

# Simulation of Tropical Hardwood Processing – Sawing Methods, Log Positioning, and Outer Shape

Pedro Ah Shenga,\* Peter Bomark, Olof Broman, and Dick Sandberg

To increase understanding of breakdown strategies for Mozambican timber, simulations were carried out using different sawing patterns that can be alternatives to the low degree of refinement performed for export today. For the simulations, 3D models of 10 Jambirre and 5 Umbila logs were used. The log shape was described as a point cloud and was acquired by 3D-laser scanning of real logs. Three sawing patterns (cant-sawing, through-and-through sawing, and square-sawing) were studied in combination with the log positioning variables skew and rotation. The results showed that both positioning and choice of sawing pattern had a great influence on the volume yield. The results also showed that the log grade had an impact on the sawing pattern that should be used for a high volume yield. The volume yield could be increased by 3 percentage points by choosing alternative sawing patterns for fairly straight logs and by 6 percentage points for crooked logs, compared to the worst choice of sawing pattern.

*Keywords:* Yield; Value; Positioning; Saw method; *Millettia stuhlmannii*; *Pterocarpus angolensis*

*Contact information:* Luleå University of Technology, Wood Science and Engineering, SE-931 87, Skellefteå, Sweden; \*Corresponding author: [pedro.shenga@ltu.se](mailto:pedro.shenga@ltu.se)

## INTRODUCTION

Extensive studies regarding the sawing of raw material from temperate zones can be found in literature, but studies of the sawing of tropical hardwood species, particularly from Miombo woodlands, are rare. The Miombo woodlands cover the central region of Zimbabwe and extend into Mozambique, southern Zambia, and Malawi. In Mozambique, the Miombo woodlands cover approximately two-thirds of the natural forest area, and timber from these woodlands is an important resource for the Mozambican sawmills industry. The Miombo species have a particularly irregular outer shape (crook in all directions, ovalness, and “bumpiness” as a result of large branches), and therefore the trunks are bucked to fairly short logs at harvesting. The log requirements for sawing are in general an average diameter of about 70 cm and a length of 2 to 3 meters. The lengths used are kept short to reduce the effect of log crookedness on the volume yield of sawn timber. At the harvesting site, logs that are too crooked and do not fulfill the size requirements, having a low proportion of heartwood or a large number of knots or other defects, are often left behind in the forest.

Logs are in general graded into four classes (Siteo and Bila 2008; Bunster 2012): Grade 1 - logs with a very low degree of crook, Grade 2 - logs with one pronounced crook, Grade 3 - logs with more than one crook, and Grade 4 - logs that contain rot and/or have a length less than 1 meter. There is also a minimum diameter for harvesting. This diameter is measured at breast height and is 40 cm for the most commercial species. The Miombo species in Mozambique is processed in sawmills with a simple layout of

bandsaw or circular-saw headrigs. Small-scale firms produce relatively small volumes of sawn timber for the domestic markets, and most of the logs are processed for export. For export, the logs are sawn into blocks or cants consisting mainly of heartwood, with little processing as possible in order to fulfill the national regulations, which merely require some degree of processing of the logs before export.

The sawmill work in Mozambique is largely a manual operation with no kind of technical support for transporting logs or sawn timber during the sawing process or for positioning the log (skew and rotation) in the saw machine to determine the position of the first cut. The manual positioning operations and the non-optimal choice of sawing pattern often results in large amounts of waste in the sawing (Ah Shenga *et al.* 2013). For economic reasons, and also for increased sustainability, there is thus a need to increase the volume yield in the sawing process, especially from logs with an irregular and crooked shape, *i.e.* logs of grades 2 or 3. There is also a need to increase the use of low-grade logs that are often left in the forest. Log shape measurement and simulation techniques could be a way to improve the understanding of how to manage a sawing process in general, and thereby increase the use of raw material in the process.

Several computer simulation models have been developed to study the volume yield and value recovery of sawn timber (Dogan *et al.* 1997; Gibson and Pulapaka 1999; Nordmark 2005; Shu-Yin and Que-Ju 2005; Lin *et al.* 2011). Todoroki and Rönqvist (1999) used dynamic programming to describe some procedures to determine the optimal cutting of flitches into graded dimensional boards. Lin *et al.* (2011) concluded that the log grade, log diameter, species, log sweep, and log length affect the value and volume yield of sawn timber. Lin and Wang (2012) studied the choice of the best opening face in sawing, edging, and trimming of the sawn timber, and found that an optimization system for the process stages could significantly improve the value recovery and could also assist mill managers and operators in the daily operation of the sawing process. In an optimization study, Lundahl and Grönlund (2010) showed that an optimal combination of rotation and parallel positioning of the log in the first and second saw-machines of a typical Swedish sawmill could on average increase the volume yield by 4.5 percentage points. Fredriksson (2014) complemented this study by using computed-tomography data to optimize the positioning of the logs before sawing according to the knot structure in the log, and he showed that it was possible to achieve a gain of the sawn timber of up to 21%.

Similar studies related to the sawing process of tropical hardwoods are scarce. Iwakari (1990) reported a volume yield of 45 to 55% when sawing Pau Rainha (*Brosimum rubescens*) and Macaranduba (*Manilkara huberi*) from Brazil. These tropical hardwood species have some similarities to the Miombo species such as high density, large diameters, and large proportions of heartwood. Volume yield data of some logs species from Mozambique were presented by Egas *et al.* (2013), who carried out interviews at sawmills, where they assessed the volume yield to be about 40%.

To build up a competitive wood industry in Mozambique there are great needs for change and development in both the sawmilling and the forestry sector. If logs of lower grade (crooked and irregular shaped logs) could be processed to a great extent with less waste, this could be one way to increase profits, to modernize sawmills, and also to put an emphasis on the secondary processing of the sawn timber.

The overall aim of the present study has been to show how the volume and value yields can be improved in the sawing of logs from the Miombo woodlands, specifically in Mozambique.

The objective of this study was to investigate how the volume yield of two miombo species was affected by log positioning, selection of breakdown strategy, and an additional secondary processing step. The study focuses on the sawing of crooked logs with an irregular shape.

## MATERIAL AND METHODS

This study investigates the impact of crook, sawing pattern, and log positioning on volume yield by a simulation of the sawing process based on the outer shape of 15 logs that had been scanned, and the data were further processed in a log database. All the logs were also sawn with a single specific sawing pattern, and the results were used as a reference for the simulation.

### The Log Database

The logs were selected from among the most exploited species from a log yard at a local sawmill. A total of 10 Jambirre (*Millettia stuhlmannii* Taub.) and 5 Umbila (*Pterocarpus angolensis* D.C.) logs were selected for the database, where 11 of the logs had a high degree of crook (Grade 3) and the other four logs were straighter (Grades 1 or 2). Results are shown in Table 1.

The logs were measured and graded by sawmill employees according to the rules used in the Mozambican wood industry (Bunster 2012). Figure 1 shows some typical log shapes.



**Fig. 1.** Three examples of log shapes and their grades according to Bunster (2012). Log numbers according to Table 1

The log shape was obtained using a three-dimensional (3D) phase-shift laser scanner, FARO Focus 3D S-120 (FARO 1981), and the data used the outer shape of the logs as 3D models described by point clouds. The scanning was performed in Cabo Delgado, Mozambique, at the Kwekwe sawmill. The log models were cropped on both ends to reduce problems with missing scan data.

To limit the size of the database and increase the speed of the sawing simulations, each log was characterized at every 10 mm by log-discs. Additional information regarding the processing of point cloud data to build up a log model is given in Ah Shenga *et al.* (2014).

**Table 1.** Description of the Log Database

Log No.	Species	Grade*	Top diameter** (cm)	Butt diameter** (cm)	Length (cm)
1	jambirre	3	31	33	275
2	jambirre	2	24	32	177
3	jambirre	3	25	28	244
4	jambirre	3	23	26	240
5	jambirre	3	31	36	244
6	jambirre	1	36	36	248
7	jambirre	3	28	31	229
8	jambirre	3	25	34	286
9	jambirre	3	30	35	266
10	jambirre	3	34	43	282
11	umbila	3	38	42	309
12	umbila	3	39	41	317
13	umbila	2	35	41	320
14	umbila	3	36	40	376
15	umbila	2	38	43	324

\* Grade 1 - logs with a very low degree of crook, Grade 2 - logs with one pronounced crook, Grade 3 - logs with more than one crook, and Grade 4 logs containing rot and/or that have a length less than 1 meter.

\*\* The manual measurement was made using the average of two perpendicular diameters.

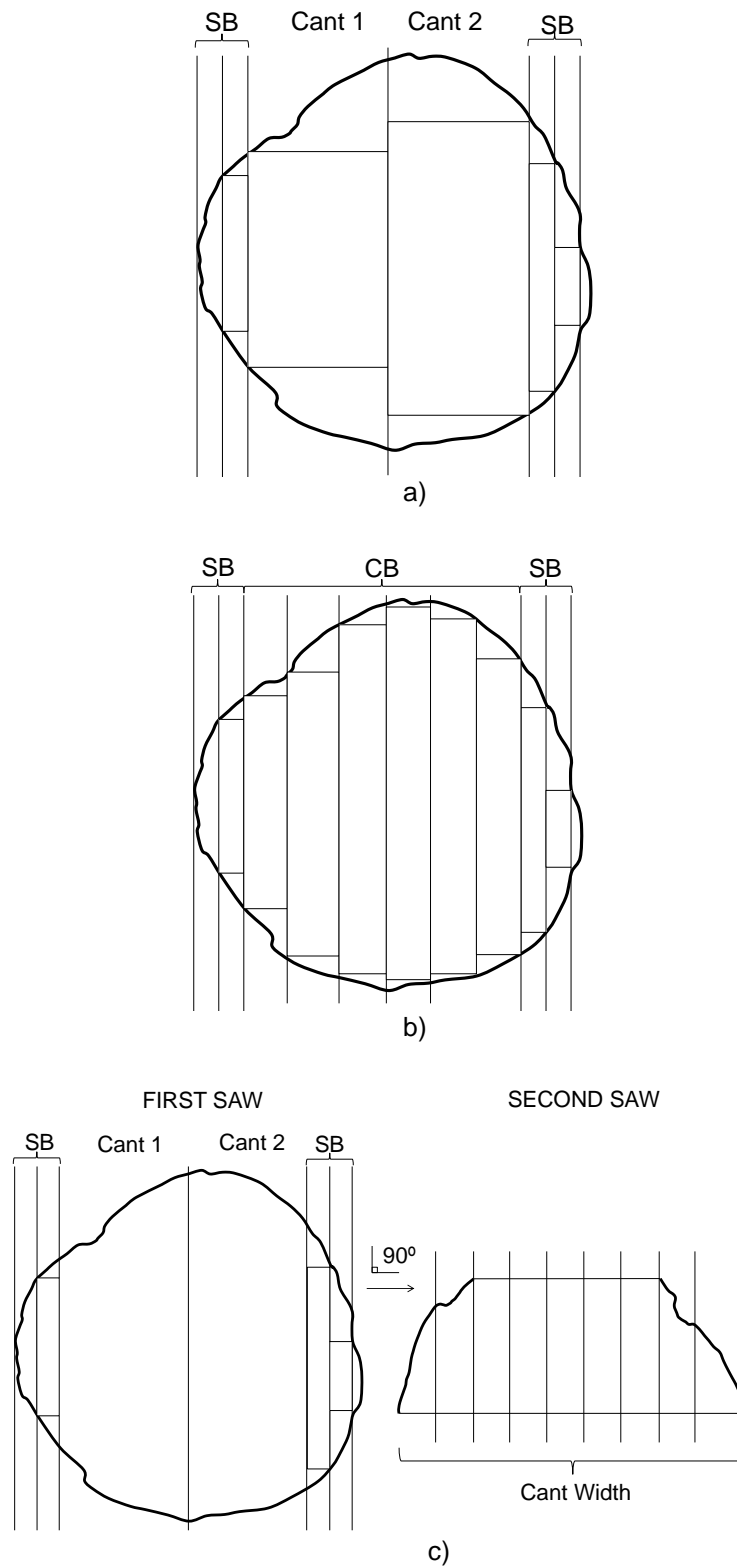
### Breakdown Strategies for Use in the Simulation

The breakdown strategy for this study was to try to find a way of sawing that *a*) increases the volume yield of sawn timber, especially from crooked logs, and *b*) also increases the degree of refinement directly at the sawmill or close to its production site. This target should in practice be reached using the same type of production equipment that is used today, *i.e.* a bandsaw or circular-saw headrig.

Today sawmills use cant-sawing and through-and-through sawing patterns (Fig. 2) to process the logs to sawn timber for both export and the domestic market. The cant-sawing method requires simple equipment, and the sawn timber is exported with low added value. The sawn timber from through-and-through sawing is in general processed further at sawmills or at separate joineries to fabricate consumer products such as furniture, interior fittings, or joinery for house building.

As a result of a combination of practices seen in the field, three sawing patterns were identified as being interesting to study (Fig. 2):

- Cant-sawing (CS): This method is commonly used to process sawn timber for export, the main products being cants and sideboards.
- Through-and-through sawing (TT): This method is used to process sawn timber for the domestic market. The main products are un-edged centerboards and sideboards.
- Square sawing (SS): This method is commonly used in sawmills that also produce end-user products. In this process, two cants and a number of sideboards are normally produced in the first stage, and after 90° rotation the cant is rip-sawn.



**Fig. 2.** Cross-sectional views (top-end of the log) of sawing-patterns used in the simulation: a) cant-sawing (CS), b) through-and-through sawing (TT), and c) square-sawing (SS). SB and CB are respectively sideboards and centerboards

Depending on the top-diameter of the logs, the dimensions of the sawn timber for the three sawing patterns were selected according to Table 2. All the sawn timber was manufactured sharp-edged in the simulation, although this is not the general practice at a Mozambican sawmill. The reason for this decision was that different grading rules regarding wane for sawn timber are used in Mozambique, and the rules are also applied differently depending on the market. To avoid uncertainty in the study, the simulation procedure was therefore set to include only sharp-edged sawn timber.

When executing the simulations, the resulting positioning of a log that maximizes the yield is in this study was defined as the Best Opening Face (BOF) direction for the specific log and sawing pattern. For the second stage in square-sawing (Fig. 2c, right), the dimensions of the sawn timber were set as follows:

- For a cant width  $\leq 339$  mm: the board thickness was set to 25 mm and the cant-height to 50 or 75 mm, and
- For a cant width  $\geq 340$  mm: the board thickness was set to 50 mm and the cant-height to 100 mm.

Prior to the simulation, log-diameter classes were defined based on the top-diameter of the log and the diameter interval for each class was set to 40 mm. For each log-diameter class, a fixed sawing-pattern was decided for cant-sawing, through-and-through sawing, and square-sawing (Table 2).

**Table 2.** Sawing Patterns for Cant-sawing, Through-and-through Sawing, and Square-sawing, Showing the Thickness of Sideboards and Centerboards for Each Log-diameter Class

No.	Log-diameter class (mm)		Boards thickness (mm)															
	Min	Max	Cant-sawing (CS)			Through-and-through sawing (TT)				Square-sawing (SS)*								
1	0	249	25	25	50	50	25	25	25	25	25	25	25	25	25	25	25	CS + 25 (rip-sawing)
2	250	289	25	25	75	75	25	25	25	25	25	50	50	25	25	25	25	CS + 25
3	290	329	25	25	100	100	25	25	25	25	50	50	50	50	25	25	25	CS + 25
4	330	369	30	30	100	100	30	30	30	30	50	50	50	50	30	30	30	CS + 25 or 50
5	370	409	30	50	100	100	50	30	25	50	50	50	50	50	50	30	30	CS + 50
6	410	449	30	75	100	100	75	30	25	50	50	75	75	50	50	25	25	CS + 50
7	450	489	50	75	100	100	75	50	25	75	75	75	75	75	75	25	25	CS + 50

\* SS was a combination of cant-sawing (same sawn-timber thicknesses) and a second sawing stage where the cant was rip-sawn into boards of equal thickness. A board thickness of 25 mm was used when cant width  $\leq 339$  mm, and for a cant height of 50 or 75 mm, but the board thickness was set to 50 mm for a cant-width  $\geq 340$  mm and a cant-height of 100 mm.

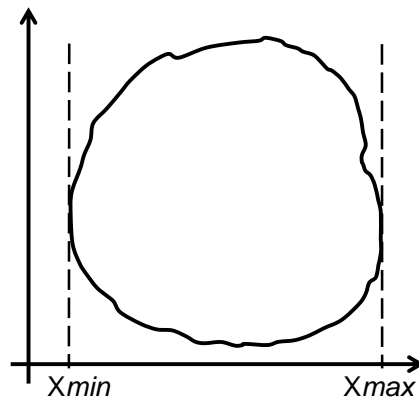
## Simulation

A MATLAB algorithm was developed to simulate the sawing process. First the algorithm determined the top-end of the log and matched the top-diameter to the predefined log-diameter class. The sawing process consists in placing planes previously defined by the board thickness of each sawing pattern (Table 2). When the sawing pattern had been selected, the log was sawn using combinations of skew and rotation. In

addition, the set-up parameters of the band-saw mill were used (commonly used in Mozambique). For cant-sawing (CS) and through-and-through sawing (TT), the kerf width was set to 3 mm, and for square-sawing (SS) a kerf width of 3 mm was set for the bandsaw (first saw) and 4 mm for the rip saw (second saw). To compensate for the shrinkage during drying, 4% was added to the target cross-sectional dimensions regardless of the main direction of the wood. The main steps used by the algorithm are described as follows:

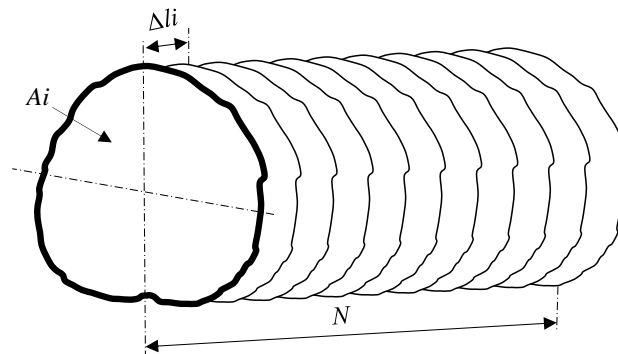
#### *Determination of top diameter and definition of log volume*

The first procedure of the simulation was to determine the top-end of each log. Using the cross section of the first and the last log discs of each log (log-discs with a thickness of 10 mm), the difference  $X_{\max} - X_{\min}$  (Fig. 3) at every 15° rotation angle (0, 15, 30, ... 135, 150, 165) were determined. The log diameter was calculated as the average of the calculated measurements. The first and last log-disc diameters were then compared and the lowest average diameter was assigned as the top diameter of the log. The top-diameter was then used to match a log to a specific log-diameter class in Table 2.



**Fig. 3.** Principle for determination of the diameter of the log. The value ( $X_{\max} - X_{\min}$ ) was calculated for every 15° rotation step, and the log diameter was defined as the average of the calculated measurements

The volume of each log was determined by using the volume integration formula, Fig. 4.



**Fig. 4.** The volume of each log was calculated as the sum of the volume of each log-disc with the thickness  $\Delta l_i$  according to the volume integration formula (Eq. 1).  $A_i$  is the cross-sectional area of each log-disc with the thickness  $\Delta l_i$  (=10 mm) and  $N$  – number of discs in each log

Figure 4 represents a calculation employing Eq. 1,

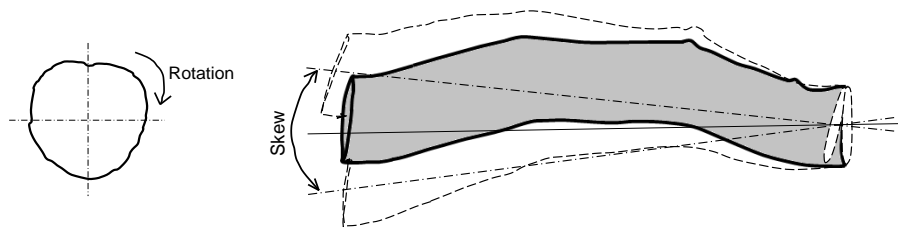
$$V = \sum_{i=1}^N (A_i \cdot \Delta l_i) \quad (1)$$

where  $A_i$  is the cross-section area of the  $i^{\text{th}}$  log-disc determined using Green's theorem (Arfken *et al.* 2012),  $\Delta l_i$  is the thickness of each disc (10 mm), and  $N$  is the number of discs representing the log.

### Log positioning

The simulation algorithm positions the log before sawing by skewing and rotating the log (Fig. 5). The positioning was made using the skew as base *i.e.*, the log was first skewed at a certain angle and then rotated and sawn; when this sawing was completed, the log was rotated and then again sawn until all rotation positions were completed, and so on until all combinations of skew and rotation were completed.

In skewing, the top-end of the log had a fixed position and the butt-end was skewed at angles from  $-1^\circ$  to  $1^\circ$  at intervals of  $0.5^\circ$ , which represents a maximum shift of the butt-end of  $\pm 35$  mm for a 2 m long log. The rotation angles were set from  $0^\circ$  to  $180^\circ$  at intervals of  $2^\circ$ .



**Fig. 5.** Rotation and skew orientation: to the left a cross-sectional view of the log and to the right a length-wise view of the log with the top-end indicated in white

### Edging and calculation of board volume

For a given sawing pattern, the volume of all the boards or components at each positioning (skew and rotation) were calculated and the maximum and minimum sawn timber volumes from the log were recorded. At the end, the simulator displayed the two volumes with its comprehensive skew and rotation positions.

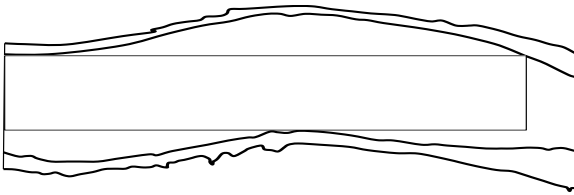
During the edging of the sawn timber from the CS and TT sawing patterns, the board volume was maximized. The minimum width accepted was 5 cm, a width module of 5 mm was used, but no length modules were used (Fig. 6). The volume of sharp-edged boards (cants and sideboards) was calculated for the following,

$$\text{Cant-sawing sawing (CS)} \quad V_{CS} = \sum (V_{SB} + V_{cant}) \quad (2)$$

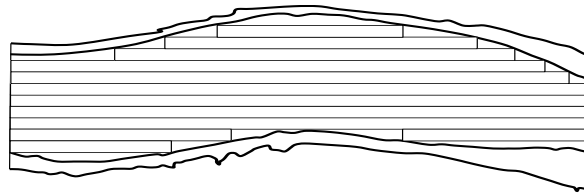
$$\text{Through-and-through sawing (TT)} \quad V_{TT} = \sum (V_{SB} + V_{CB}) \quad (3)$$

where  $V_{SB} = A_{rectSB} \cdot Thick_{SB}$  is the volume of sideboards,  $V_{cant} = A_{rectCant} \cdot Thick_{Cant}$  is the volume of the cants,  $V_{CB} = A_{rectCant} \cdot Width_{CB}$  is the volume of centerboards, and  $A_{rect}$  is the area of the maximum rectangle fitted to the board. CB, SB, and Cant are centerboards, sideboards, and cants, respectively.





**Fig. 6.** Flat view of simulated cant from cant-sawing (CS) or board from through-and-through sawing (TT). The rectangle represents the maximum fitted size of a sharp edged board or cant.



**Fig. 7.** Flat view of simulated board from the second saw in square-sawing (SS). Each rectangle represents a ready-to-use sharp-edged component.

For the SS pattern (sideboards and ready-to-use components), the volume was given by,

$$V_{SS} = \sum (V_{SB} + V_B) \quad (4)$$

where  $V_{SB} = A_{rectSB} \cdot Thick_{SB}$  is the volume of sideboards, and  $V_B$  is the volume of ready-to-use components.

The minimum length of a component was set to 20 cm (which is the minimum length of raw material to produce one component of flooring parquet). Figure 7 shows an example of sawn products obtained when using SS.

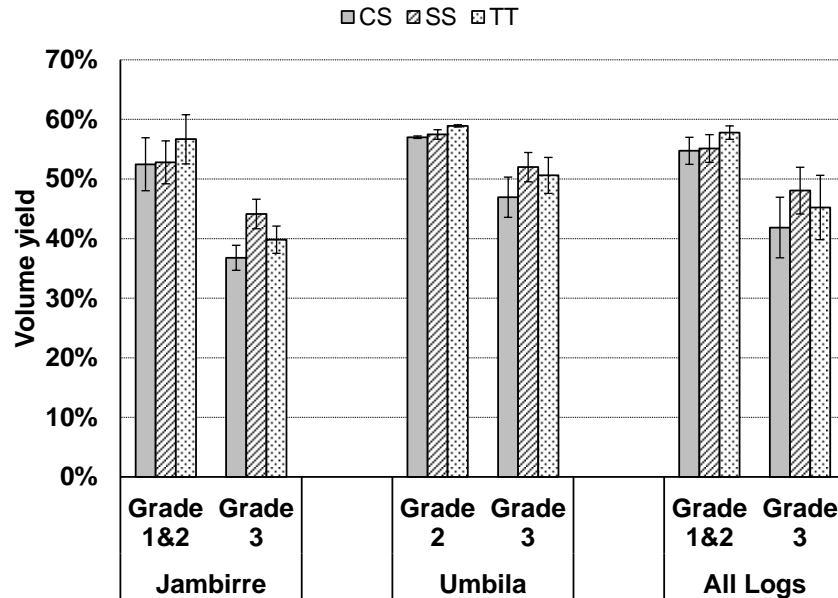
## RESULTS AND DISCUSSION

This simulation study was limited in the sense that it only includes the outer shape information from 15 logs of two species. No other sources of variation that may play a role in a real sawing situation were considered. Nevertheless, the influence of sawing pattern and log positioning on the volume yield of sawn timber should be of general interest, since the same logs were sawn many times simulating different processing conditions. Comparing this work to a real sawing situation, one should bear in mind that the simulation result is an overestimation, since the sapwood content and inner features of logs were not considered. On the other hand, the simulations considered only sharp-edged sawn timber, which reduces the volume of sawn timber considerable when crooked logs are sawn, compared to the practical sawing situation where a certain amount of wane is often allowed.

Figure 8 shows the maximum volume yield at the optimal position (combination of skew and rotation) as an average of all log-diameter classes, and grouped according to sawing pattern, species, and log grade. The volume yield from cant-sawing (CS) was here used as reference in comparison to the other two saw methods because it is the most frequently used sawing pattern in Mozambique.

The results show that the CS pattern gave the lowest volume yield for all log grades and that the through-and-through sawing (TT) gave a higher yield than CS regardless of log grade or species. Square-sawing (SS) gave the highest yield when grade 3 logs were sawn. Thus the results indicate that, when aiming for a high volume yield, straight logs should preferably be sawn with TT instead of CS with a potential of a 3 percentage points greater volume yield (all logs, in Fig. 8). The potential for

improvement with crooked logs was 6 percentage points with SS instead of CS. In addition, if a sawmill does not have the equipment for secondary processing (SS) a change from CS to TT is predicted to still improve the volume yield of crooked logs with a potential of about 3 percentage points.

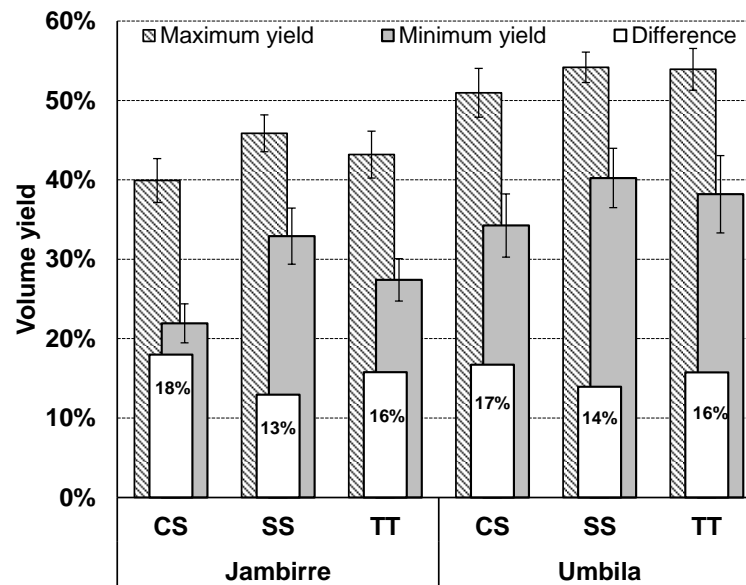


**Fig. 8.** Maximum volume yield with optimal positioning (combination of skew and rotation) as an average of all log-diameter classes for different sawing patterns, species and log grades. Bars indicate standard deviation, and CS – cant-sawing, SS – square-sawing, and TT - through-and-through sawing

The simulations also showed that crooked and irregularly shaped logs (grade 3) will give a lower volume yield than the straighter and even-shaped logs.

Figure 9 shows the maximum and minimum volume yields (at the optimal and worst positioning) as an average of all log-diameter classes, grouped according to sawing pattern and species. The average difference between maximum and minimum volume yield for all sawing patterns was 15 percentage points. The CS pattern showed the greatest difference between maximum and minimum volume yield, followed by the TT and SS methods. The trend was the same for all log grades and it indicated that the standard CS pattern is the most sensitive to incorrect log positioning and that the SS pattern is the best in that respect. Overall, the results stress the importance of positioning the log prior to sawing to find the best opening face that will maximize the volume yield.

With regard to the species, Fig. 9 shows that with optimal positioning, Jambirre logs had volume yields of 40% (CS), 46% (SS), and 43% (TT) and Umbila logs 51% (CS), 54% (SS), and 54% (TT). This between-species difference is partly explained by the fact that the Umbila logs had not only larger diameters but also less irregular outer shapes than the Jambirre logs. Figure 8 also shows that the difference in volume yield between CS and SS patterns was somewhat larger on the smaller crooked Jambirre logs than on the straighter and larger Umbila logs. This stresses the need to choose the saw pattern at a Mozambican sawmill according to grade and species.



**Fig. 9.** Average volume yield with optimal and worst positioning and the difference for cant-sawing (CS), square sawing (SS), and through-and-through sawing (TT). The range of investigation was set to  $\pm 1^\circ$  in skew and every  $2^\circ$  increments in log rotation. Bars indicate standard deviation, and CS – cant-sawing, SS – square-sawing, and TT - through-and-through sawing

Overall, the simulation results show that the volume yield can be increased if square sawing (SS) or through-and-through sawing (TT) is used instead of the commonly used cant-sawing pattern (CS). In comparison with the yield of 40% reported by Mozambican sawmills (Egas *et al.* 2013), the simulation results (Fig. 8) show an improvement with optimal positioning for all types of logs except the grade 3 logs of Jambirre (CS and TT sawing patterns). Analyzing the logs according species, it can be seen that only one group (Jambirre, CS) gave a yield as low as 40% with optimal positioning. All the sawing methods and log types gave yield less than 40% with the worst positioning of the logs. This stresses the importance of executing good positioning prior to sawing. Unfortunately no data are available that show how well a Mozambican sawyer usually positions the logs prior to sawing. Most of the operations are done manually and without any supportive technique such as log shape measurements or computer optimization.

## CONCLUSIONS

1. For tropical hardwood characterized by an irregular outer shape and crookedness, log positioning and sawing patterns are important for sawn timber volume, *i.e.* volume yield. The results of this study show that the use of simple and easy methods for log scanning prior to sawing to assist in log positioning could be one way to increase the volume yield in tropical hardwood sawmills in developing countries.
2. The alternative sawing patterns studied gave a better yield than the standard sawing pattern normally used in Mozambique. The square-sawing method gave the highest volume yield when sawing crooked logs, while the through-and-through method gave

the highest yield for the fairly straight grade 1 and grade 2 logs. The improvement in volume yield by choosing the best sawing pattern was 3 percentage points for grade 1 and 2 logs and 6 percentage points for grade 3 logs.

3. The study also shows the importance of proper log positioning prior to sawing. In the optimal position, *i.e.* with the best opening face, the volume yield could reach 40 to 46% for crooked logs and 51 to 54% for fairly straight logs.

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