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Original Article

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The Effect of Weather on Air-Drying of Messassa Wood

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Abstract

This study intended to assess the effect of weather on the air-drying process of messassa wood (*Brachystegia spiciformis* Benth) in two areas of Mozambique (Machipanda and Beira city). First, the logs were sawn into 27 mm thick boards. Every five days the moisture content of the wood was determined by the control samples. For each region, the drying rate and wood quality post sawing and drying were estimated. The drying time differed between the regions under investigation, with Machipanda revealing the higher value. Messassa wood, which revealed a low drying rate (0.33% U/day), was categorized as slow drying wood. Both regions showed average final moisture content of 15.3% in the boards, with only slight variations in moisture inside the stacks. After outdoor drying, only a few defects were noted and as it was free from tensions, hence it was classified as good quality wood.

Keywords: Mozambique, drying rate, wood quality, *Brachystegia spiciformis* Benth.

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1. INTRODUCTION

As the noble or first-class timber species were subjected to extensive exploitation over the centuries, their availability has sharply declined over the last few decades, and second-class wood species have been used instead. Regarding this, this study performed in Mozambique emphasizes the use of the messassa wood species – *Brachystegia spiciformis* Benth (Fabaceae). Based on data drawn from the last forest inventory, the species has the greatest commercial volume (Diretório Nacional de Terras e Florestas, 2008).

This species enjoys a geographic distribution throughout tropical Africa up to just south of the equator and occurs in Tanzania, Zambia, Zaire, Malawi, Mozambique and Zimbabwe, extending roughly across 270 million hectares. In Mozambique, the principal forest type is the Miombo Mopane, where the genus investigated in this work has established itself in about 2/3 of the total area, chiefly to the north of the Limpopo River (Sitoe et al., 2004). The messassa tree varies from 6 to 20 m in height, with an open crown and a tall and subcylindrical trunk with light gray or quite dark ritidoma and deciduous leaves. This wood species finds use in making railway sleepers as well as for civil construction. This wood can be used to build truck bodies, as plywood and for general use, besides making furniture and parquet sections (Chudnoff, 1984).

The sapwood in this species is very well defined, with the following features: whitish-brown in color gradually becoming more intense to yellowish or even dark brown, at times with spots and variable tones; growth layers; scanty, dispersed pores; paratracheal and aliform parenchyma with thin but scarcely visible rays in abundance (Bolza & Keating, 1972; Höhn, 1999). One of the crucial parameters for assessment of wood quality is basic density (Foelkel et al., 1971). Abbot & Lowore (1999) report that this wood shows medium high basic density on average (0.582 g/cm^3). The messassa wood has low permeability with slow drying and high likelihood of having deformations, particularly twisting, giving rise to surface and top cracks (Chudnoff, 1984). The moisture content is inversely proportional to the wood density, implying that the greater the water content the lesser will be the quantity of other chemical elements in the wood (Foelkel et al., 1971). According to Kollmann & Côté (1968), 115% is the maximum initial moisture content estimated for this species in response to an apparent specific gravity at 0% moisture.

The industrial sector of Mozambique is dependent on wood from natural forests, and the regions of Manica and Sofala have high consumption of wood of several species due to the intense concentration of furniture companies. The wood is usually unfolded in single-band saws, after which it is exposed to natural drying (Abbot & Lowore, 1999).

Air-drying in the outdoors is affected by the climatic factors prevailing in the region and is dependent upon the operations employed to best utilize it (Eleotério et al., 2014; Duarte et al., 2015; Liebl et al., 2017). According to Jesus et al. (2016) and Stangerlin et al. (2009), drying is intensely affected by the procedures involved in it, but is principally influenced by environmental factors in the region. Wood drying guarantees its dimensional stability (Severo, 2000), and has the advantages of being a simple and cheap method when conducted in the open (Braz et al., 2015).

The messassa species (*Brachystegia spiciformis* Benth) has plentiful availability and the potential to meet the demands of the growing market. However information on wood drying is rather sparse. Therefore this study aimed at determining the influence exerted by the climatic factors on the feasibility of outdoor drying of timber in two regions of Mozambique (Machipanda and Beira city).

2. MATERIAL AND METHODS

2.1. Study location

Conducted in two regions, the first part of the study was limited to the city of Beira, Sofala province, Mozambique, located between the coordinates 19°50' S and 34°51' E, at 14 m altitude (Muchangos, 1999). With its typical tropical climate, the city experienced much more rainfall in summer than in winter. Based on the Köppen and Geiger classification the region enjoys the Aw type of climate throughout the year. The mean temperatures range from 20 to 31 °C with an annual average of 24.6 °C. The wind speed hovers on average between 13 and 18 km/h (Ferro & Bouman, 1987). The second part of the study was done in another region situated at CEFLOMA (Centro Agroflorestal de

Moçambique in Machipanda), in the city of Chimoio, province of Manica, located between the coordinates 19°17' S and 33°47' E, at 732 m altitude (Muchangos, 1999). In general, the climate is warm and temperate with much less rainfall in the winter than in summer. According to the Köppen and Geiger classification the climate is of the Cwa type. Through the year the average temperatures are found in the range of 13 to 30 °C with the annual average at 21.2 °C. The lowest temperature in the year is recorded in July. The wind speed is on average between 9 and 13 km/h (Ferro & Bouman, 1987).

As the city of Beira is located on the coast, it is characterized by high relative humidity and temperature. Machipanda, however, located in Chimoio, is in a region where altitude affects the climate and is therefore characterized by lower relative humidity, lower temperatures and lower equilibrium humidity than the city of Beira (Figure 1).

2.2. Sawmill of logs and construction of piles

In this study, 15 logs were sawed in a single vertical band-saw, which is a model of successive tangential cutting. The boards were cut at a nominal 27 mm thickness, between 3.5 and 4.0 m in length with the width being variable and dependent upon the log diameter. The time spent between the cutting of trees, sawing of logs and construction of piles was about 25 days, during which two (2) piles were set up for outdoor drying, one in the city of Beira and the other in CEFLOMA, Machipanda.

After mounting the piles on a wooden base roughly 0.60 m above the exposed and clean ground, each stack was built up using 15 layers of boards to achieve the final dimensions of 120 × 120 × 350 to 400 cm (height, width and length). Each pile included an average of 64 boards (each board having 0.28 m width on average) and was covered to protect it from insolation and direct precipitation.

An average of eight separating strips were used per layer with the nominal dimensions of 2.5 × 2.5 × 120 cm, arranged equidistantly from the top. The stacks were mounted in the open air, ensuring that the pile length was oriented perpendicular to the wind direction at the time.

2.3. Determination of basic density and initial and final moisture contents

The gravimetric method was used to determine the moisture content, while the basic density was calculated by the ratio between dry mass and saturated volume of the wood. The analyses were performed based on the standard NBR-7190 (ABNT, 1997).

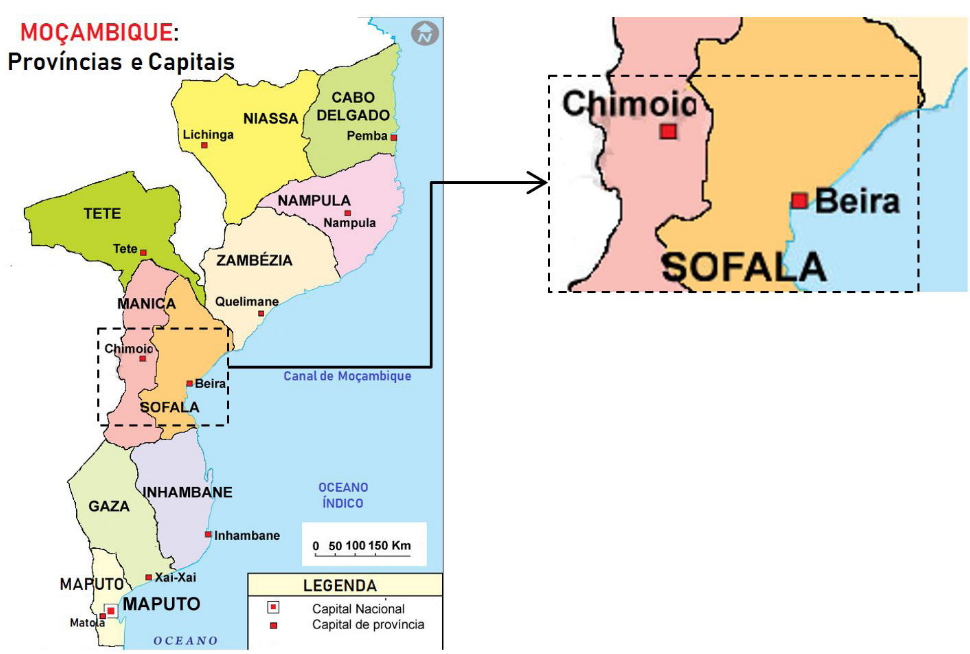

Figure 1. Location of the study in Mozambique.

2.4. Moisture control and drying rate

The moisture loss during outdoor drying was controlled using the control samples, prepared based on the method described by Simpson (1991), and weights were recorded every five days. For each cell, six control samples were prepared, three of each side of the cells. The drying rate was determined applying the equation suggested by Severo (2000),

$$Ts = \frac{TUi - TUf}{t} \times 10 \quad (1)$$

where: Ts = drying rate (% U/day); TUi = initial moisture content (%); TUf = final moisture content (%); t = time (days).

From the findings of the drying rate the different moisture ranges were determined: Range 1) initial moisture up to 30%, in free water withdrawal, considering 30% the fiber saturation point (PSF); Range 2) from 30% moisture up to 15%, considering the removal of the impregnated water (adsorbed water); and Range 3) initial moisture up to 15%, in the free water withdrawal and impregnation.

2.5. Evaluation of wood quality

Assessment of the warping (bow and crook) and cracking (top and surface) in all planks was done post splitting and after outdoor drying. The defects were estimated incorporating the method of Severo (2000). Table 1 lists the criteria for evaluation of the drying in terms of the incidence of defects.

For the final quality analysis, 10 boards from each pile were selected to assess the final moisture content, moisture gradient in the board thicknesses and drying tensions (fork test), based on the method adopted by Simpson (1991).

2.6. Statistical analysis

Data were tabulated and analyzed using the Statgraphics Plus statistical package. Homogeneity of the variance test was applied to confirm the normality of the data (Bartlett's test). The results were submitted to the analysis of variance (ANOVA) adopting the completely randomized design (DIC), and the factors were assessed (localities – Beira and Machipanda city). The confidence interval selected was 95% ($\alpha = 0.05$) and, when significant, the Tukey test was performed to compare the means.

3. RESULTS AND DISCUSSIONS

3.1. Moisture content and basic density of the messassa wood

The drying process commenced in June 2014 and ended in November 2014, regarded as the end of the winter season, characterized by lower temperatures and poor precipitation. In the Beira city region, the drying was done in 155 days, whereas in the Machipanda region at CEFLOMA it took 130 days. Table 2 reveals the mean results of the initial and final moisture contents, drying time and basic density of the messassa wood in the city of Beira and Machipanda.

As the messassa wood in the two regions revealed mean initial moisture content of 57%, they were therefore regarded as statistically equal. The results were within the range identified for medium high-density hardwood (Ponce & Watai, 1985). Authors like Chudnoff (1984), Foelkel et al. (1971) and Kollmann & Côté (1968) recommend that the time between logging, debrading and stacking of the sawn wood should be kept to as minimal as possible as it could affect the initial moisture content of the wood. The findings of this study revealed that the time of the year (winter) and the processes of unfolding, transportation and assembling of the piles influenced the initial moisture content.

The boards from the city of Beira registered higher average initial moisture content than those

Table 1. Criteria for classification of drying defects.

Samples showing defects (%)	Ranking
0 - 10	SLIGHT
11 - 30	MODERATE
> 30	LARGE

Source: Brandão & Jankowsky (1992).

Table 2. The means of the initial and final moisture contents, drying time and basic density of the *messassa* wood in the two regions of Mozambique.

Region	TUi (%)	TUf (%)	Days	DB
Machipanda	55a	14.7a	130	0.626a
	(24.5)	(10.6)		(8.6)
City of Beira	59a	15.9a	155	0.632a
	(22.52)	(12.3)		(10.2)

TUi = initial moisture content; TUf = final moisture content; DB = basic density. Within each region, averages followed by different letters differ significantly (Tukey, p > 0.05). The coefficients of variation are given in parentheses.

from Machipanda. This was because Machipanda is situated around 300 km away from the city of Beira, hence the time spent with the transport logistics of the wood was the likely reason for the decrease in the initial moisture content of the boards. Although slight variations were observed in the mean initial moisture, the results were regarded as statistically equal. These results for the initial moisture content of the messassa wood were similar to those reported by Abbot & Lowore (1999). According to Kollmann & Côté (1968) the difference in the initial moisture content within the species occurs because of age, season and place that the species is found, as well as inside the stem in the spinal cord and in the base portion of the tree. Foelkel et al. (1971) propose that the moisture content of the wood is inversely proportional to its density. The findings of this study show that the average basic density calculated was 0.629 g/cm^3, categorizing it as medium high-density wood. The results concur with those of Abbot & Lowore (1999) but are less than the values noted by Chudnoff (1984), who recorded an average basic density of 0.67 g/cm^3.

With respect to the final moisture content, the drying process was completed when the moisture loss stabilized over time. In Machipanda, the mean final moisture content of the wood was lower by 1.2% than the value of that in the city of Beira (Table 2). This was because the equilibrium moisture content in the city of Beira was higher (Manhiça, 2006; Ferro & Bouman, 1987), which induced slower drying and consequently a higher mean final moisture content in the boards. Besides, the wind's lack of defined orientation in the city of Beira may have played a part, resulting in a lower drying rate. Simpson (1991) and Liebl et al. (2017) suggested the strong influence that wind direction can exert on the drying rate.

In both the regions investigated the average final moisture content calculated between the boards was 15.3% with the coefficient of variation being 11.4%. This indicates that the dry wood had high homogeneity when the final moisture between the boards was assessed and that the drying was sufficient. As the values of the final moisture content were statistically equal and acceptable as low, this wood was qualified for internal use, particularly in the manufacture of components and furniture by and large (Ponce & Watai, 1985).

The drying time recorded in this study was on average 142 days, within the time range achieved for the outdoor drying of low permeability wood (Chudnoff, 1984). Interestingly, Stangerlin et al. (2009) reported identical results. This drying time, however, was longer than the one Duarte et al. (2015) obtained, where the outdoor drying of the Eucalyptus spp. in Frederico Westphalen, state of Rio Grande do Sul, took 116 days when boards of dimensions 310 × 25 × 3 cm (length, width and thickness) were used, and when the similar mean initial moisture content (54.7%) ultimately dropped to the final moisture content of14.1%.

Outdoor drying can be optimized without necessarily waiting until the moisture loss is completely stabilized. From Figure 2 it is evident that during the drying of the messassa, the wood attained the average of 18.7% of humidity in 75 days in both the regions. Duarte et al. (2015) reported duration of 63 days for the drying of the Eucalyptus spp., and an average of 15.5% final moisture content was achieved. Therefore, the messassa wood drying could be done in 75 days because it lies

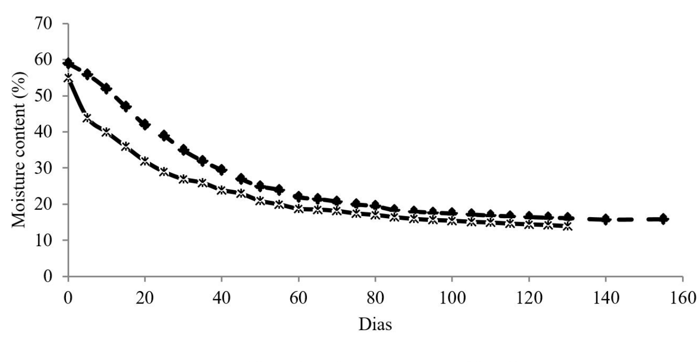

Figure 2. Average moisture loss from the messassa wood during the air drying process, in the city of Beira and Machipanda.

within the humidity range used for drying wood in the open air.

A practical and simple method of estimating outdoor drying, where the wood pile is mounted, is the typical drying curve (Braz et al., 2015). In Figure 2 the moisture curves for the two regions, Machipanda and Beira city, are shown.

The initial moisture content findings were accepted as statistically equal in both the regions under investigation; despite there was a difference between the means Stangerlin et al. (2009) reported similar results. Figure 2 reveals, from the moisture curves, a difference in the drying rate between the regions. A sudden decline in the initial moisture was observed when the drying process began in Machipanda, and a higher drying rate was maintained throughout the time. One reason for the higher drying speed in the Machipanda region is most likely due to the prevailing lower air equilibrium humidity (Ferro & Bouman, 1987).

According to Ferro & Bouman (1987), despite the slightly higher wind velocity present in the city of Beira than in Machipanda, the wind direction in Machipanda was clearly a very prominent factor that may have enabled the faster drying rate. Several authors cite the intrinsic effect of wind direction on the wood drying rate (Liebl et al., 2017; Simpson, 1991).

3.2. Drying rate

In Figure 3, the drying rate for the two regions is observed. The drying rate revealed a steady decline over time, showing a sharp drop below the fiber saturation point (PSF), achieving a 5.9-times reduction in the drying rate. For all the moisture ranges analyzed the messassa wood in Machipanda displayed the higher drying rate.

Figure 3 shows a statistical difference in the drying rate by the elimination of free water in the initial moisture range 30%, which suggests that this is the phase where the drying is strongly affected by the climatic factors of the region, besides the operational options. These findings concurred with the results of Stangerlin et al. (2009) and Braz et al. (2015). However, in the case of the removal of the adsorbed water below the PSF, the drying rates remained very close in both regions, displaying no statistical difference; thus clearly indicating that, below the PSF, it is the intrinsic characteristics of the wood which control the drying rate (Batista et al., 2013; Redman et al., 2012). According to Braz et al. (2015) the factor wood density exerts a negative influence on the drying rate, causing the wood drying rate to slow down.

Messassa wood is regarded as hard to dry because the tyloses present in it lower the permeability (Höhn, 1999) principally by withdrawing the free water, causing it to be considered similar to the Eucalyptus species. The findings of this study correspond to those recorded by Duarte et al. (2015) in the outdoor drying of the Eucalyptus spp., wood which had a drying rate above the PSF of 1.21% U/day and 0.16% U/day in the removal of the impregnation water, and an average drying rate of 0.36% U/day. However, Stangerlin et al. (2009) reported in their study on the outdoor drying for three Eucalyptus species average drying rates much higher than those of this study, clearly showing that the messassa wood can be classified as difficult to dry.

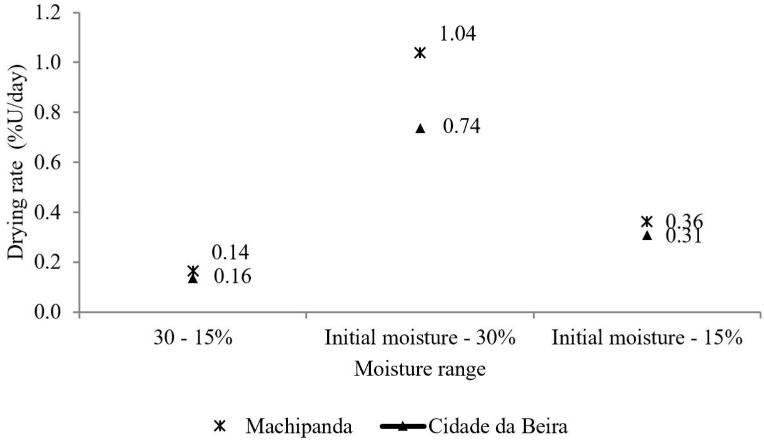

Figure 3. Drying rate for the two regions in different moisture ranges.

It is easy to observe that messassa wood is difficult to dry when the drying rate is compared with that of the other species. In comparison with the study of Susin et al. (2014), the messassa (*Brachystegia spiciformis*) (0.629 g/cm^3) wood in the present study showed an average drying rate 11 times lower than that of the outdoor drying of the *Hovenia dulcis* wood (0.534 g/cm3) of 25 mm thickness. These results were chiefly because of the high permeability and lower basic density of the *Hovenia dulcis* wood.

3.3. Drying quality

3.3.1. Drying stress and moisture gradient

The messassa wood was free drying stress in all the samples studied, possibly because of the slow drying which was responsible for the good wood quality. Stangerlin et al. (2009) observed similar findings and reported no drying stresses in the Eucalyptus wood post outdoor drying. Tensions in the wood parts are usually induced by the drying speed and drying conditions via surface compression forces and tensile forces developing right in the center of the boards (Batista et al., 2015).

The average moisture gradients determined in the drying process were regarded as low in both the regions, with means of 0.7% and 1.2% for Beira and Machipanda, respectively. The slight difference in the values noted between the two regions could be attributed to the longer permanence of the wood pile during the drying period in the Beira region, which ensured that the humidity inside the boards was homogeneous. Klitzke & Batista (2010) noted that the moisture gradient was directly linked to the existence of drying stresses. According to the authors, the higher the gradient, the most probable the development of drying stresses, which encouraged defects like cracks and warps to occur. This study observed no such tensions, which supported good wood quality.

3.3.2. Surface and top cracks

The Table 3 mean results prior to and post air-drying of the cracks recorded in Machipanda and the city of Beira.

In both regions the indexes of top and surface cracks were low in intensity based on the classification of Brandão & Jankowsky (1992). The Machipanda region revealed a higher intensity of top cracks, probably induced by the sudden moisture loss when the drying commenced and the direct incidence of the sun on the treetops. The findings of top and surface cracks, however, presented no statistical difference between the regions studied.

When *Eucalyptus* spp. were subjected to outdoor drying under climatic conditions similar to those of Machipanda, Liebl et al. (2017) reported identical indexes of top cracks induced by the rapid drying of the wood, lending support to the findings of the present study. While Stangerlin et al. (2009) and Susin et al. (2014) reported similar values for surface cracks, the top cracks gave values substantially lower than those reported here.

3.3.3. Warp in the wood

Table 4 shows mean results of the empties obtained prior to and post air-drying of the messassa wood in Machipanda and the city of Beira.

The low rates of bow and crook were categorized according to Brandão & Jankowsky (1992) with a low occurrence of drying defects, showing the high quality of the wood. Table 4 clearly shows that the bow even decreased once the drying was completed, thus improving the wood quality. This was likely because the wood had been properly stacked while assembling

Table 3. Average values of the top and surface cracks before and after air-drying of messassa wood.

Region	Top crack (%)		Surface crack (%)	
	before	after	before	after
Machipanda	2.5a	22.5b	3.3a	9.2a
	(23.12)	(15.30)	(12.65)	(9.22)
City of Beira	1.5a	12.5a	2.5a	10.3a
	(25.89)	(12.37)	(10.52)	(11.32)

Means followed by different letters within each species differ significantly (Tukey, $p > 0.05$). The coefficients of variation are given in parentheses.

Table 4. Average values of warping prior to and post air-drying.

Region	Bow (mm/m)		Crook (mm/m)	
	before	after	before	after
Machipanda	2.0a	1.4a	1.2a	1.8a
	(8.12)	(12.82)	(25.66)	(16.42)
City of Beira	1.8a	1.0a	2a	2.5b
	(10.51)	(9.40)	(38.30)	(18.25)

Means followed by different letters within each species differ significantly (Tukey, $p > 0.05$). The coefficients of variation are given in parentheses.

the wood piles, carefully maintaining the alignment and dimensions of the separating battens. These results concurred with those reported by Stangerlin et al. (2009), Duarte et al. (2015) and Jesus et al. (2016) in outdoor drying.

Crook resulted in a slight but visible increase after drying. Duarte et al. (2015) and Stangerlin et al. (2009) also noted a small increase in the mean arching arrow after open air drying. Statistically low and equal warping indices were obtained.

4. CONCLUSIONS

The following conclusions are drawn based on the results obtained:

The mean final moisture content determined for the messassa wood (*Brachystegia spiciformis*) was 15.3% in both the regions studied.

The basic density of the messassa wood was 0.629 g/cm^3 on average, hence classified as medium high-density wood. As the air-drying rate was low, the messassa is regarded as a wood of difficult drying. The Machipanda region recorded the highest drying rate and lowest moisture content.

The messassa wood (*Brachystegia spiciformis* Benth) revealed no drying tensions with low humidity gradients, and therefore gave low defect indexes post drying. It was classified as high-quality wood and could find use in the production of greater value products.

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