

Conventional Low-density Particleboards Produced With Particles From *Mauritia Flexuosa* and *Eucalyptus* Spp. Wood

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Abstract

The use of alternative raw materials to produce particleboards is an interesting strategy to add value to lignocellulosic biomass and diversify the forest products industry. The aim of this study was to evaluate the potential for using *Mauritia flexuosa* particles in association with *Eucalyptus spp.* wood for the production of particleboards. Prior to the production of the panels, the raw materials were evaluated for basic density and chemical composition. The panels were produced with particles of *Eucalyptus spp.* and *Mauritia flexuosa* in mass proportions of 100/0%, 90/10%, 80/20%, 70/30% and 60/40%, respectively. The quality of the particleboards was evaluated by water absorption and thickness swelling, internal bonding and static bending tests. As *Eucalyptus spp.* particles were replaced by *Mauritia flexuosa*, the panels showed less dimensional stability, due to the fact that the compression ratio increased due to the lower density of *Mauritia flexuosa* particles. The substitution of 1% of *Mauritia flexuosa* particles caused a reduction of 10.49 MPa for MOE, 0.09 MPa for MOR and 0.01 MPa for internal bonding. The results demonstrate that it is feasible to replace up to 17.5% of *Eucalyptus spp.* wood with particles from *Mauritia flexuosa* so that the panels have physical and mechanical properties appropriate to the marketing standards.

Introduction

Due to the industrial expansion of wood panels, there is an increase in the demand for raw material, making it necessary not only the expansion of plantation areas with forest species, but also the search for new options for lignocellulosic raw materials (Faria et al. 2021).

In recent years, studies reporting the potential for insertion of lignocellulosic material particles in association with *Pinus* and *Eucalyptus* woods have been reported in the literature, such as coffee husks (Martins et al. 2021); corn cob (Ramos et al. 2021) and sesame stem (Legesse et al. 2021). These studies showed that there is a large availability of lignocellulosic waste with potential for the production of particleboards, adding value to these wastes and diversifying the raw materials used.

The production of particleboards from lignocellulosic materials allows adding value to these raw materials, reducing production costs and the possibility of inserting residual biomass (Chalapud et al. 2020). Current perspectives demonstrate that there is technical-scientific feasibility of using non-wood biomass for the production of particleboards.

A lignocellulosic material that can be an alternative for the production of boards is the sheath and petiole of the Buriti tree. *Mauritia flexuosa* (buriti) is a natural palm from the Amazon and spreads over the Cerrado and Pantanal of Brazil, occupying poorly drained soils, with an altitude of less than 1000 meters, being considered the most abundant palm in the country. The petioles are internally composed of very light and fibrous material.

Thus, this work aims to analyze the potential use of particles of *Mauritia flexuosa* in association with wood of *Eucalyptus spp.* aiming to improve the physical and mechanical properties of particleboards

and, consequently, subsidize the future diversification of the forest products industry in Brazil, with possible applications in civil construction and the furniture industry.

Material And Methods

Collection and characterization of *Mauritia flexuosa* and *Eucalyptus spp.*

The particleboards were produced using particles of *Mauritia flexuosa* (Lnn.f.) and wood of *Eucalyptus spp.* Five 7-year-old *Mauritia flexuosa* palm trees were used to collect fiber bundles, which were collected in the rural area of the city of Trizidela do Vale-MA, removed from the sheath and petiole of the leaves, in the green condition. Three 3-year-old *Eucalyptus spp.* trees were collected in an experimental plantation located on the Jatobá campus of the Federal University of Jataí. The trunks were sectioned into 60 cm long logs and later crushed in a hammer mill.

The fiber bundles of *Mauritia flexuosa* were oven dried at 105 ± 2 °C for 24 h to reduce moisture content to a final value of 3%. After drying, they were processed in a hammer mill to obtain sliver particles. Afterwards, the particles were sieved in a vibrating sieve, and only the particles retained between the 10 mesh (2.00 mm) and 30 mesh (0.595 mm) sieves were used in the production of the particleboards.

Prior to the production of particleboards, the raw materials studied were characterized according to their basic densities and chemical constituents. The basic density of *Mauritia flexuosa* particles was obtained after particle saturation and subsequent volume measurement in a measuring cylinder. The particles were oven dried at 105 ± 2 °C for 24 h and the dry weight/saturated volume ratio was calculated, following the methodology described by Scatolino et al. (2019). The basic density of the wood was carried out following the guidelines of the NBR 11941 (ABNT 2003) standard. For the chemical analysis, the materials were transformed into sawdust in a knife mill and the particles used were those between 40 mesh (0.420 mm) and 60 mesh (0.250 mm) sieves. The following standards were used to determine the chemical constituents of lignocellulosic materials: total extractive content - NBR 14853 (ABNT 2010); insoluble lignin content - NBR 7989 (ABNT 2010) and ash content - NBR 13999 (ABNT 2017).

Production of particleboards

For the bonding of the particles, urea-formaldehyde adhesive was used, with solids content of 53.07%, pH of 8.32, viscosity of 0.465 Pa.s and gel formation time of 49 seconds, applied at a rate of 10% in relation to the dry mass of the particles, a rotating drum being used to spray the adhesive onto the particles.

The particleboards were produced with dimensions of 250 mm x 250 mm x 15 mm and target density of 0.60 g/cm³. Five different compositions were evaluated by substitution of different percentages of *Eucalyptus spp.* by particles of *Mauritia flexuosa*. Each composition had five replications (five particleboards), totaling 25 particleboards. The different percentages of *Mauritia flexuosa* used in the five compositions are shown in Table 1.

Table 1 Compositions of particleboards

Abbreviation	<i>Eucalyptus spp.</i> + <i>Mauritia flexuosa</i>
E100/M0	100% + 0%
E90/M10	90% + 10%
E80/M20	80% + 20%
E70/M30	70% + 30%
E60/M40	60% + 40%

The particleboards were pre-pressed at 0.5 MPa for 5 min at room temperature. Subsequently, the boards were pressed at a temperature of 160 °C at a specific pressure of 4.0 MPa for a period of 15 min. Then, the boards were placed in a climatic chamber at a temperature of 20 ± 3 °C and relative humidity of 65 ± 5% until reaching equilibrium humidity of approximately 12% and the complete polymerization of the adhesive. Fig. 1 shows the stages of production of particleboards.

Evaluation of physical and mechanical properties of particleboards

The compression ratio (RC) was calculated by the bulk density of the panel divided by the basic density of the particles of *Mauritia flexuosa* and *Eucalyptus spp.*, as described by Scatolino et al. (2017).

$$RC = \frac{da}{dbm \times (mf\%) + eud \times (eu\%)}$$

In which: *da* is the bulk density of the particleboard (g/cm³), *dbm* is the basic density of *Mauritia flexuosa* (g/cm³), *mf%* is the *Mauritia flexuosa* content in the panel, *eud* is the basic density of the wood of *Eucalyptus spp.* (g/cm³), and *eu%* is the content of *Eucalyptus spp.* wood on the panel.

For the evaluation of the technological properties of the particleboards produced, 4 specimens were removed per panel in the dimensions of 50 x 50 mm to determine the water absorption after 2 and 24 hours of immersion (WA 2h and WA 24h), thickness swelling after 2 and 24 h of immersion (TS 2h and TS 24h) and internal bonding (IB) according to the procedures of standard D1037 (ASTM 2012). To calculate the modulus of rupture (MOR) and elasticity (MOE) in the static bending test, 3 test specimens were extracted in dimensions 250 x 50 mm per panel, based on DIN-52362 (1982) standard.

To evaluate the technological properties of the particleboards, the data were analyzed considering completely randomized design, being submitted to analysis of variance (ANOVA) and regression, both at 5% significance, to evaluate the effect of inclusion of particles of *Mauritia flexuosa* in the composition of particleboards. Data were processed in Sisvar 5.6 software (Ferreira et al. 2014).

Results And Discussion

Physical and chemical characterization of *Mauritia flexuosa* and *Eucalyptus spp.*

The particles of *Eucalyptus spp.* had a basic density of 0.40 g/cm³ while the particles of *Mauritia flexuosa* had a 0.11 g/cm³ one. A lower basic density of particles results in a greater quantity of particles to obtain the same mass, thus increasing the compression ratio that influences the physical and mechanical properties of the particleboards produced.

Biomass with lower densities is required to produce high quality particleboards, as is the case of agro-industrial waste. However, there is a minimum limit for the density of the raw material in order to obtain the ideal compression ratio and, consequently, the production of particleboards with satisfactory properties for use in civil construction and the furniture industry. As the basic density of the particles of *Mauritia flexuosa* was 3.6 times lower than those of *Eucalyptus spp.* the panels produced may present a reduction in several physical and mechanical properties, due to the greater volume of particles in the panels (Scatolino et al. 2019).

Several researchers have studied the replacement of wood with these wastes in the production of particleboards. In general, lignocellulosic waste usually have low basic density, as verified for soybean pods - 0.200 g/cm³ (Faria et al. 2020) and coffee parchment - 0.100 g/cm³ (Scatolino et al. 2017).

As observed in Table 2, the particles obtained from non-wood biomass had higher total extractives contents in relation to the particles of *Eucalyptus spp.* The physical and chemical properties of the raw materials used in the production of particleboards are directly related to the final characteristics of the panels produced. Therefore, such properties can vary according to cultivation methods, environmental conditions such as rainfall and soil fertility.

Table 2 Basic density and chemical composition of *Eucalyptus spp.* and *Mauritia flexuosa*

Raw material	Total extractives (%)	Insoluble lignin (%)	Ash (%)
<i>Eucalyptus spp.</i>	3.59 ± 0.06*	27.27 ± 0.53	0.51 ± 0.02
<i>Mauritia flexuosa</i>	12.43 ± 0.23	20.88 ± 0.28	5.25 ± 0.08

* Standard deviation.

For total extractives, *Mauritia flexuosa* presented higher mean values. It has been reported in the literature that non-wood lignocellulosic biomasses have a higher content of extractives in their chemical composition. Scatolino et al. (2017) determined for the coffee parchment 26.24% of total extractives, while the *Eucalyptus* wood presented 3.59%. The higher content of extractives in non-wood biomass can influence the physical-mechanical performance of particleboards. Iwakiri (2005) reports that the higher the content of total extractives in lignocellulosic raw materials, the greater their chances of not generating quality reconstituted panels, due to their propensity to cause problems with adhesive consumption, reduced mechanical strength and water absorption, in addition to the occurrence of air bubbles during pressing.

Non-wood lignocellulosic materials stand out with lower lignin contents and higher proportions of extractives in their compositions when compared to wood lignocellulosic materials. Pereira et al. (2016) reported that lignin increases the cohesion and adhesion forces of particles, which consequently can improve the quality of adhesiveness in particleboards of lignocellulosic materials with higher amounts of lignin. Thus, lignin is directly related to the stiffness of the panel.

The ash content observed in *Mauritia flexuosa* particles was 10 times higher than the mean value found for *Eucalyptus spp.* Ash values above 0.5% negatively interfere with the panel's adhesiveness, by affecting its pH and hindering material processing, increasing the wear of cutting tools (Iwakiri 2005).

Physical properties of particleboards

There was no significant effect of the replacement of *Mauritia flexuosa* particles on the bulk density of the particleboards produced (Fig. 2). This result is considered positive, as it allows us to precisely understand the consequence of the addition of *Mauritia flexuosa* particles on the physical and mechanical behavior of chipboards.

It is observed that the averages of the bulk density values varied between 0.48 and 0.55 g/cm³ (Fig. 2), with the panels classified as having low density (Iwakiri 2005). The average bulk densities obtained were lower than the nominal density of 0.60 g/cm³, a fact that can be justified due to the loss of particles during the formation of the mattress and the return in thickness of the panels after removal from the press and packaging. These results do not compromise the interpretations of this research, as the variation in bulk density of the chipboards produced was statistically similar. In addition, there was standardization of the production process at the laboratory level. Thus, the results observed for the physical and mechanical properties of the boards refer exclusively to the effect of the raw materials used and not to the production process.

It is observed that the addition of *Mauritia flexuosa* particles insertion causes a linear increase in the compression ratio (Fig. 3). The results demonstrate that for each 1% insertion of *Mauritia flexuosa* in the composition of the panel, there is an increment in the compression ratio in the order of approximately 0.02. Such results are due to the low density of particles of *Mauritia flexuosa* (0.11 g/cm³) in comparison with wood of *Eucalyptus spp.* (0.40 g/cm³). Maloney (1993) established that the ideal range for the compression ratio is between 1.3 to 1.6. Replacing these values recommended by these authors in the regression equation obtained, it is observed that the amount of *Mauritia flexuosa* added to panels that meet this requirement ranged between 5.6 and 24.2%.

In the case of low-density particleboards, it is observed in the literature that the compression ratio increases as lignocellulosic waste are inserted into the panels to replace wood, as observed by Guimarães et al. (2019), with an increase in the compression ratio from 1.5 to 2.2 in particleboards produced with 0 and 50% of soybean hulls in substitution of *Eucalyptus grandis* wood, respectively.

It is observed that the increase in the insertion of *Mauritia flexuosa* in the panel in the order of 1% provides an increase of 0.99 and 0.90% in water absorption after 2 and 24 hours of immersion, respectively (Fig. 4). This can be explained by the increase in the compression ratio of the panels, as those produced with greater amounts of *Mauritia flexuosa* showed an increase in this property, which leads to a greater number of compacted particles in the same volume and, consequently, a greater amount of hydroxylic sites and greater affinity of this material with water. Another justification for the increase in water absorption values is due to the addition of empty spaces in the panels, a fact caused by the greater number of particles.

For water absorption levels, a similar behavior was described by Guimarães et al. (2019) in a study with low density particleboards. The authors evaluated the replacement of *Eucalyptus grandis* wood by soybean crop waste and found an increase in water absorption levels, ranging from 30.15 to 125.1% for water absorption after 2 hours of immersion and from 50 to 145% for water absorption after 24 hours of immersion. In this sense, the results suggest that *Mauritia flexuosa* provided the panels with dimensional behavior similar to that reported in the literature. Thus, the behavior observed for water absorption can be associated with pressing conditions, occurrence of empty spaces, compression ratio of particleboards and chemical composition of the lignocellulosic material used.

In Fig. 5, the properties of thickness swelling can be seen after 2 and 24 hours of immersion in water. The smallest coefficients of determination (R^2) of the regression models indicate greater variation in thickness swelling values in relation to the adjusted line. In general, the percentage of *Mauritia flexuosa* explained from 56% to 60% the swelling in thickness after 2 and 24 hours of immersion in water.

Despite the increase in thickness swelling contents, the coefficients of variation for this property reduced as higher percentages of *Mauritia flexuosa* particles were inserted into the panels. For thickness swelling after 2 hours of immersion in water, the coefficient of variation decreased from 20.89 to 7.38% for panels produced with 0 and 40% of *Mauritia flexuosa* particles, respectively. On the other hand, for thickness swelling after 24 hours of immersion in water, the variation was from 11.43 to 6.0%. The homogeneity of the physical properties is a fundamental criterion for the application of chipboards in the production of furniture, especially in conditions where the furniture will be exposed to variations in ambient relative humidity.

It can be noted that the increase in the insertion of particles of *Mauritia flexuosa* in the panel in the order of 1% provides an increase of 0.16 and 0.10% of swelling in thickness after 2 and 24 hours of immersion, respectively. This trend can be explained by the fact that compositions with greater amounts of *Mauritia flexuosa* present higher values of compression ratio. According to Mendes et al. (2012), a higher compression ratio leads to a lower amount of adhesive per particle, which causes poorer quality of bonding and greater swelling in thickness. A higher compression ratio can be related to the increase in the amount of particles, and, consequently, greater densification of the panel, thus promoting greater hygroscopic swelling of the *Mauritia flexuosa* particles and the release of greater compression tensions generated during the high temperature pressing process.

Scatolino et al. (2019) produced low density particleboards with *Eucalyptus urophylla* x *Eucalyptus grandis* wood and cotton waste and observed mean values ranging between 11.34 and 23.93% for thickness swelling after 2 hours of immersion and 14.17 and 27.45% after 24 hours of immersion, therefore, values close to those observed in this work. The Commercial Standard - CS 236-66 (1968) stipulates maximum thickness swelling values after 24 hours of immersion of 30% for low density particleboards produced with urea-formaldehyde adhesive. In summary, despite the trends found, all panels met this regulatory requirement.

Mechanical properties of particleboards

In Fig. 6, the property of internal bonding for the particleboards produced is verified. The linear regression was the one that best represented the relationship between the inclusion percentage of *Mauritia flexuosa* particles and the internal bonding values. There was a reduction in the mean values of this property with an increase in the proportion of *Mauritia flexuosa* in the composition of low-density particleboards.

For internal bonding, the observed trend can be explained by the increase in the proportion of extractives in the panels, with the increase in the insertion of *Mauritia flexuosa* particles. Marra (1992) states that lignocellulosic materials with high extractive contents present bonding difficulties, resulting in low resistance of the adhesive bond between the particles. Another factor to which this result can be attributed to is the low density of *Mauritia flexuosa* particles, which increases the compression ratio. This causes lower availability of adhesive per particle, which could have harmed bonding (Iwakiri 2005).

Guimarães et al. (2019) reported similar behavior in a study carried out with soy hulls for the production of low-density particleboards, in which the authors observed a tendency to reduce the mean values of internal bonding as particles of the soybean hulls were inserted, varying between 0.85 and 0.10 MPa for panels produced with 0 and 100% waste, respectively.

The CS 236-66 (1968) commercial standard establishes a minimum value of 0.14 MPa for internal bonding strength in low density panels produced with urea-formaldehyde adhesive. In this sense, by equating the norm value with the equation observed in the linear regression, it is noted that the maximum insertion of *Mauritia flexuosa* in the panel to meet the normative requirements is 31.6%.

Fig. 7 shows the behavior of the mean values of MOE and MOR to the static bending test for the particleboards produced with particles of *Mauritia flexuosa*. It can be seen that the 1% increase in the proportion of *Mauritia flexuosa* in the panel promotes a decrease in MOE in the order of 10.5 MPa and in MOR of 0.1 MPa.

For the MOE and MOR values, the observed trend can be explained due to the reduced lignin content (20.9%) in the *Mauritia flexuosa* particles when compared to *Eucalyptus spp.* (27.3%). This is due to lignin's intrinsic characteristics of increasing the rigidity of the cell wall and contributing to the consolidation of particles in function of functioning as a natural adhesive (Mani et al. 2006). Another fact that justifies the decrease in MOE and MOR as the insertion of *Mauritia flexuosa* particles increases is

probably linked to the compression ratio. Maloney (1993) emphasize that higher compression ratios can lead to an increase in the specific surface area of the particles. Under these conditions, the application of the same adhesive content reduces its availability per unit of surface area of the particles, which can result in panels with lower values in mechanical properties. Some extractives can result in a decrease in mechanical properties due to the inhibition of reactions between adhesive and raw material (Iwakiri 2005).

Martins et al. (2018) evaluated different percentages of soybean pod particles in replacement of *Eucalyptus sp.* in low-density particleboards and observed the same trend as in this work. The values obtained by these authors ranged from 435.21 to 1297.68 MPa for MOE and 2.41 to 7.57 MPa for MOR. The authors justify that the observed decreasing trend would have occurred due to the low basic density of the waste, which increased the compression ratio of the panels, which varied between 1.21 and 2.95. The results indicate that the compression ratio is a more relevant factor to explain the mechanical properties of the panels compared to the chemical composition. The low density of lignocellulosic waste can overcome the effect of the chemical composition on the quality of adhesion and, consequently, the high compression ratio values can result in a decrease in the mechanical properties of the chipboards. However, as previously reported, the ideal compression ratio values can vary significantly according to the lignocellulosic biomass used in the production process of the particleboards. According to Guimarães Junior et al. (2011), the traction strength and the modulus of elasticity of lignocellulosic materials are directly proportional to the cellulose content. In addition, the carbohydrate content of biomass is related to a higher occurrence of interfibrillar bonds, because of the chemical functionality for the formation of hydrogen bonds. This can affect, for example, the mechanical properties of particleboards.

The CS 236-66 (1968) commercial standard establishes as a minimum value for low density and urea-formaldehyde adhesive panels the value of 1052 MPa for MOE and 5.6 MPa for MOR. When the normalized value is equaled in the linear regression generated for this property, it is observed that the limit point for insertion of *Mauritia flexuosa* particles in the panel to meet the normative requirements is 17.5% for MOE. As for MOR, all treatments presented values higher than the requirements of the standard.

Based on the results presented, *Mauritia flexuosa* becomes a possible raw material with potential to replace the traditional species used in the production of particleboards, *Pinus* and *Eucalyptus*. The use of alternative biomass proves to be viable not only in terms of economic factors, but also ecological and social (Mendes et al. 2010), thus being able to add value to the clean production chain associated with extractivism in *Mauritia flexuosa*.

Conclusion

The replacement of *Eucalyptus spp.* by *Mauritia flexuosa* led to an increase in the values of water absorption and thickness swelling, in addition to a decrease in mechanical properties. This behavior was justified by the low density of non-wood waste, with more particles and, consequently, a reduction in the availability of adhesive per particle, affecting the panel when it is subjected to traction forces.

Finally, the results verified in this work allowed the inclusion of *Mauritia flexuosa* as a promising biomass in the production of particleboards.

Declarations

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Availability of data and material

The datasets supporting the conclusions are included in the manuscript. Further, the datasets analyzed in this research are available from the corresponding author upon request.

Code availability

Not applicable

Authors' contributions

Douglas Lamounier Faria and Jane Cecília Oliveira Guimarães: Conceptualization, Methodology, Investigation, Roles/Writing - original draft; Thiago de Paula Protásio: Writing - review & editing; Lourival Marin Mendes and José Benedito Guimarães Junior: Supervision, Funding acquisition, and Project administration. All authors read and approved the final manuscript.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures



Figure 1

Production stages of particleboards

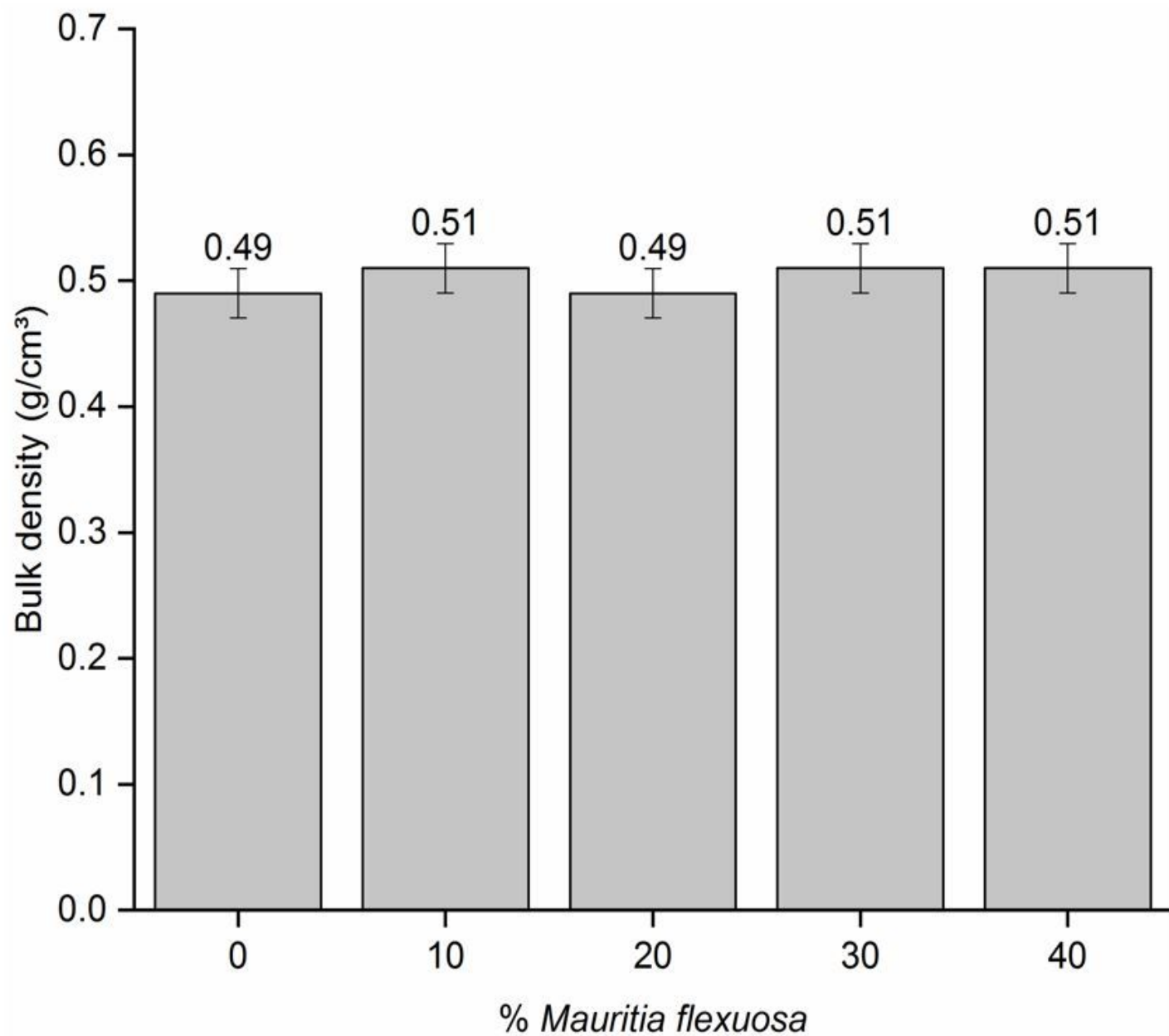


Figure 2

Bulk density of particleboards

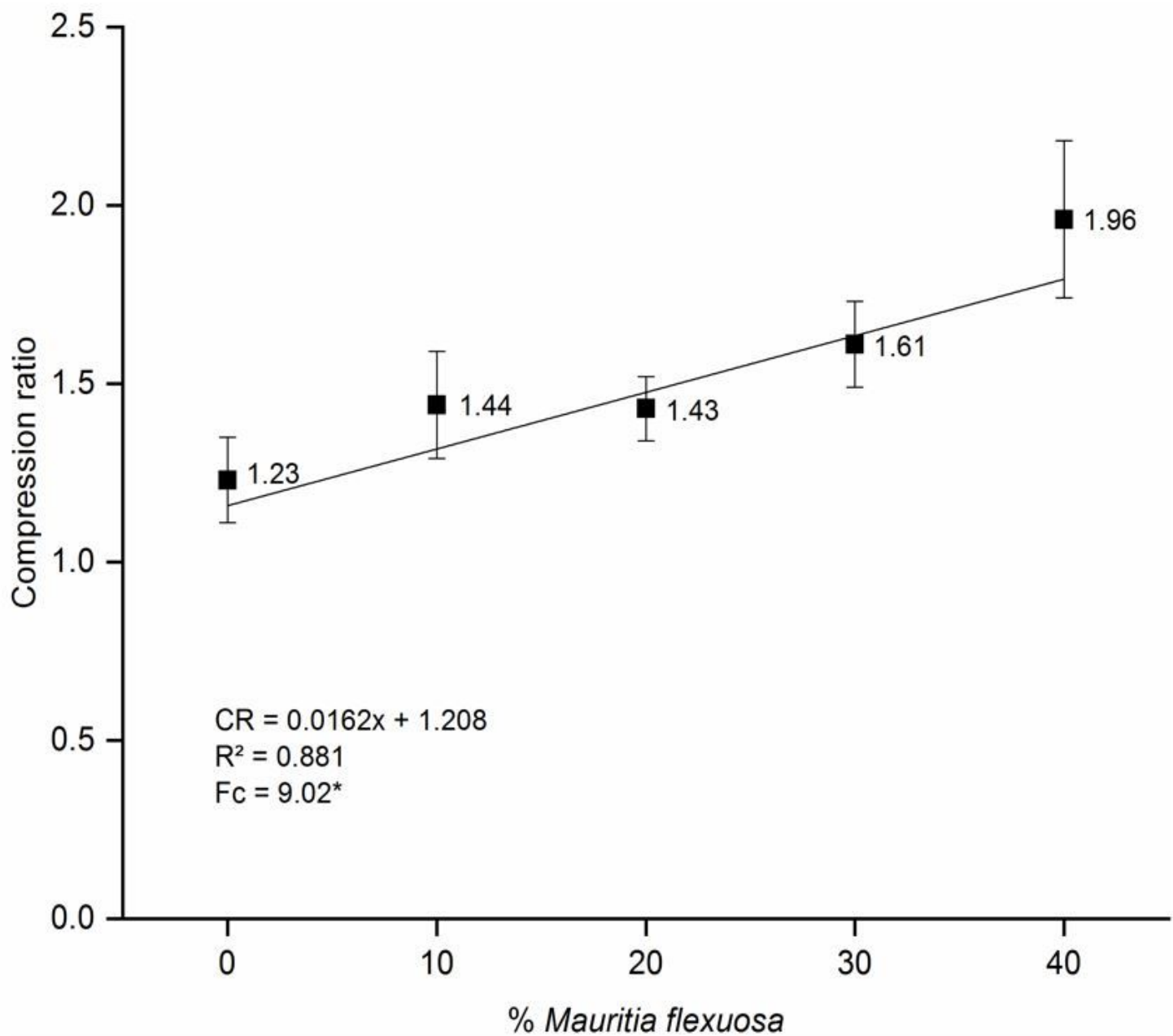


Figure 3

Compression ratio of particleboards. *Significant at 5% significance

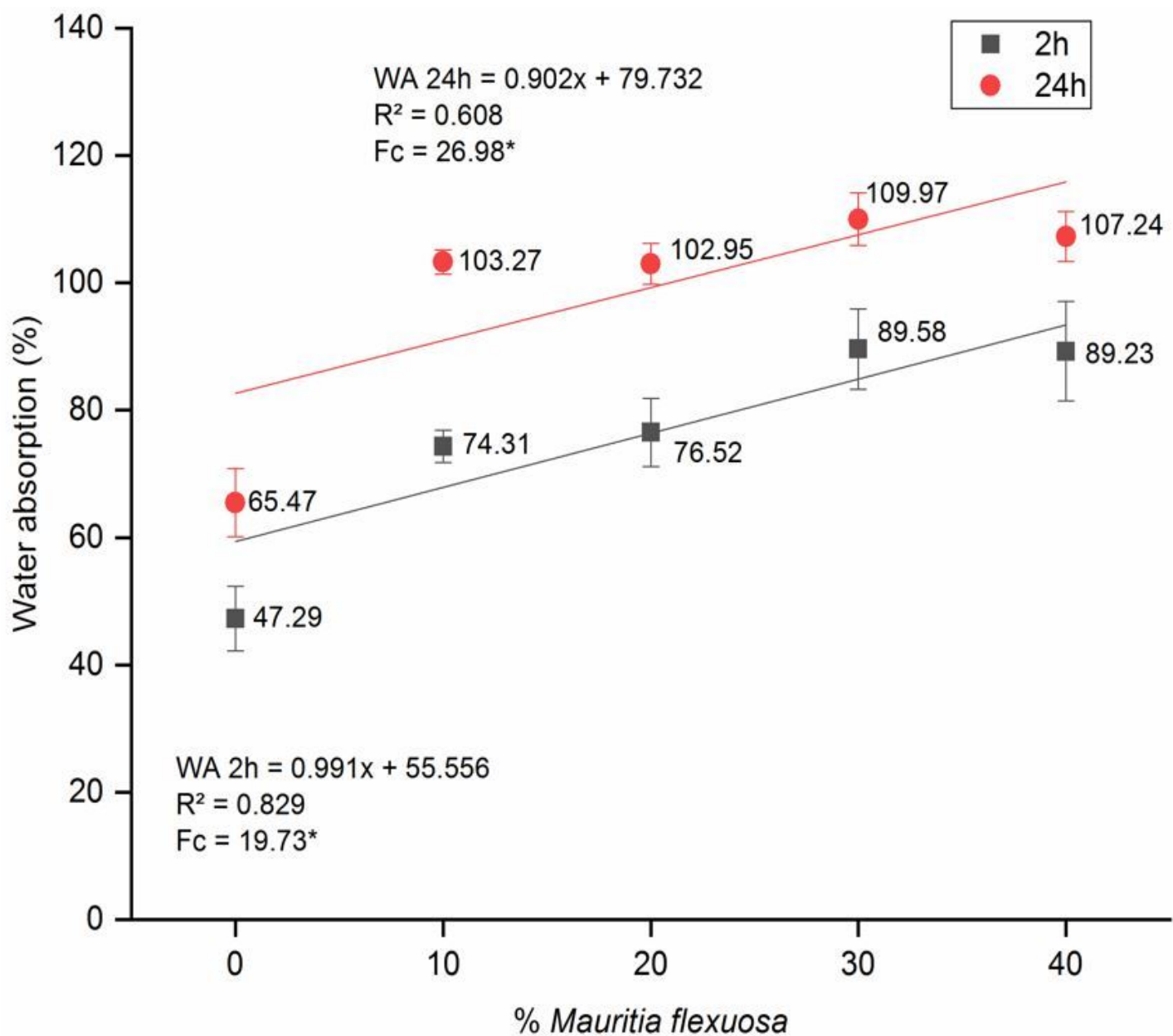


Figure 4

Water absorption after 2 and 24 hours of immersion of the particleboards, where (*) - significant at the 5% level of significance

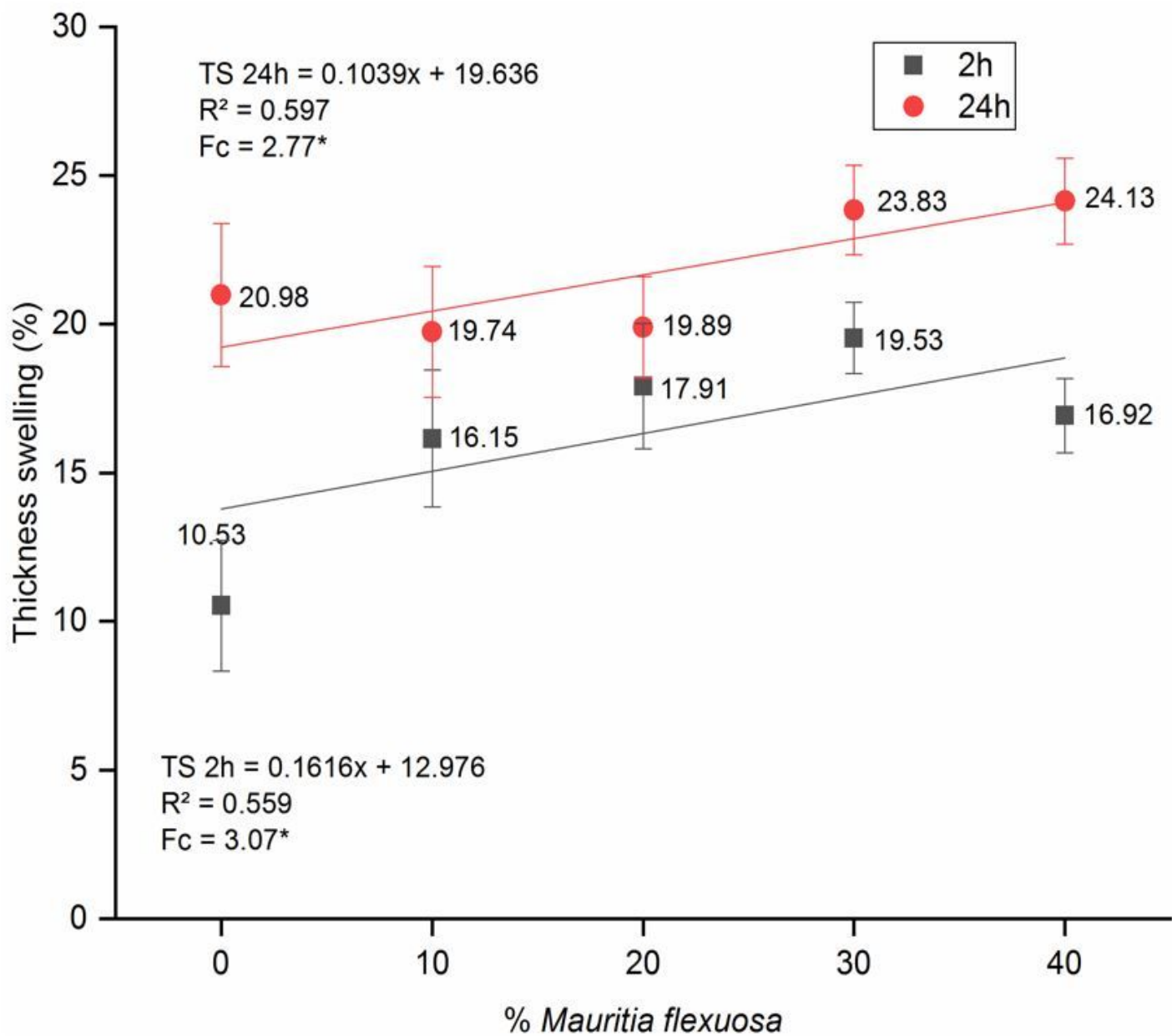


Figure 5

Thickness swelling after 2 and 24 hours of immersion of the particleboards, where (*) - significant at the 5% level of significance

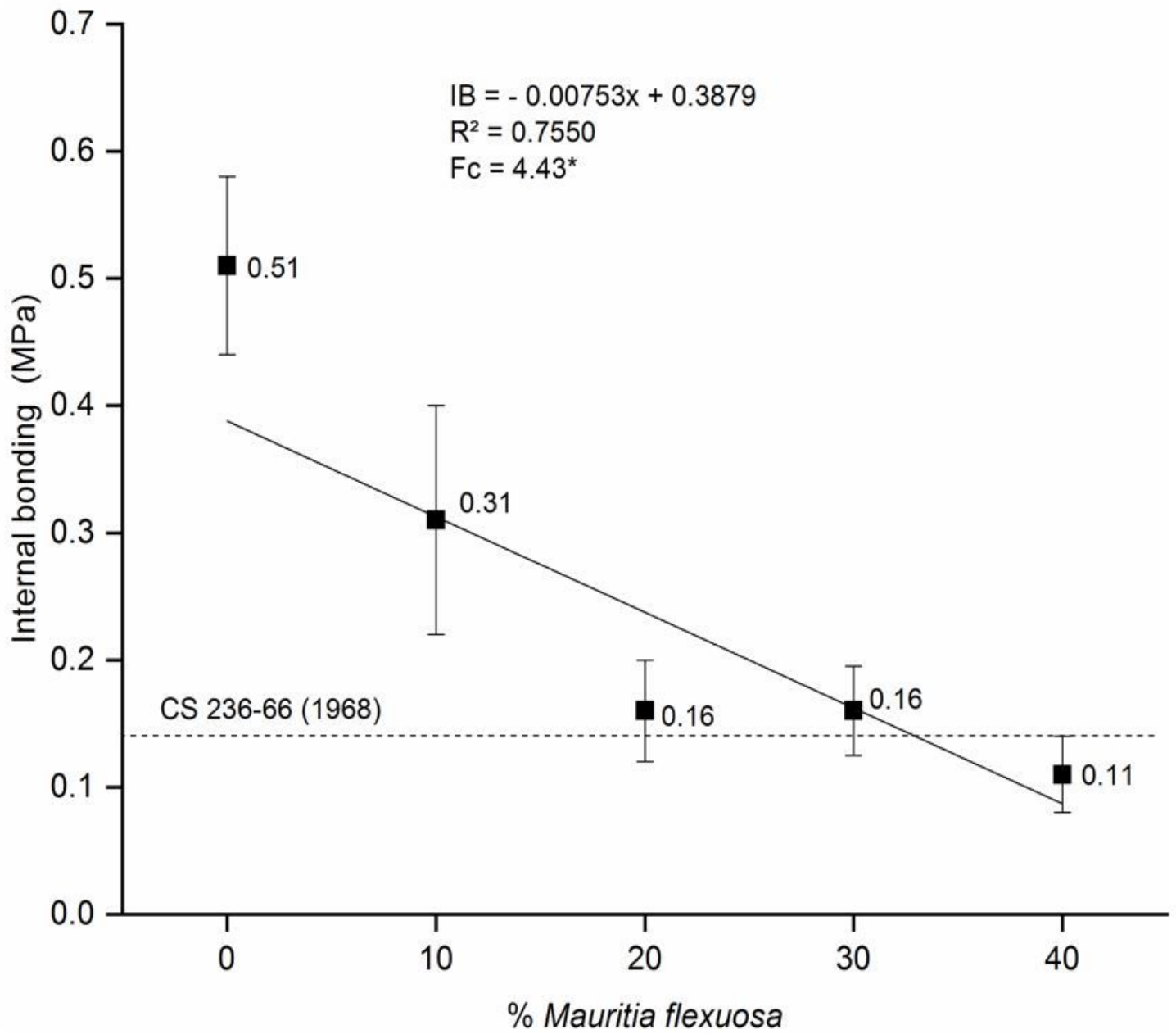


Figure 6

Internal bonding of the particleboards, where (*) - significant at the 5% level of significance

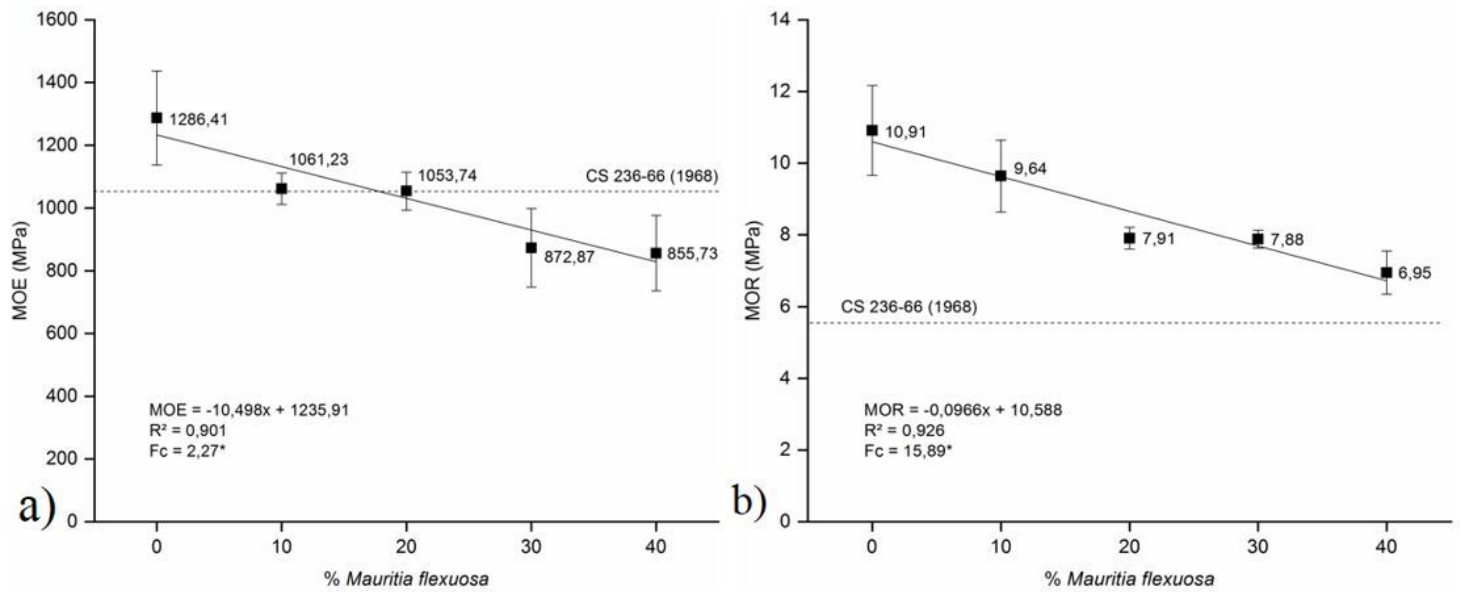


Figure 7

Modulus of elasticity (a) and Modulus of rupture (b) to the static bending test of particleboards, where (*) - significant at the 5% level of significance