect to the direction of exit of the pieces from the saw, in order to identify any problems with the equipment. The measurements are made with a caliper up to the precision of a tenth of a millimeter, in areas of healthy wood, avoiding knots, rotting and other defects.

Due to the complexity and volume of the calculations, especially in calculating thickness variations in the sawmill when a large sample is available, it was necessary to find an agile and feasible tool for processing the data (Sundholm, 2015).

For this purpose, the Control software version 5.1 was used, which allows the determination of the optimal sawing dimensions; as well as the determination of the variation in thickness, which is based on the formulation proposed by Brown, (1986) for the calculation of the optimal dimension of the assortment and other parameters that we will now describe (Equation 5); (Equation 6); (Equation 7) and (Equation 8).

Calculation of the optimal dimension (Do)

$$D_o = \frac{DF+TC}{(1-\%C)} + Z * St \qquad (5)$$

Where:

Do- optimum green wood cutting dimension, mm;
DF- final dimension, mm;
TC- planing tolerance on both sides of the assortment, mm;
C- shrinkage tolerance of the wood,
%; *Z*- minimum acceptable dimensional factor (dimensionless);
St- total sawing variation, mm

$$St = \sqrt{Sd^2 + Se^2} \qquad (6)$$

Where:

Sd- standard deviation of the sawing process within the pieces (mm);
Se- standard deviation of the sawing process among pieces (mm).

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$$Sd = \sqrt{\bar{S}^2} \qquad (7)$$

$$Se = S^2(\bar{x}) - \frac{Sd^2}{n} \qquad (8)$$

Where:

$S^2(\bar{x})$- represents the variance of the averages of the thicknesses of each piece sampled;
n - number of measurements per piece.

On the other hand, the Critical Dimension (Dc) variable, which is related to the dimension of green wood, should be taken into consideration if pieces could be produced without sawing variation. The mathematical expression that makes it possible to determine this dimension is the following (Equation 9).

$$D_c = \frac{DF + TC}{(1 - \%\, C)} \qquad (9)$$

The data of the analyzed samples are processed from the Control program, considering the following specific aspects:

Where:

DF = 25 mm;
TC = 0;
C- the value of the tangential shrinkage of the analysed woods is used: Moabi = 8.7 (CIRAD, 2012);
Tiama = 8.7 (CIRAD, 2012);
N' Kassa = 8.5 (Bosch, 2006);
Ngulo Mazi = 7.7 (Opuni- Frinpong and Opuni-Frinpong, (2012);
Z- 5 % according to Zavala, (1991) and Najera, (2011).

RESULTS AND DISCUSSION

Analysis of the quality of the logs of the different species used at the Amorim sawmill, Cabinda

During conversion, log defects have a very significant impact on lumber yields and quality. In Table 1, the magnitudes of the defects determined in the logs of the species investigated can be defined (Table 1).

Table 1. - Results of log defects

Species	Conicity, cm/m	Ovality, %	Eccentricity, %
MUABI	0,13	9,29	9,04
TIAMA	0,21	16,65	14,37
N"KASSA	0,16	3,61	7,54
NGULO MAZI	0,10	3,37	8,31

Conicity

The Tiama logs have the highest rate of conicity. However, it is important to point out that the values shown in Table 1 for the four species are below 1 cm/m, which is lower than those found by Polli *et al.*, (2006), for different *Eucalyptus* clones, as they obtained average conicity values of 1.8 cm/m; as well as Hornburg *et al.,* (2012), which obtained values ranging from 0.76 - 1.19 cm/m for six species of *Eucalyptus sp*. Stragliotto *et al.,* (2019), also obtained conicity values higher than those obtained in this work for the species *Qualea paraensis* (1.57 cm/m) and *Erisma uncinatum* (1.28 cm/m).

On the other hand, we can establish from the Brazilian standard of classification of hardwoods (IBDF, 1984), that the logs of the four species investigated, can be classified as superior quality logs or SU, starting from the fact that these same logs present conicities below 3 cm/m, defining furthermore that these conic magnitudes will not have a negative influence on the efficiency of the Amorim sawmill; coinciding with Ãlvarez *et al.,* (2017), reaffirming the approaches of Zhang *et al.,* (2005) and Leckoundzou, (2012), exposed in the following mathematical expression, which has as references the analysis of elasticity (Equation 10).

$$E = (Rend, Con) = \left({}^{\partial Rend}/_{\partial Con}\right)\left({}^{Con}/_{Rend}\right) \qquad (10)$$

Eccentricity of the spine

The eccentricity indicates the distance of the pith from the geometric centre of the tree and is used as a reference to evaluate the resulting effect of the tree growth stresses. When classifying the eccentricity results of the species analyzed from the standard (IBDF, 1984), all logs are classified as Quality I, taking into consideration that the eccentricity values obtained do not exceed 10 % (Figure 4).

Figure 4 - Tiama logs with eccentricity

The average value of the eccentricity of the N'Kassa logs (7.54) is lower than the results obtained by Blanco *et al.,* (2014), for 9 %. In general, high values of eccentricity suggest the presence of tension wood, which demerits the drying process of the wood with the appearance of deformations, also producing a negative effect on the surface of the sheets after sanding [Shi and Walker, 2006; quoted by Medhurstad *et al*., (2011)].

The species that presents the highest rates of eccentricity is Tiama, so it can be defined that in the sawmill analysed it is feasible to expose that processed pieces of this species could present deformations during the drying of the wood, as a consequence of the magnitudes of eccentricity and the presence of tension wood; coinciding with Kozakiewicz *et al*., (2018).

Ovality

In relation to the Ovality, in Table 1 it can be seen that the Tiama presents the highest magnitudes, in an average of 16.65 %, which exceeds the permissible limits for the classification of the superior quality of the logs, which accepts up to 10 % of ovality, according to the Brazilian standard of classification of the broadleaf logs (IBDF, 1984) (Figure 5). This element undoubtedly affects sawn timber yields and productivity in sawmills; coinciding with the results presented by Blakemore *et al.,* (2010).

Figure 5 - Tiama logs with ovality

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It can be defined, then, that these logs with irregularities are potentially generators of higher percentages of residues, implying a significant affectation of the sawn timber yields; to perfect the use of these logs with defects, mainly ovality and eccentricity, it is significant to optimize the width of the first opening cut of the logs to obtain the highest volumes of sawn timber, taking into consideration the mathematical analysis shown in Figure 6, below (Equation 11); (Equation 12) and (Equation 13).

$$A_c = ab \quad (11)$$

In which:

Ac = rectangle with the largest area on the circumference

$d^2 = a^2 + b^2$
$b^2 = d^2 + a^2$

$$b = \sqrt{d^2 - a^2} \qquad (12)$$

Replacing (12) in (11) we have to: $A_c = a\sqrt{d^2 - a^2}$

Deriving according to the variable a:

$$\frac{dA_c}{da} = \frac{d^2 - 2a^2}{\sqrt{d^2 - a^2}} \frac{dA_c}{da} = 0d^2 - 2a^2 = 0a = \sqrt{\frac{d}{2}}$$

$$a = \sqrt{r} \qquad (13)$$

Applying the criterion of the second derivative (Equation 14); (Equation 15); (Equation 16) y (Equation 17).

$$\frac{d^2A_c}{da^2} = \frac{a(2a^2 - 3d^3)}{(d^2 - a^2)^{3/2}} \quad (14)$$

As 8r is less than zero for all positive r, it can be guaranteed that $a = \sqrt{2r}$ is maximum.

For P = a/2 which makes it possible to obtain $P = \frac{\sqrt{2r}}{2}$;

$$A_r = 2(x * y_1) \qquad (15)$$

$$A_1 = x * y_1 \qquad (16)$$

$$y_1 = \sqrt{r^2 - (p + x)^2} \qquad (17)$$

Replacing (17) in (16), we have to: (Equation 18) y (Equation 19).

$$A_1 = x * \sqrt{r^2 - (p-x)^2}\,\frac{\partial A_1}{\partial x} = \left(x\sqrt{r^2-(p-x)^2}\right)_x \frac{\partial A_1}{\partial x} = 0$$

$-2x^2-3px+r^2-p^2 = 0 \qquad x = \frac{\sqrt{(p^2+8r^2)}-3p}{4}$

How

$P = \frac{\sqrt{2}r}{2}$ (18)

$$\frac{\sqrt{\left[\left(\frac{\sqrt{2}r}{2}\right)^2 + 8r^2\right]} - 3\,\frac{\sqrt{2}r}{2}}{4}$$

$0{,}7288689868 * |r| - 0{,}5303300858 * r$

Considering that (r) positive: 0,7288689868 * r – 0,5303300858 * r

X = 0,198538909 r (19)

To affirm that x = 0.198538909 r is maximum we have to use the criterion of the second derivative (Equation 20).

$$\frac{\partial^2 A_1}{\partial x^2} = \left[\frac{-2x^2-3px+r^2-p^2}{\sqrt{r^2-(p-x)^2}}\right]'_x$$

$$\frac{2x^3-6px^2+3x(2p^2-r^2)+2p(p^2-r^2)}{(-x^2-2px-p^2+r^2)^{3/2}} \qquad (20)$$

Substituting (18) and (19) in (20), we obtain that - 6.875550801 r < 0 for all positive r, guaranteeing that x = 0.1985389009 r is the maximum.

Substituting (12) and (13) in (11) we obtain (Equation 21); (Equation 22); (Equation 23).

$Y_1 = 0{,}4240352562$ r (21)

Where as

$2y_1 = y = 2(0{,}4240352562\ r)$ (22)

y = 0,9 r (23)

Where *y = 0.9 r* is the mathematical expression that defines the first opening cut in the logs to reduce the effect on lumber yields in logs with a marked presence of ovality, as is the case with Tiama logs (Figure 6).

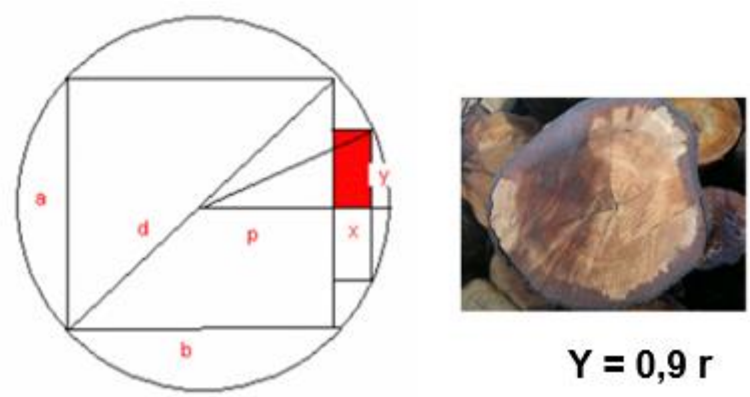

Figure 6. - Determining the first opening cut
Source: Álvarez *et al.,* (2010)

Statistical control of the cutting process at the Amorin sawmill, Cabinda

At the Amorim sawmill in the city of Cabinda, there is a general oversizing of the sawn timber (Table 2).

Table 2. Sawing variation at the Amorim sawmill

Parameters	Parts of 3-4 m in length		
	Muabi	N´Kassa	Tiama
Optimum dimension (Do), mm	26,7582	26,7680	26,5837
Final Dimension (Df), mm	25,0000	25,0000	25,0000
Variation within parts (Sw), mm	0,1273	0,1578	0,1302
Variation among pieces (Sb), mm	0,1579	0,1736	0,1123
Total process variation (St),mm	0,2028	0,2346	0,1719
Brush tolerance (Rc),mm	0,0000	0,0000	0,0000
Shrinkage tolerance (C), %	8,7000	8,4000	8,0000
Critical Dimension (Dc), mm	26,3769	26,3269	26,2605

According to the average values of thickness for the pieces represented in Table 2, values are shown for the three species, above the established as final dimension (25 mm), with variations higher than 1.5 mm, representing a considerable loss of sawn wood; which implies the need to develop in the sawmill the process of statistical control of the process, coinciding with Barrera, (2016).

The use of the Control program to determine the optimal dimensions of sawn timber, as well as the construction of control charts (Figure 6, Figure 7 y Figure 8), constitutes a suitable tool for making decisions aimed at increasing the yields and quality of sawn timber, explaining that automation is an excellent tool for data management and decision making in sawmills.

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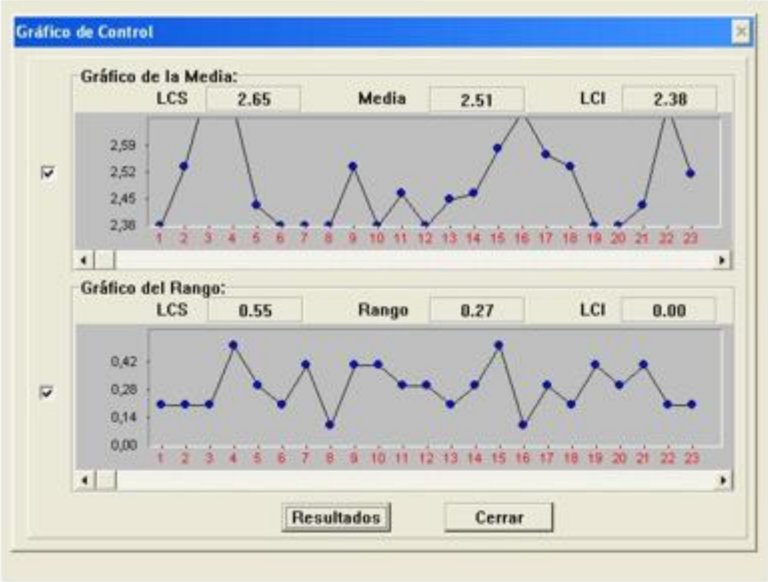

Figure 7 - Sawing variation of Moabi pieces

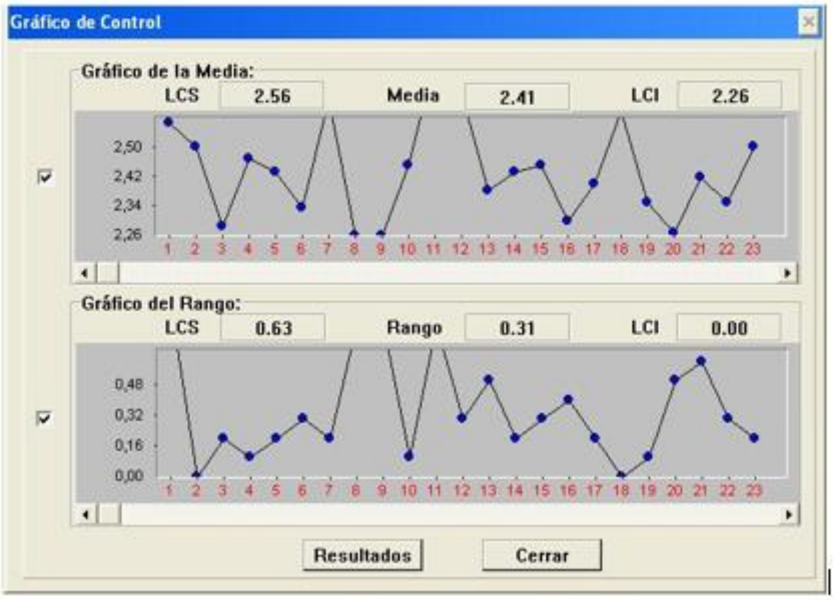

Figure 8 - Sawing variation of N'Kassa pieces

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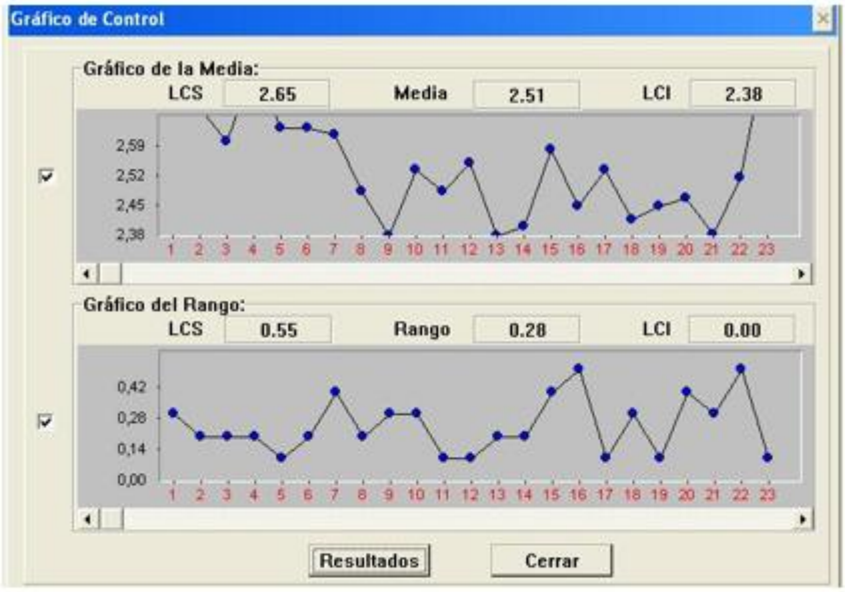

Figure 9 - Sawing variation of Tiama pieces

Eccentricity and ovality are the two major defects, with Angolan Entandrophragma logs showing the lowest levels of quality.

According to the average values of thickness for the pieces represented, values are shown for the three species, above the established as final dimension (25 mm), with variations greater than 1.5 mm, representing a considerable loss of sawn wood, which implies the need to develop in the sawmill the process of statistical control of the process.

The use of the Control program for determining the optimal dimensions of sawn timber, as well as the construction of control charts, is a suitable tool for making decisions aimed at increasing the quality of sawn timber.

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The authors have participated in the writing of the work and analysis of the documents.