

Machining Operations on Messassa Wood

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Abstract

This study aimed to evaluate the effect of machining operations on the surface quality of the messassa wood (*Brachystegia spiciformis* and *Julbernardia globiflora*) for use in the furniture industry. The wood comes from Mozambican Miombo Woodland. The following machining operations were performed: planing, shaping, milling, tearing and boring based on technical standard. The wood had a surface quality approval rating above 70% in all tested machining operations. A perfect surface quality was obtained with a feed speed of 6 m.min⁻¹ in planing. *Brachystegia spiciformis* had easy workability and extremely well performance compared to *Julbernardia globiflora*. Nevertheless, both wood species have great potential for use in higher value-added products such as furniture and frame production.

Keywords: *Brachystegia spiciformis*, *Julbernardia globiflora*, surface quality, higher value-added products, planing, shaping, milling, tearing, boring.

Introduction

The Mozambican furniture industry needs modernization and expansion as well as demand for new and lesser-used woodspecies in the domestic and international market. Therefore, knowledge of the possible applications of wood from the native species is essential, considering the high biodiversity existing in the biomes of Mozambique and the different technological characteristics of timber species. In recent years, there has been a tendency for research in Mozambique to indicate other potential species for wood production by determining their anatomical characteristics (Uetimane *et al.* 2009 and 2018; Bila *et al.* 2018), chemistry (Lhate *et al.* 2010), physical and mechanical properties (Ali *et al.* 2008; Cristovão *et al.* 2011), and cutting forces (Lhate and Cristovão 2007). Thus, as in the technological characterization of the species, knowledge about machining evaluation and surface quality of wood is extremely important for their use.

The species *Brachystegia spiciformis*. Benth and *Julbernardia globiflora* (Benth.) Troupin commonly known as common messassa and red messassa, respectively, represent the largest availability of commercial timber in the country, with approximately 46% of the total volume (Magalhães 2018). Such species have the potential to be inserted in different sectors of the timber segment for higher value-added products (DNFT 2017). However, due to the lack of knowledge about the behavior of these species under different machining processes, they are relegated to less noble uses in civil construction. It is noteworthy that the optimization in the use of wood involves the knowledge of its characteristics, as well as it is interaction with different machining operations (Silva *et al.* 2005; Aguilera and Muñoz 2011).

According to Brown (1998) and Silva (2002), wood machining is the mechanical process that aims to give the

desired shape regarding the dimensions and quality of wood products. In addition, Lucas (2004) affirm that machining and it's cause and effect relationships with the variables involved in the process are paramount for positioning against the competition and for the development of a more efficient manufacturing process. Taylor *et al.* (1999) and Gupta *et al.* (2019) state that during machining process, different species tend to exhibit distinct behavior due to their inherent wood characteristics, such as density, moisture content, anisotropy, presence of silica and minerals, wood grain and texture, juvenile wood, age, reaction wood, presence of knots, among others.

Wood machining includes various operations such as cutting, planing, sanding, milling, boring and turning, requiring specific machines, which can be manual or automatic, aiming a better appearance on their surfaces facilitating a better application of finishing products (Palermo *et al.* 2010; Zamarian, *et al.* 2012). Machining quality can be assessed by calculating normative values for tooth feed (fz) or the presence of surface failures, which are generated as a function of the intrinsic structure of the wood or by the roughness parameters Ra, Rz provided by the roughness meter (Silva 2002; Braga 2014). However, it is common to infer the quality of the machined wood surface through the use of ASTM D1666-11 (2011) which consists of assigning grades after visual inspection of some defects such as raised grain, fuzzy grain, torn grain, crushing, chip marks, etc. In this assessment, lower grade numbers describe surfaces that would be acceptable in a manufacturing environment, while higher grades require additional rework, resulting in additional production costs (Hernández *et al.* 2011).

Thus, the present study aimed to evaluate the behavior of two messassa wood species under machining processes such as planing, shaping (top, side, and winding axial), axial and transverse milling, tearing and boring (pin

and hinge) in order to contribute to the country's timber sector by disseminating scientific and technological information with a view to adapting these species to furniture production, allied to the issues of better use of tropical wood.

Materials and Methods

Materials

Wood from two Mozambican native lesser-used species, *Brachystegia spiciformis*. Benth (red messassa) and *Jubernardia globiflora*. Benth (common messassa) whose basic density are (0.670 and 0.680) g.cm⁻³ respectively, were used. Tangential planks were obtained from 15 logs of *B. spiciformis* and 12 logs of *J. globiflora*, of 1500 mm in length, and width variation based on the diameter of the trees, which ranged from (260 to 550) mm. Subsequently, the planks were ripping in a multiple circular saw, into board of size 25 x 150 x 650 mm³ and conditioned at temperatures of 20 ± 2°C and 65 ± 5°C, with a relative humidity to the moisture content of 12 ± 2%. Then, 20 samples of each species were randomly selected for machining tests. These samples were selected

representative of the intrinsic characteristics of the species with smaller heartwood region, when compared with the sapwood, because generally, the heartwood tends to rot in the core and some samples have heartwood and sapwood, in different proportions. This sampling allowed to test the wood as it is marketed in the country.

Methods

Machining Operations Tests. The machining operations tests followed ASTM D 1666-11 (2011). The machining parameters used in the operations followed the methodology of Zamarian *et al.* (2012). It is noteworthy that to avoid the influence of cutting edge wear on the machined surface quality, the sequence of the samples in each operation were randomly selected. With the exception of planing, the average feed speeds presented for the remaining operations were manual and obtained by the ratio of machining offset to the programmed time required to perform. All tests were carried out on the same sample using the following technical machining parameters (Table 1).

Table 1. Machining parameters used for *Brachystegia spiciformis* and *Jubernardia globiflora* wood

Machining operation	Nr.	n (min ⁻¹)	D (mm)	V _s (m.s ⁻¹)	V _F (m.min ⁻¹)
Planing	3	3445	105	18.93	6.0;15.0
Top frame	2	8000	135	56.52	0.65
Side frame	2	8000	135	56.52	0.78
Winding axial frame	4	8000	90	37.68	0.50
Tearing	2	3380	8	1.42	2.58
Axial milling	1	27000	5	7.07	0.78
Transversal milling	1	27000	5	7.07	1.38
Pin drilling	2	1735	8;10;12	0.73;0.91;1.09	0.50
Hinge drilling	2	1735	35	3.18	0.17

Where: Nr. = number of knives; n = tool holder spindle rotation speed; D = tool diameter; V_s – Cutting speed; V_F = Feed speed.

Planing was performed on an *Omil* model DES 400 planer, with frequency of 60 Hz. The samples were planed on opposite faces parallel to the grain with each face having distinct feed speed and constant cutting speed (Table 1). Two passes were made on each side with a depth of cut of 0.5 mm.

Shaping (top and side frame) were performed on a *Invicta* model TI-14 router, crosswise and along the grain respectively using a standard cutter shaping LEN-Profile 24. For winding axial frame, a flat forming knife was used and consisted of performing a winding curve parallel to the grain and along the length of the sample as shown in Figure 1.

The tearing test was performed in the same corner on the side where the winding axial frame was made, using a

hand-feed *Invicta* FIC – 15 horizontal drill. Only one rip was made in each sample, whose geometry were 5 x 8 x 70 mm³ corresponding to the depth, width and length, respectively.

Axial and transverse milling had dimensions of 7 x 50 x 100 mm³, depth, width and length, respectively, forming an “L” shape. Manual column spindle *Makita* 3709 machine having 1200W, 127V, 60 Hz and engine speeds ranging from 8000 to 27000 rpm were used.

Boring tests were carried out in a single hand-feed type *Motomil* boring machine having 1.735 rpm. For pin hole, three twist profile carbon steel drills having diameters (8, 10 and 12) mm were used. Three holes for hinge (one through hole and two non-through hole) were also drilled using a 35 mm diameter drill as shown in Figure 1.

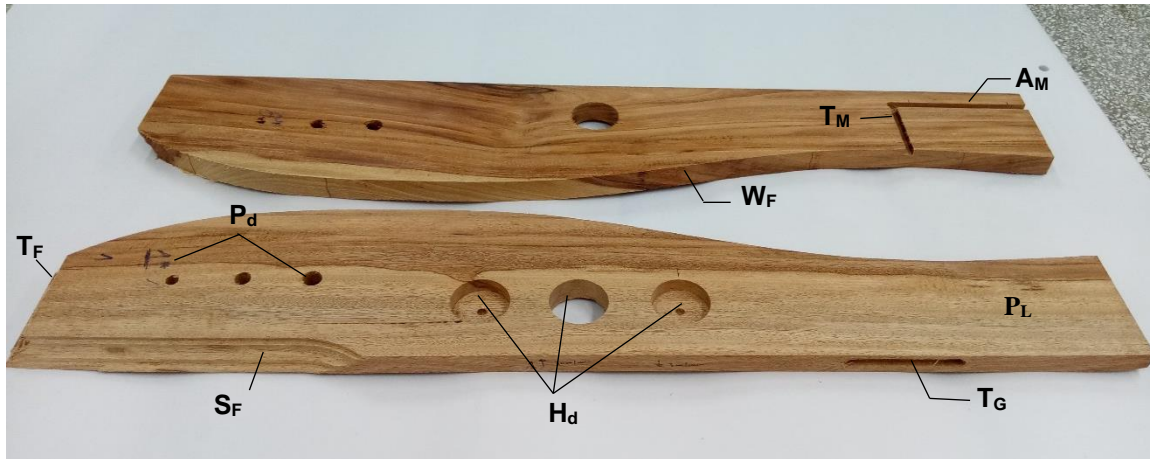


Figure 1. Messassa wood sample in machining test. P_L – Planing; A_M, T_M – Axial and transversal milling; T_F, S_F– Top and side frame; W_F - Winding axial frame; T_G – Tearing; P_d, H_d – Pin and Hinge drilling.

Assessment of Machining Operations. The machined wood surface in each operation were visually examined according to ASTM D 1666-11 (2011) on post-machining defects. The examination was made by a team of three evaluators who gave (separately) scores ranging from 1 to 5

in defects according to their intensity and frequency. Defect values were compiled for each operation as a percentage for a given grade. Table 2 summarizes the assignment of defect values used in this study.

Table 2. Quality grades used in determining overall performance for each machining operation

Grade	Surface quality criteria*	Performance
1	Surface free of any defects	Excellent
2	Mild to medium raised, torn grain, crushing	Good
3	Strong raised and slight chipped, torn grain, tearouts	Fair
4	Strong raised and mild to medium chipped, torn grain, crushing	Poor
5	Strong raised, chipped, rough-end grain, crushing, tearouts	Very Poor

*Adapted from ASTM 1666-11 (2011)

The assigned value allowed grouping the samples into five surface quality grades: Grade 1 (excellent) - no defects in the sample; Grade 2 (good) - presence of less than 50% of defects; Grade 3 (Fair) - presence of 50% of defects; Grade 4 (Poor) - presence of more than 50% of defects and Grade 5 (very poor) - presence of 100% of defects. Figure 2 illustrates the surface quality grades in planing.

Analysis

As the purpose of this study was to test the messassa wood for use in products whose surface quality is paramount, such as furniture, frames, doors, windows, among others, the Hotelling T² test was applied to infer the existence of differences between the grades awarded by the evaluators. Then, a single value per surface was determined when at least two of the three evaluators rated a given sample in the same class or by the arithmetic mean when the three assigned different grade without consensus. The correlation between machining operations by Spearman's test was also verified. The results in machining operations were compared based on percentages of samples as grades 1 and 2.

Results and Discussion

Machining Test

Table 3 shows the percentage of surface quality grade in different machining operations for *B. spiciformis* and *J. globiflora* under the specified test conditions. It can be seen that most samples of both species had an approval percentage above 70% and graded between 1 and 2 corresponding respectively to excellent and good surface quality. However, it is noteworthy that, only in the tearing operation for *J. globiflora* wood the surface quality was grade 4. In turn, there was no samples graded 5 for both species throughout the study.

The larger observed number of samples graded 1 and 2 in the different machining operations demonstrates a satisfactory performance of both species, therefore, suitable for use in higher value-added products, such as furniture and frame production. The indication of these species for furniture production, for example, is justified by the good performance in axial, transverse and hinge drilling operations (Table 3). In turn, the indication for frame

production is supported by the good results in the top, side and winding frame tests.

In Table 3, it can also be seen that for the planing with feed speed of 6 m.min⁻¹ most grades were between 1 and 2. In contrast, the planing with feed speed of 15 m.min⁻¹ led to the appearance of defects such as raised, torn and chipped grains, as evidenced by the higher percentage of the samples in grade 3 (fair). Vančo *et al.* (2017) and Kaplan *et al.* (2018) also reported for *Pinus Sylvestris* L. and Oak wood (*Quercus cerris*) respectively, a decrease in surface quality (increased roughness) as a function of

increased feed speed. Thus, these results (table 3) demonstrate the importance of planing this species with low feed speed to ensure a good surface quality, as well as to avoid higher wood consumption during sanding that aims to eliminate waviness and smooth the machined surface of the wood (Silva 2002; Laina *et al.* 2017). Burdurlu *et al.* (2005), Hernandez *et al.* (2001), Ratnasingam and Scholz (2007), and Gupta *et al.* (2019) state that parameters such as cutting angles and number of knives also have different effects on the quality of the machined wood surface, but were not analysed in the present study.

Table 3. Percentage of samples in each surface quality grade for machined wood of *B. spiciformis* and *J. globiflora*

Machining operation	Parameter	Grade (%)									
		1		2		3		4		5	
		<i>Bs</i>	<i>Jg</i>	<i>Bs</i>	<i>Jg</i>	<i>Bs</i>	<i>Jg</i>	<i>Bs</i>	<i>Jg</i>	<i>Bs</i>	<i>Jg</i>
Planing	6 m.min ⁻¹	60	45	25	35	15	20	0	0	0	0
	15 m.min ⁻¹	30	15	25	30	45	55	0	0	0	0
Top frame	-	10	5	85	80	5	15	0	0	0	0
Side frame	-	85	80	15	15	0	5	0	0	0	0
Axial winging frame	-	90	80	10	20	0	0	0	0	0	0
Tearing	-	10	10	60	35	30	30	0	25	0	0
Axial milling	-	85	70	15	25	0	5	0	0	0	0
Transversal milling	-	15	0	85	90	0	10	0	0	0	0
Pin drilling	8 mm	0	20	70	65	30	15	0	0	0	0
	10 mm	15	15	45	60	40	20	0	0	0	0
	12 mm	10	20	55	70	35	10	0	0	0	0
Hinge drilling	Through	35	25	65	60	0	15	0	0	0	0
	Non-through	40	15	60	65	0	20	0	0	0	0

Where: *Bs* - *B. spiciformis* and *Jg* - *J. globiflora*.

Comparison between wood species in planing reveals better performance of *B. spiciformis*. Possibly, this result was due to the species *J. globiflora* having intercrossed

grain, which hinders the planing at high feed speed. The surface quality grades obtained in planing are illustrated in Figure 2.

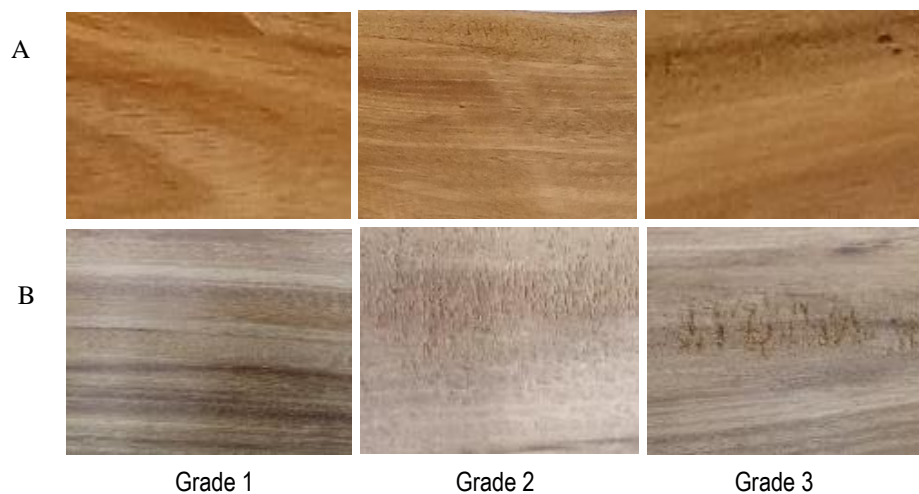


Figure 2. Surface quality grades in planing of *B. spiciformis* (A) and *J. globiflora* wood (B)

The molding operation had a percentage of approved sample above 85 % and rated excellent (grade 1) and good surface quality (grade 2) on the top and side frame (Table 3). In turn, the axial winding frame showed 100 % approval in both species. These operations were performed with different cutting and feeding speeds, all of which were lower in the axial winding frame due to the operation requirement (Table 1). Unlike the other moldings, the winding axial frame is undoubtedly the least delicate due to the orientation of the cutting efforts in relation to the fibers, which favored the observed results. It is noteworthy that, besides the possible effects of wood anatomy, cutting and feeding speeds on the good results obtained in machining operations (Silva *et al.* 2005; Bustos *et al.* 2010), the use of tool without wear and

good condition of the machines used contributed to the better quality of the machined wood surface.

It should be noted that the wood needs some care for tearing and boring operation. In these operations both species had a similar performance in which the samples were mainly graded 2, followed by grade 3. Exceptionally for the species *J. globiflora*, in the tearing operation, there were samples graded 4 (Table 3). This grade occurred in samples whose tearing coincided in the sapwood region and was characterized by the chilling and strong pull-out of the fibers (Figure 4). Despite that, this defect little compromises the acceptability of the species for this operation because it can be eliminated with sanding. In addition, further studies on cutting parameters such as cutting speed and feed speed or changes in tool edge angles may improve this operation.



Figure 3. Tear with presence of chills and pullout of the fibers in *J. globiflora* wood

Raised and chipped grains were the common defects observed during boring. In the through holes the evaluation was made in the exit of the drill. For non-through holes (hinge) were assessed at the bottom of the hole. Although some samples were graded 3 in the pin drilling mainly for the *B. spiciformis* species, these do not affect the final surface quality as they will be eliminated during sanding. Overall, the species performed well against the boring operation.

Axial milling also performed satisfactorily with most samples approved in grade 1, equivalent to the high quality wood surface. Particular emphasis should be given to the cross-milling operation which, despite being performed with orientation of cutting effort perpendicular to the fiber arrangement, the wood of both species performed well, with most of samples lying in the graded 2 (good quality) with a percentage of (85 and 90) % for *B. spiciformis* and *J. globiflora* respectively. According to Silva (2002), the wood profiling, especially against the fibers, allows to really evaluate the machinability of the wood, since it is machined under drastic conditions, and can demonstrate its true potential. In addition, according to the same author for intercrossed grain wood species, such as *J. globiflora*, it is recommended concurrent milling, ie the workpiece moves in

the same direction of rotation of the machine to minimize the machining defects.

The results obtained for machining operations (except the tearing operation) of studied species are similar to those of wood with good machining, such as the african mahogany species (*Khaya ivorensis*) reported by Carvalho *et al.* (2010). On the other hand, Table 4 presents the comparison of the average grades results found in the present study for the different machining operations in relation to some species also commonly used in the manufacture of furniture such as *Swietenia macrophylla* (Mahogany) basic density of 0.530 g.cm⁻³, *Ocotea porosa* (Imbuia) of 0.540 g.cm⁻³ and *Eucalyptus grandis* of 0.510 g.cm⁻³ obtained by Silva (2002).

Although the results presented in Table 4 were not obtained under the same test conditions, the comparison with the species commonly used in furniture manufacture illustrates better performance of *B. spiciformis* and *J. globiflora* species in most of machining operations, which shows the suitability of the species under study for more noble uses such as furniture and frame production. Barcik *et al.* (2014), Gaff *et al.* (2015) and Gupta *et al.* (2017) state that parameters such as density, cutting speed, among others, have a direct proportionality with the roughness of the wood, resulting in the improvement of the machining

surface quality as they increase. Hernández *et al.* (2001) and Belleville *et al.* (2016) reported good machining performance as the density of *Picea glauca* and *Eucalyptus* wood increases, respectively. From this point of view,

considering the average density of the messassas wood, it can be inferred that it favors the workability and, therefore, the good performance demonstrated in machining operations.

Table 4. Assigned average grades by machining operation for *B. spiciformis* and *J. globiflora*, along with *Ocotea porosa*, *Swietenia macrophylla* and *Eucalyptus grandis*.

Machining operation	<i>B. spiciformis</i>	<i>J. globiflora</i>	Imbuia*	Mahogany*	<i>E. grandis</i> *
Planing	2.3 (20.2)	1.6 (33.9)	3.1	1.5	2.1
Top frame	2.0 (15.5)	1.9 (19.1)	3.8	1.7	3.2
Side frame	1.2 (25.0)	1.2 (30.5)	2.3	4.5	5.0
Winding axial frame	1.2 (16.4)	1.3 (18.8)	1.3	-	3.6
Tearing	2.4 (25.4)	2.8 (22.9)	2.4	3.4	2.9
Axial milling	1.2 (22.0)	1.3 (31.2)	2.9	2.9	3.9
Transverse milling	1.8 (16.4)	2.1 (16.4)	2.2	2.4	4.3
Pin hole	2.4 (14.7)	2.6 (12.9)	-	-	-
Hinge hole	2.3 (11.9)	2.3 (15.4)	-	-	-

*Silva, (2002); Numbers in parenthesis represent the coefficient of variation; - absent

Correlations between Machining Operations

The Spearman's correlation between wood machining operations on *B. spiciformis* and *J. globiflora* wood did not show significant correlations in most cases at 1 and 5 % probability. Exceptionally, it was observed that there was a positive correlation between the transverse milling and the top frame operations, besides the side frame and winging axial frame in both species (Figure 4). However, it is

important to state that, in general, the correlations found were weak witnessed by the R^2 coefficient well below 30 %.

The absence or weak correlation between the operations presupposes the non-influence of one operation on the results of the other and may be performed differently from the sequential order adopted in the present research. However, planing is known to be one of the first operations in wood machining.

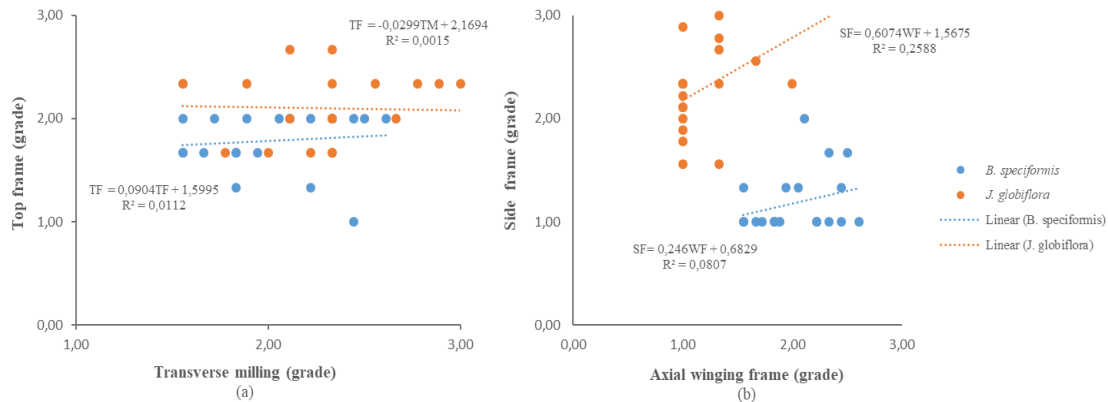


Figure 4. Correlations between top frame (T_F) and transverse milling (T_M) operations (a); and Correlations between side frame (S_F) and axial winging frame (W_F) operations (b) for species *B. spiciformis* and *J. globiflora* wood.

The observed correlations between the operations (Figure 4) may occur due to the possibility of these operators occurring in the same direction relative to the grain direction (Figure 1). There were no relevant literature reports on correlations between these operations. However, studies that aim to verify this trend by varying if the machining parameters in these operations for the same or another target group of species, as well as correlating them with the anatomical properties, are pertinent and needs continued reasearch.

Conclusions

The wood of species *B. spiciformis* and *J. globiflora* presents ease of machining in planing, side frame, top frame, axial and transverse milling, winding axial profiling, tearing, pin and hinge drilling. The surface quality of the machined wood under the test conditions was considered satisfactory and superior for *B. spiciformis* compared to *J. globiflora* specie. Both *B. spiciformis* and *J. globiflora* are suitable for use in the Mozambican furniture industry, especially for furniture and frame production. Thus,

considering the good performance of the species under study in the different machining operations, there is a possibility to promote forest management activities aimed at improving their health, especially in younger stands, in order to guarantee the good quality raw material for the wood industries.

Acknowledgments

The authors thank the Ministry of Science and Technology, Higher Education and Technical-Professional of Mozambique for financial support.

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