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Development and investigation on physical and mechanical properties of mahogany sawdust particleboards made with tannic powder of Indian tamarind (*Pithecellobium Dulce Benth*)

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Abstract

The recycling of forest residues was investigated in the present study. It arms to determine the physical and mechanical properties of particleboards from mahogany sawdust bonded by pearls bone glue or tannic powder of peel of Indian tamarind (*Pithecellobium Dulce*). The influence of the size of particles on the physical and mechanical properties of the particleboards is studied. Five different granulometries (raw sawdust; $2.5 < g \leq 5$; $1.6 < g \leq 2.5$ and $0.8 < g \leq 1.6$, and $g \leq 0.8$) were investigated. The rate of the adhesives used were 5; 6.5; 7; 7.5; 8; 10, 12.5 and 15 percent. Physically, the density, thickness swelling (TS) and water absorption (WA) were evaluated. Mechanically, the modulus of elasticity (MOE), the modulus of rupture (MOR), the modulus of Young E, the tensile modulus of rupture (MOT) and the internal bond (IB) were determined. The results obtained showed that the granulometry has a great influence on the physical as well as the mechanical properties of the Mahogany sawdust particleboards. The pressing temperature is 160 °C. The threshold fixed by the American standard ANSI A208.1-2016 for the MOE and the MOR are widely reached. The values of the density classified the particleboards from sawdust of Mahogany wood in the categories of low and mean density. The thickness swelling and water absorption has not respectful to the American standard ANSI A208.1–2016 [1]. So, the manufactured boards can only be used in dry conditions.

Keywords: Sawdust particleboards; Tannic powder; Pithecellobium Dulce Benth peel; Binder content; Physical and mechanical properties

1. Introduction

Research work on the development of composite materials made from biodegradable resources are of great interest lately. Biodegradable resources such as agricultural residues are abundant and their management causes some environmental issues when not well addressed. For example, in certain regions in Togo, residues from agricultural crops are burnt and become very pollutant. Therefore, a good recycling of these residues is necessary in order to bring in some added value for economic benefits. Composite materials combine the strength of the matrix with the hardness of the

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binder to obtain a material with specific desired properties such as great strength, great resistance, light weight, etc. The wastes of agricultural crops can be used in the production of wood and plastic-based particleboards materials [1–5]. Particleboards are composite materials with a variety of utilization in the field of automotive industries, aeronautic, furnishing and building construction. They have become consumables since 1940 and since then their usage is always increasing, passing from 14 million of cubic meters (m^3) in 1998 to 32 million of cubic meters in 2004 [6]. Particleboards made from Kenaf stems have been deeply studied in the literature [7–11] and the latest results showed that these particleboards meet the panels properties values required by the standard ANSI A 208.1- 2016 [12, 13]. The use of a natural binder such as pearls bone glue which is of animal origin is motivated by an eco-friendly purpose against usual binder that is made from formaldehyde. Despite the fact that formaldehyde-made binder is cheaper and used widely in the industry, it has been proven that it is dangerous for Human and its environment [14]. In the present study, sawdust of Mahogany wood has been used. The particleboards are manufactured by thermic pressing and with the use of two binders: tannic powder of Indian tamarind and pearls bone glue. The physical properties (density, water absorption and thickness swelling rate) and the mechanical properties (MOE, MOR, E, MOT and IB) of the composite are determined, in order to study the possibility, use the sawdust of Mahogany wood as partial or complete alternative in wood–based particleboards.

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2. Material and methods

2.1. Preparation of the tannic powder of the peel of Indian tamarind

The peels of *Pithecellobium Dulce Benth* are dried in an oven of MEMMERT type, from the LARASE (Laboratory of Research on The Agric resources and Environmental Health) at the University of Lomé. The temperature of drying is 72°C and the time of drying is seventy–two (72) hours. These peels are then cut into small pieces and crushed (Figure 1a). The grinder has knives and is of RETSCH SK 1000 type. It is equipped with a sieve with the diameter of the mesh of 0.125 mm to obtain tannic powder (Figure 1). This powder of peel of Indian tamarind is mixed with the particles of sawdust of Mahogany wood at different rates.

a b

Figure 1 Indian tamarind: (a) The peel and (b) tannic powder

The purity of *Pithecellobium Dulce* tannin is from 25.40 to 34.70

2.2. Preparation of the particleboards of sawdust of Mahogany wood

The mixture of binder and particles weight are 700 grams. The binder and particles weight are determined according to the rate of the binder. The results are presented in the following table (Table 2). Water at a rate of 20% (140 gr) is added to the mixture. The mixture is kneaded for five (5) minutes. The table 1 represent the content of the mixture

Table 1 Weight of the binder and the particles according to the rate of the binder

Binder rate (%)	Binder weight (gr)	Particle's weight (gr)
5.0	35	665
6.5	45.5	654.5
7.0	49	651
7.5	52.5	647.5
8.0	56	644
10	70	630
12.5	87.5	612.5
15	105	595

2.3. Thermal pressing of the particleboards

The mixture is put uniformly in a mould. The mould has been primarily heated up to 160°C. It is then placed between two heating plates of the heat press of CARVER type. A pressure of 11 bars is then applied and maintained during twenty (20) minutes. After, the board is unmoulded, immediately weighted, labelled, its thickness is measured, then it is stored to prevent it from moisture and other alterations. The steps of the preparation of the particleboard are shown in Figure 2. Six (6) particleboards of each rate of binder and a type of binder have been manufactured.

a b c

Figure 2 Thermal pressing steps: mixture in the mould (a), particleboard pressed (b), unmoulded particleboard (c)

2.4. Sample preparation

According to the standard ANSI A208.1–2016, six (6) specimens of dimensions 150 × 50 mm for the three points bending test (Figure 4a), ten (10) specimens of dimensions 50 × 50 mm for the determination of the density (Figure 4c), twelve (12) specimens of the same dimensions for the test of thickness swelling, and six (6) specimens of dimensions 150 × 20 mm for the tensile test, are needed. Three types of specimens are cut from each particleboard: specimens for the three points bending test, specimens for tensile test and thickness swelling (Figure 3).

a b c

Figure 3 Samples for tests: of three points bending (a), tensile (b), thickness swelling and internal bond (c)

3. Results and discussion

3.1. Physical properties

The physical properties are the density, the thickness swelling and water absorption.

3.1.1. Density

The density of the particleboard from sawdust of mahogany increases according to the type of binder and its rate. The following histogram (Figure 4) present the variation of the density of boards of mahogany made with the tannic powder of the peel of P. Dulce according to, its rate and the granulometry. The particleboards manufactured have the density between 663 and 767kg/m³, they are of medium density (MD) according to the standard ANSI A208.1 – 2016. The density increases slightly with the rate of binder for the raw sawdust and fine (g ≤ 0.8). But those of 2.5 < g ≤ 5; 1.6 < g ≤ 2.5 and 0.8 < g ≤ 1.6 decreases

The rate of binder is a parameter which significantly influences the density of the particleboards. It increases with the binder rate and leads to an improvement in the physical behaviours of the particleboards [6–8]. The ANOVA analysis on R gives results which are in table 2.

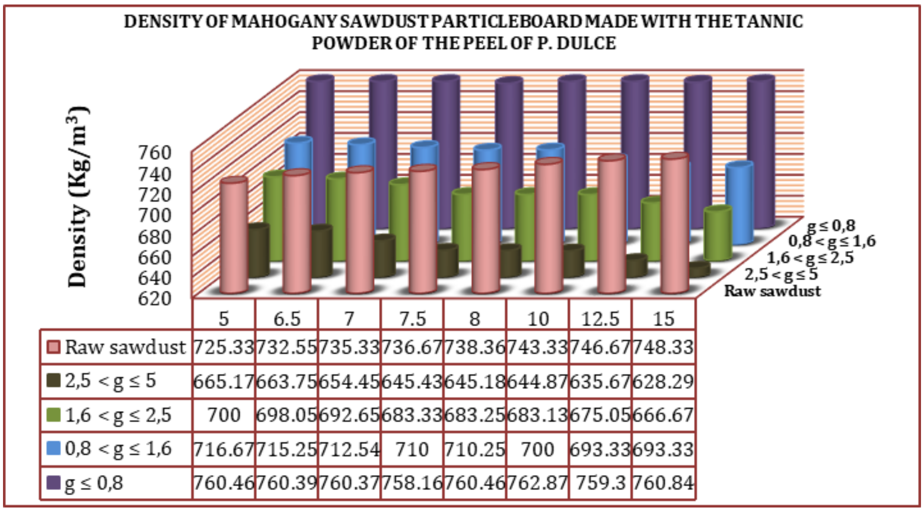


Figure 4 Histogram of the density according to the particle granulometry, binder and its rate

Table 2 Factors effect on the density of mahogany sawdust particleboards

Response density					
Factors	**D.f**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	8278	8278	67.7976	1.382 e-14 ***
Granular	5	258853	86284	706.706	< 2.2 e-16 ***
Binder rate	8	20802	2972	11.060	< 2.2 e-16 ***
Type of binder x Granular	5	5029	1676	13.7293	2.886 e-08 ***
Type of binder x Binder rate	8	295	42	0.3450	0.93238
Granular x Binder rate	40	4076	194	1.596	0.0594.
Residuals	230	27959	122		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom; Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

This result shows that the density varies according to the rate of binder and the granulometry. According to the interactions between different factors, there is no significative interaction between the binder rate and the granulometry. Tukey test in the R software, shows that the first five binder's rates (5; 6.5; 7; 7.5 and 8) and the last three (10; 12.5 and 15) are different. It means that we had to consider only two rates (5 and 10) instead of the eight to investigate the densities.

3.1.2. Thickness swelling (TS)

According to the ANSI A208.1 – 2016, the thickness swelling is 20% for floor panels, 8% for roof panels after two (2) hours and 50% after 24 hours for all types of particleboards. The particleboards from sawdust of mahogany manufactured with tannic powder of the peel of P. Dulce have the thickness swelling rates greater than 20% after 2 hours. After 24 hours immersion the TS is more than for those made with tannic powder of the pod of husk of African locust bean presented by DROVOU and al [9]. Although the particleboards of the peel of *P. Dulce* have a thickness swelling rate higher than the threshold set by the standard, note an improvement compared to the results obtained by Nénoné and Kadja who worked respectively on the panels of kenaf with bio–resins from plants and animals' origins [10, 11]. These results presented in Figures 6 and 7, confirm those of Drovou, [13] and Kadja [11] who characterized the kenaf and cotton panels with pearls bone glue and found that the rate of thickness swelling decreases with the rate of binder. The figures 5 and 6 represent respectively the histogram of the thickness swelling rate after 2- and 24-hours immersion according to the binder rate and the granulometry.

The ANOVA analysis on R result presented in Tables 3 and 4 reveals that the factors (type of binder and the rate of binder) have a significant effect on the TS after 2 hours and 24 hours immersion. The table 3 is the result of TS after 2 hours.

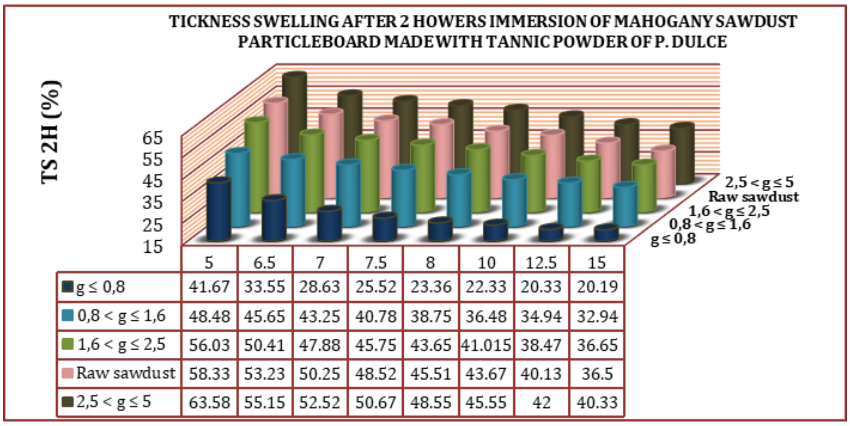


Figure 5 Histogram of the thickness swelling rate after 2 hours immersion according to the binder rate and the granulometry

Table 3 Factors effect on the thickness swelling after 2 hours immersion of mahogany sawdust particleboards

Response TS_2H					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	7945	7945	115.0990	< 2.2 e^{-16} ***
Granular	5	50080	16693	241.8263	< 2.2 e^{-16} ***
Binder rate	8	13006	1858	26.9153	< 2.2 e^{-16} ***
Type of binder x Granular	5	2992	997	14.4471	1.187 e^{-08} ***
Type of binder x Binder rate	8	242	35	0.5010	0.8333
Granular x Binder rate	40	707	34	0.4879	0.9727
Residuals	230	15808	69		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

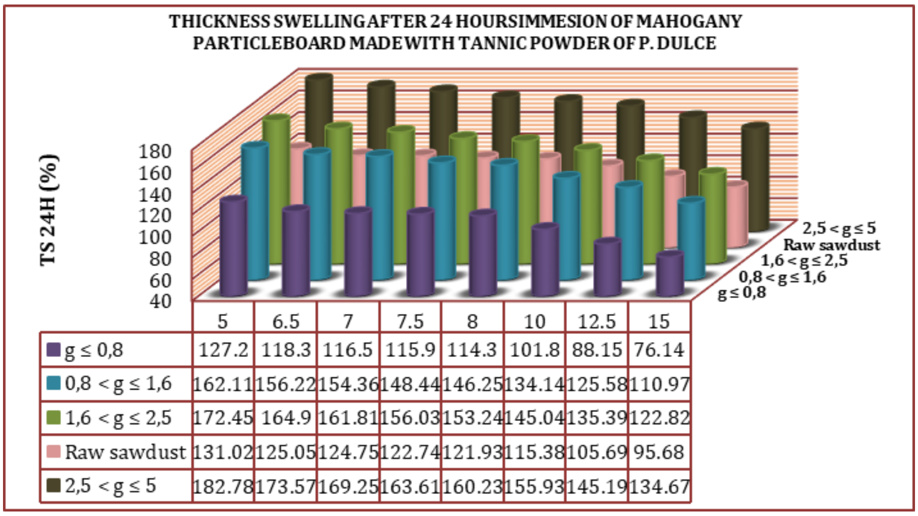


Figure 6 Histogram of the thickness swelling rate after 24 hours immersion according to the binder rate and the granulometry

The interactions between the binder rate and the granulometry are not significant [13, 14].

Analysis of the mean with the Tukey test in the R software shows that the two binders are different according to the thickness swelling rate. As for the binder rates, the first six rates (5; 6.5; 7; 7.5; 8 and 10) and the last two (12.5 and 15) are different. This means that, only two rates of binder (5 and 12.5) instead of the eight are to be considered to investigate the density of all the particleboards. The ANOVA analysis on R gives results which are in table 4.

Table 4 Factors effect on the thickness swelling after 24 hours immersion of mahogany sawdust particleboards

Response TS_24H					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	65506	65506	1167.5358	< 2 e-16 ***
Granular	5	60158	20053	357.4066	< 2 e-16 ***
Binder rate	8	18235	2605	46.4308	< 2 e-16 ***
Type of binder x Granular	5	5580	1860	33.1515	< 2 e-16 ***
Type of binder x Binder rate	8	230	33	0.5853	0.7676
Granular x Binder rate	40	631	30	0.5357	0.9537
Residuals	230	12848	56		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The rate of thickness swelling of the particleboards from sawdust of mahogany with the peel of P. Dulce is higher than the threshold set (20%) after 2 hours and 50% after 24 hours immersion by the standard ANSI A208.1–2016 and could not be used on the floor. The thickness swelling observed in the present study is far from that reported by [15, 16]. For the latter, the thickness swellings obtained for bark panels made with 12% of UF resin binder are 14.1% and 14.2%, after 2 and 24 hours, respectively. It is also higher than those reported by [16] where the thickness swellings vary between 3.3 and 4.5% for a UF resin binder content of 10%.

3.1.3. Water absorption (WA)

The water absorption rate of particleboards from sawdust of mahogany manufactured is higher than 16% after 2 hours and 94% after 24 hours of immersion (figure 7 and figure 8.) The standard ANSI A208.1–2016 has no requirements for water absorption rate.

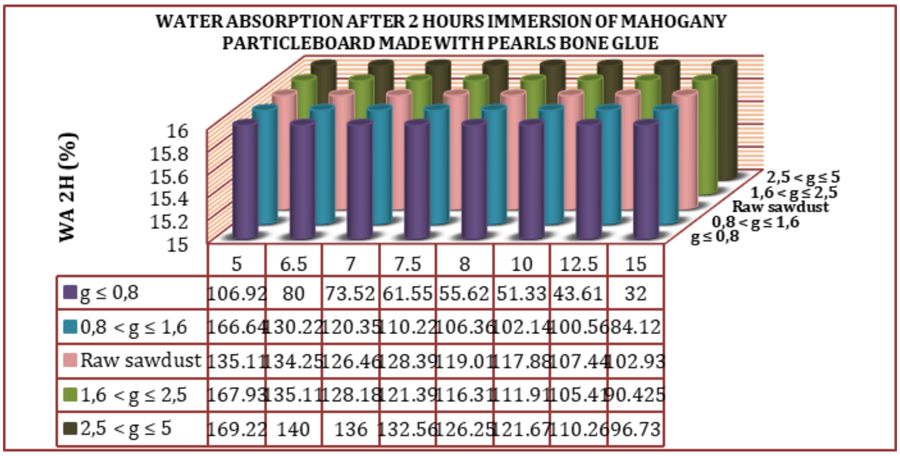


Figure 7 Histogram of the water absorption rate after 2 hours immersion according to the granulometry and the binder rate

The Analysis of the results (Figures. 8 and 9) shows that the particleboards manufactured with the tannic powder of the peel of P. Dulce have absorbed less than those manufactured with those of P. Biglobosa by DROVOU [18]. The ANOVA analysis on R gives results which are in table 5 below.

Table 5 Effect of factors on the water absorption rate after 2 hours immersion of mahogany sawdust particleboards

Response WA_2H					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	1	0.6	0.0054	0 941397
Granular	5	92807	30935.6	294.8076	< 2.2 e^{-16} ***
Binder rate	8	48990	6998.6	66.6945	< 2.2 e^{-16} ***
Type Of binder x Granular	5	1676	558.8	5.3248	0.001452 **
Type of binder x Binder rate	8	270	38.6	0.3682	0.920119
Granular x Binder rate	40	665	31.7	0.3019	0.998922
Residuals	230	24030	104.9		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The water absorption rate has followed that of the thickness swelling. this confirms those of Kadja [10] which characterized the panels of kenaf and cotton with pearls bone glue and Drovou et al. [18].

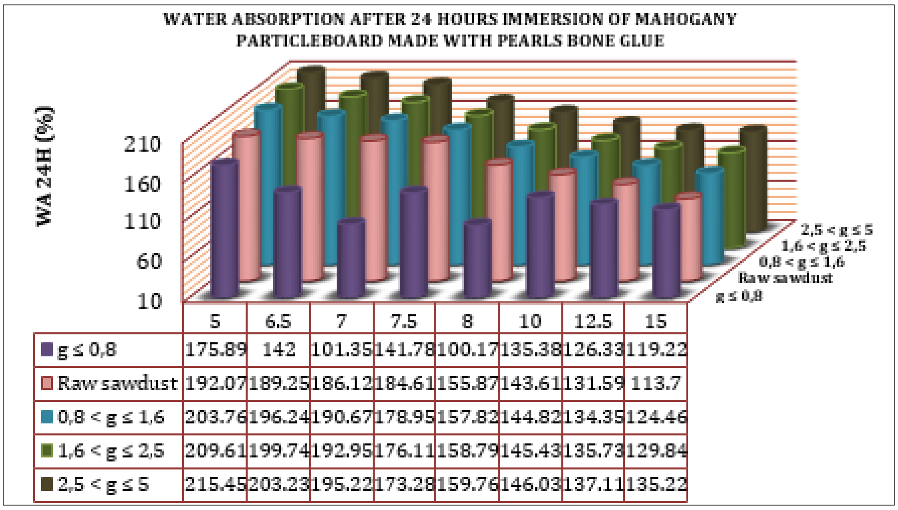


Figure 8 Histogram of the water absorption rate after 24 hours immersion according to the particle size and binder rate

The variance analysis of water absorption rate on the R software is grouped in table 6 for 24 hours immersion.

Table 6 Effect of factors on the water absorption rate after 24 hours immersion of mahogany sawdust particleboards

Response WA_24H					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	323	323.3	2.0876	0.1498706
Granular	5	74679	24892.9	160.7588	< 2.2 e^{-16} ***
Binder rate	8	52989	7569.9	48.8862	< 2.2 e^{-16} ***
Type of binder x Granular	5	3032	1010.6	6.5264	0.0002968 ***
Type of binder x Binder rate	8	176	25.2	0.1624	0.9920995
Granular x Binder rate	40	804	38.3	0.2473	0.9997715
Residuals	230	35460	154.8		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative; Df: Degree of freedom; Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The The water absorption rate of particleboards from sawdust of mahogany varies considerably according to the binder rate. However. The interactions analysis of the above factors shows that the binder rate and the granulometry have no effect on the water absorption rate of the particleboards from sawdust of mahogany after 2 hours and 24 hours immersion. The Tukey test analysis in the R software shows that instead of eight rates of binder, only three (10; 12, 5 and 15) are need to investigate water immersion. This leads to say that only we had to consider two binder rates (5 and 10) instead of the eight to characterize all the panels from sawdust of mahogany.

3.2. Mechanical properties

The mechanical properties are from the three–points–bending, the longitudinal and the facial tensile tests. The properties from those tests are the modulus of elasticity (MOE) and the modulus of rupture (MOR), the young modulus of elasticity (E), the tensile strength (MOT), the internal bond (IB).

3.2.1. Modulus of elasticity (MOE)

The value of MOE of particleboards made with the peel of P. Dulce are in the figure 10. It appears that the behaviour is the raw sawdust. The MOE of mahogany sawdust particleboards varies considerably with the rate of binder (Figure 9). The analysis of the interactions of the above factors shows that the factors have a very significant effect on the MOE. The ANOVA analysis on R gives results which are in table 7 below.

Table 7 Effect of the factors on the MOE of mahogany sawdust particleboards

Response MOE					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	5236925	5236925	8.9245	0.0031199 **
Granular	5	7082271130	236090377	402.3347	< 2.2 e-16 ***
Binder rate	8	104818959	1497414137	25.5183	< 2.2 e-16 ***
Type of binder x Granular	5	13080480	4360160	7.4304	9.043 e-05 ***
Type of binder x Binder rate	8	1289559	1842180	3.1394	0.0034706 **
Granular x Binder rate	40	3095534	1474059	2.5120	0.0004428 ***
Residuals	230	134377829	586801		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 *: significative; ***: very significative. Df: Degree of freedom; Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The Tukey test analysis of the mean in the R software shows two different binder rates: (5; 6.5; 7; 7.5 8; and 10) and (12.5 and 15). It means that to investigate the MOE of all the panels, only the two binder rates is need (5 and 12.5) instead of the eight we considered.

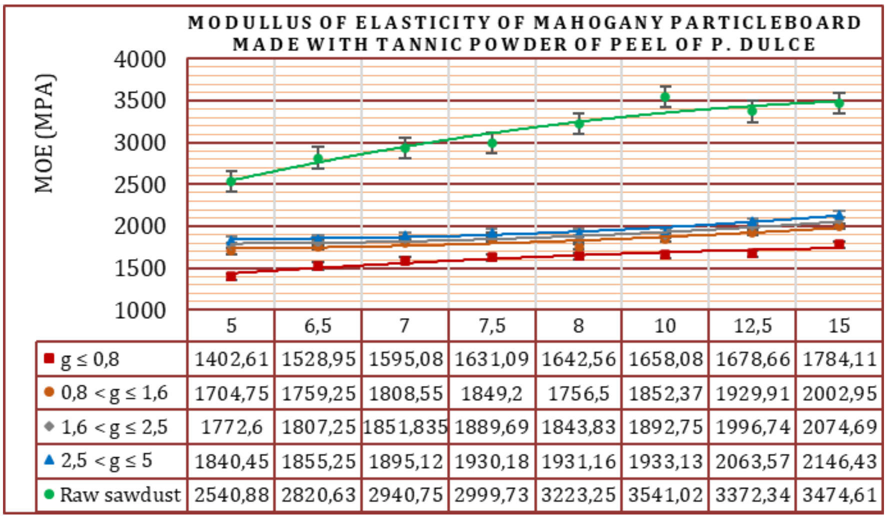


Figure 9 Variation of the modulus of elasticity according to the granulometry and binder rate

The requirements of standard ANSI A208.1–2016 (MOE = 1725 MPa) is satisfied. These results are clearly superior than those obtained by Sellers and Haupt [19] (MOE = 125 MPa), and Xu et al. [20] (950 to 1750 MPa) in the case of panels without binder, treated by injection of water vapor, under a pressure of 6 MPa, at a temperature of 190°C, in the presence of water vapor and for 7 to 25 min.

The particleboards made from the ecological binder (tannic powder of P. Dulce peel) are medium density class 1 (MD – 1) according to standard ANSI A208.1–2016.

3.2.2. Modulus of rupture (MOR)

The MOR follows the MOE strength. It reaches a maximum of 21.65 MPa at the rate of 15% of the tannic powder of the peel of Indian tamarind (Figure 10). The values of the MOR of the mahogany sawdust panels obtained are greater than the minimum values fixed by the standard ANSI A208.1–2016 which are 11 MPa for medium density panels.

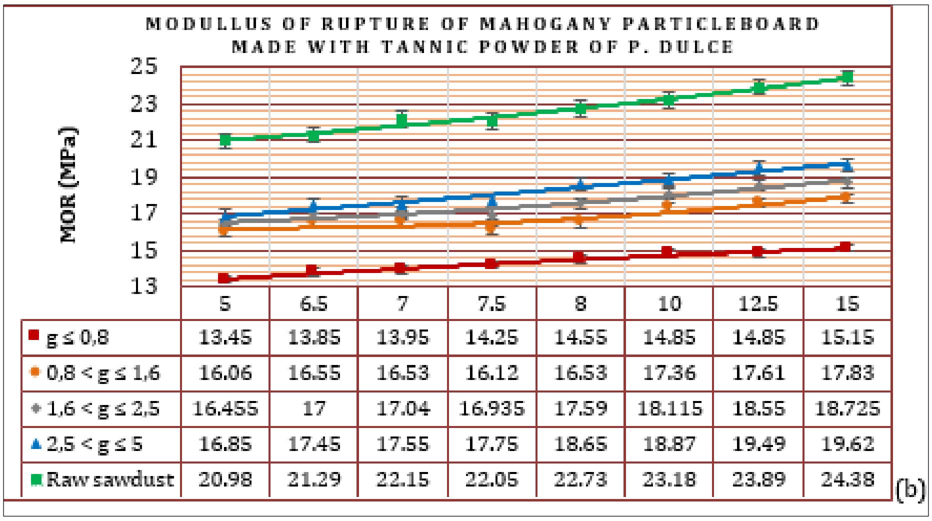


Figure 10 Variation of the modulus of rupture according to the granulometry and binder rate

The results of variance analysis relating to the MOR generated by the R software are recorded in table 8 below.

Table 8 Effect of the factors on the MOR of mahogany sawdust particleboards

Response MOR					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	101.5	101.47	60.7375	2 268-13 ***
Granular	5	878.9	292.97	175.3657	< 2.2e-16 ***
Binder rate	8	567.4	81.06	48.5211	< 2.2e-16 ***
Type of binder x Granular	5	1.8	0.59	0.3503	0.7889
Type of binder x Binder rate	8	15.8	2.26	1.3528	0.2265
Granular x Binder rate	40	37.3	1.78	1.0628	0.3900
Residuals	230	382.6	1.67		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative; Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The MOR of the mahogany sawdust particleboard (Figure 9) varies considerably with the binder rate. The interactions of factors analysis shows that the binder rate and the granulometry have no effect on the MOR. Tukey test analysis of the mean in the R software shows that the rates of binders, (5; 6.5; 7; 7.5 and 8) and (10; 12.5 and 15) are different. we must consider only two rates of binder (5 and 10) instead of the eight to investigate the MOR. We note that the MOR are in accordance with those obtained by Chow [6] with panels containing sawdust from red oak and by Villeneuve [20] with panels based on bark of poplar, trembling aspen. They noted that mechanical properties are improved with increasing of binder content.

The bending strengths (MOE and MOR) complied with the minimum values required by standard ANSI A208.1–2016 which are respectively for MOE: 1725 MPa for medium density particleboard class 1 (MD – 1) and MOR: 11 MPa for those of medium density class 1 (MD – 1).

3.2.3. Longitudinal modulus of elasticity (E)

The results show that the E increases with the rate of binder and reaches a maximum of 460.11 MPa at 15% of the tannic powder of the peel of P. Dulce for the raw sawdust (Figure 11). The results of the ANNOVA analysis and the interaction of the factors on E generated by the R software are reported in Table 9.

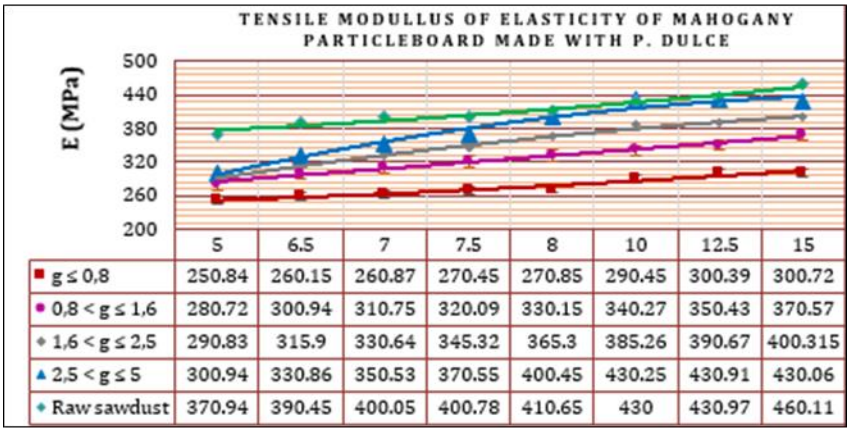


Figure 11 Variation of the tensile modulus of elasticity according to the granulometry and binder rate

The longitudinal modulus of elasticity (E) of mahogany sawdust particleboards varies considerably with factors (the binder rate and granulometry). Analysis of the interactions of the above factors shows that the binder rate and the granulometry have a very significant effect on E. The results are recorded in table 9 below.

Table 9 Factors effect on the longitudinal modulus of elasticity (E) of mahogany sawdust particleboards

Response E					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	2824424	2824424	30.9652	7.311 e^{-08} ***
Granular	5	126267284	42089095	861.4378	< 2.2 e^{-16} ***
Binder rate	8	5114034	730576	8.0096	1.059 e^{-08} ***
Type of binder x Granular	5	8444893	2814964	30.8615	< 2.2 e^{-16} ***
Type of binder x Binder rate	8	240755	34394	0.3771	0.915149
Granular x Binder rate	40	2954858	140708	1.5426	0.065244
Residuals	230	20887761	91213		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

The Longitudinal modulus of elasticity (E) of the mahogany sawdust particleboard (Figure 11) varies considerably with the binder rate. The analysis of the interactions of factors shows that the binder rate and the granulometry has no effect on the E. The analysis of the mean with the Tukey test in the R software shows that the levels of binders, the first five rates (5; 6.5; 7; 7.5 and 8) while having identical effects between them distinguish from the last three (10; 12.5 and 15) with similarly important effects. This means that we should consider only two rate of binder (5 and 10). We note that the E also are accordance with those obtained by Chow [6] with panels containing sawdust from red oak and by Villeneuve [23] with panels are based on bark of poplar, trembling aspen. They noted that mechanical properties are increasing with binder content. They also noted that the modulus of elasticity is influenced by the rate of binder.

3.2.4. Longitudinal modulus of rupture (MOT)

The MOT of mahogany sawdust particleboards increases with the binder rate. The figure 12 shows the variation of the MOT depending on the rate of binder. The tensile strength of the mahogany sawdust panels is very low compared to those of three points bending modulus. This shows that the mahogany panels are not isotropic. This character is due to the morphology of wood [10, 17, 21]. The panels made with the tannic powder of the peel of the P. Dulce are less resistant than those made with those of the pod of the husk of African locust bean. These results also agree with those of [13] for black spruce bark (*Picea Mariana*) panels with a UF binder content of 12% because these failed to reach the standard for MOT. However, the results of Maloney's work [15] show that the bark panels made from four West Coast species meet the ANSI A208.1–2016 specification for the modulus of rupture with contents of 7.5 and 10% of UF binder.

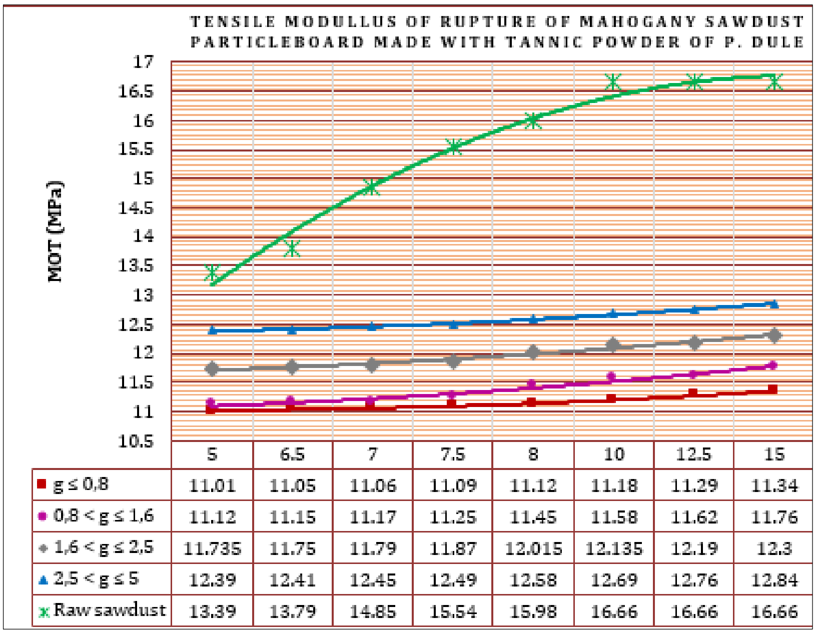


Figure 12 Variation of the tensile modulus of rupture according to the granulometry and binder rate

The table 10 presents the analysis of variance and the interaction results of the various factors on the MOT generated by the R software.

Table 10 Factors effect on the tensile modulus of rupture (MOT)

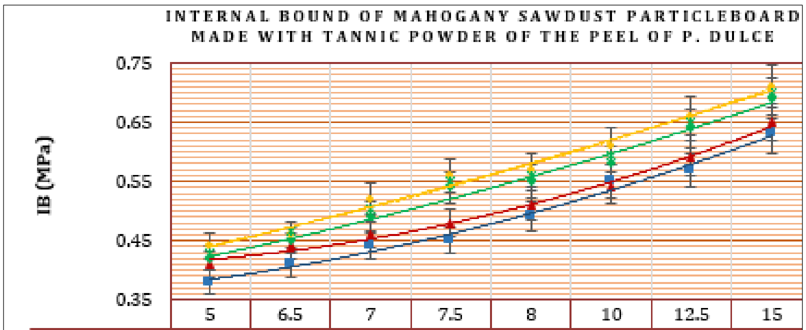
Response MOT					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	45.80	45.80	17.6044	$3.891\ e^{-05}$ ***
Granular	5	2803.34	934.45	359.2095	$< 2.2\ e^{-16}$ ***
Binder rate	8	185.69	26.53	10.1970	$4.16\ e^{-11}$ ***
Type of binder x Granular	5	57.96	19.32	7.4270	$9.083\ e^{-01}$ ***
Type of binder x Binder rate	8	2.24	0.32	0.1229	0.99669
Granular x Binder rate	40	60.51	2.88	1.1077	0.34087
Residuals	230	595.72	2.60		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event;Confidence level: 0.05 (5%)

The tensile modulus of rupture (MOT) variation with the factors (granulometry and binder rate) of mahogany sawdust particleboards is considerable. The analysis of the interactions of these factors shows that the granulometry and the binder rate, have no effect on the longitudinal modulus of rupture. The analysis of the means with the Tukey test in the R software shows that there are two different binder rates, (5; 6.5; 7; 7.5; 8; 10 and 12.5) and (15). So, to investigate the MOT we will only have to use two rates (5 and 15). Mahogany sawdust panels made from the tannic powder from the bark of P. Dulce have better tensile modulus. These resistance values obtained comply with the minimum values prescribed by the standard ANSI A208.1–2016. The tensile modulus of elasticity E and the tensile modulus of rupture MOT correspond to those obtained by [6] with panels containing sawdust from red oak and [20] with panels with poplar bark base, trembling aspen. They noted that the mechanical properties are improved with the increase in the binder rate. The low tensile strength compared to that of bending shows that the mahogany panels are more suitable for the ceiling than for posts. The longitudinal strengths (E and MOT) complied with the minimum values required by standard ANSI A208.1–2016.

3.2.5. Internal bound (IB)

The internal bound (figure13) increases with the binder rate. It is above the 0.4 MPa threshold set by ANSI A208.1–2016.



	5	6.5	7	7.5	8	10	12.5	15
g ≤ 0,8	0.38	0.41	0.44	0.45	0.49	0.55	0.57	0.63
0,8 < g ≤ 1,6	0.41	0.44	0.46	0.48	0.51	0.54	0.59	0.65
1,6 < g ≤ 2,5	0.42	0.45	0.49	0.54	0.55	0.58	0.64	0.69
2,5 < g ≤ 5	0.44	0.46	0.52	0.56	0.57	0.61	0.66	0.71
Raw sawdust	0.43	0.465	0.505	0.55	0.56	0.595	0.65	0.7

Figure 12 Variation of the internal bound according to the granulometry and binder rate

The results confirm those of Konaï et al [25] who characterized the anegre tannin as an adhesive resin; Drovou et al [18 – 19] with the kapok tree sawdust panels with the pod of the husk of African locust bean. The analysis of variance results using the R software are in Table 11 below.

Table 11 Effect of the factors on the modulus of elasticity (E) of mahogany sawdust particleboards

Response IB					
Factors	**Df**	**Sum. Sq**	**Mean Sq**	**F. Value**	**Pr (>F)**
Type of binder	1	0.6242	0.6242	32.8076	$3.817\ e^{-06}$ ***
Granular	4	19.4612	4.8653	255.7046	< $2.2\ e^{-16}$ ***
Binder rate	7	1.1936	0.1705	8.9616	$8.995\ e^{-06}$ ***
Type of binder x Granular	4	1.9141	0.4785	25.1501	$6.431\ e^{-09}$ ***
Type of binder x Binder rate	7	0.1648	0.0235	1.2377	0.31609
Granular x Binder rate	28	0.8865	0.0317	1.6640	0.09204
Residuals	229	0.5328	0.0190		

Signification codes: 0. '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '.' 1 **: significative; ***: very significative. Df: Degree of freedom
Sum Sq.: Sum of squares Mean Sq: Mean of squares; Pr: Probability of event; Confidence level: 0.05 (5%)

These results reveal that the factors (granulometry and binder rate) have significant effect on internal bound. The interactions between the granulometry and the binder rate are not significant. The mechanical characteristics, in bending (MOE, MOR), tensile (E, MOT and IB) of the particleboards of mahogany sawdust, determined, respected the requirements of standard ANSI A208.1, 2016. The panels are medium density (MD – 1). The mechanical properties are improved with the increase of the binder rate [20] reaches the same conclusion as [21 – 28] with regard to the proportional increase in the mechanical properties of the panels with the content of binder.

The mechanical properties of the panels developed in this study are satisfactory to the American norm; ANSI A208.1–2016 [12].

4. Conclusion

We use the tannic powder of the peel of P. Dulce unconventional binder, to manufacture particleboards from of mahogany wood sawdust. The mechanical properties of those particleboards meet the international standards as with conventional binders (PF and UF resin) that cause environmental issues.

- The physical properties
  - The density
    - ✓ For $g \leq 0.8$ is from 760.46 to 760.84 kg.m^{-3}
    - ✓ For $0.8 < g \leq 1.6$ is from 716.67 to 693.33 kg.m^{-3}
    - ✓ For $1.6 < g \leq 2.5$ is from 700 to 666.67 kg.m^{-3}
    - ✓ For $2.5 < g \leq 5$ is from 665.17 to 628.29 kg.m^{-3}
    - ✓ For the raw sawdust is from 725.33 to 748.33 kg.m^{-3}

The densities are between 640 to 800. They are medium density according to ANSI A208.1, 2016.

  - The thickness swelling (TS) rate after 2 hours
    - ✓ For $g \leq 0.8$ is from 41.67 to 20.19 %
    - ✓ For $0.8 < g \leq 1.6$ is from 48.48 to 32.94%
    - ✓ For $1.6 < g \leq 2.5$ is from 56.03 to 36.65%
    - ✓ For the raw sawdust is from 58.33 to36.50%
    - ✓ For $2.5 < g \leq 5$ is from 63.58 to 40.33%

They are more than 8% for roof panels and 20% for the floor panels.

  - The thickness swelling (TS) rate after 24 hours
    - ✓ For $g \leq 0.8$ is from 127.20 to 76.14%
    - ✓ For the raw sawdust is from 131.02 to 95.68%
    - ✓ For $0.8 < g \leq 1.6$ is from 162.11 to 110.97%
    - ✓ For $1.6 < g \leq 2.5$ is from 172.45 to 122.82%
    - ✓ For $2.5 < g \leq 5$ is from 182.78 to 134.00%

They are more than 50% for roof and floor panels.

  - The water absorption (WA) rate after 2 hours
    - ✓ For $g \leq 0.8$ is from 127.20 to 76.14%
    - ✓ For the raw sawdust is from 131.02 to 95.68%
    - ✓ For $0.8 < g \leq 1.6$ is from 162.11 to110.97%
    - ✓ For $1.6 < g \leq 2.5$ is from 172.45 to 122.82%
    - ✓ For $2.5 < g \leq 5$ is from 182.78 to 134.67%
  - The water absorption (WA) rate after 24 hours
    - ✓ For $g \leq 0.8$ is from 152.95 to 105.51%
    - ✓ For the raw sawdust is from 172.22 to 125.38%
    - ✓ For $0.8 < g \leq 1.6$ is from 192.92 to 146.75%
    - ✓ For $1.6 < g \leq 2.5$ is from 214.80 to 154.38%
    - ✓ For $2.5 < g \leq 5$ is from 236.37 to 162.00%

The high swelling and water absorption rate recommend that the boards developed indicate that their main use will be under dry conditions.

- The mechanical properties
  - Modulus of elasticity (MOE)
    - ✓ For $g \leq 0.8$ is from 1402.61 to 1784.11 MPa
    - ✓ For $0.8 < g \leq 1.6$ is from 1704.75 to 2002.95 MPa
    - ✓ For $1.6 < g \leq 2.5$ is from 1772.60 to 2074.69 MPa
    - ✓ For $2.5 < g \leq 5$ is from 1840.45 to 2146.43 MPa
    - ✓ For the Raw sawdust is from 2540.88 to 3474.61 MPa

- Modulus of rupture (MOR)
  - ✓ For g ≤ 0.8 is from 13.45 to 15.15 MPa
  - ✓ For 0.8 < g ≤ 1.6 is from 16.06 to 17.83 MPa
  - ✓ For 1.6 < g ≤ 2.5 is from 16.46 to 18.73 MPa
  - ✓ For 2.5 < g ≤ 5 is from 16.85 to 19.62 MPa
  - ✓ For the Raw sawdust is from 21.29 to 24.38 MPa

The MOE and the MOR meet the minimum value of ANSI A208.1, 2016 (11 and 1725 MPa respectively for MOR and MOE).

- Young modulus of elasticity (E)
  - ✓ For g ≤ 0.8 is from 250.84 to 300.72 MPa
  - ✓ For 0.8 < g ≤ 1.6 is from 280.72 to 370.57 MPa
  - ✓ For 1.6 < g ≤ 2.5 is from 290.83 to 400.32 MPa
  - ✓ For 2.5 < g ≤ 5 is from 300.94 to 430.06 MPa
  - ✓ For the Raw sawdust is from 370.94 to 460.11 MPa
- Tensile modulus of rupture (MOT)
  - ✓ For g ≤ 0.8 is from 250.84 to 300.72 MPa
  - ✓ For 0.8 < g ≤ 1.6 is from 280.72 to 370.57 MPa
  - ✓ For 1.6 < g ≤ 2.5 is from 290.83 to 400.32 MPa
  - ✓ For 2.5 < g ≤ 5 is from 300.94 to 430.06 MPa
  - ✓ For the Raw sawdust is from 370.94 to 460.11 MPa
- Internal bond strength (IB)
  - ✓ For g ≤ 0.8 is from 0.38 to 0.63 MPa
  - ✓ For 0.8 < g ≤ 1.6 is from 0.41 to 0.65 MPa
  - ✓ For 1.6 < g ≤ 2.5 is from 0.42to 0.69 MPa
  - ✓ For 2.5 < g ≤ 5 is from 0.44 to 0.71 MPa
  - ✓ For the Raw sawdust is from 0.43 to 0.70 MPa

The thermal and phonic properties are witch to complete this research and know the area where those particleboards could be used.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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