The strength properties of the sapwood and heartwood of two lesser timber species used for furniture and construction

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Abstract

In Ghana, there are several underused timber species that could substitute for the inadequate conventional species used in the furniture and construction industries. However, these industries continuously face persistent timber shortages. Additionally, due to the differences in strength between sapwood and heartwood, differences in the strength properties of *Senna siamea* (Cassia) and *Azadirachta indica A. Juss* (Neem) sapwood and heartwood should be determined. The aim of the study was to determine the modulus of elasticity (MOE), modulus of rupture (MOR), compression strength parallel to grain, and shear strength parallel to grain of sapwood and heartwood from Neem and Cassia trees for furniture and construction. The mixed analysis of variance (mixed ANOVA) test showed that all the stated properties of heartwood and sapwood from the two species were significantly different, with heartwood consistently demonstrating higher values than sapwood for both species. The findings indicated that the strength of the sapwood and heartwood of both species are comparable to those of key timber species such as *Aningeria altissima* (Asanfena), *Milicia excelsa* (Odum), and *Piptadeniastrum africanum* (Dahoma). It is important to consider the differences in strength between sapwood and heartwood from Neem and Cassia when selecting the species for furniture and construction work, particularly in applications that demand specific attention.

Introduction

The use of well-established timber species for furniture production and building construction has been a longstanding practice. Nevertheless, Ghana's tropical forests are facing significant deforestation and degradation of primary timber species, with a disturbing yearly loss of 2%, which translates to nearly 135,000 hectares of timberland cover (Kyere-Boateng and Marek 2021). The decreasing accessibility of key timber species worldwide is dangerous for the sustainability and progress of the furniture and construction industries. The most affected species included highly valued commercial timbers, such as Milicia excelsa (Odum), Nesogordonia papaverifera (Danta), Cylicodiscus gabunensis (Denya), Khaya ivorensis (African mahogany), Turraeanthus africanus (Avodire), Entandrophragma (Sapele), Aningeria spp. (Asanfena), Mansonia altissima (Mansonia), and Entandrophragma angolense (Edinam) (Chaikaew et al. 2020; Kakpo et al. 2021; McEwan et al. 2020). Consequently, significant changes must be made in how timber species are utilized without delay. While some advocate for complete halting of tree harvesting, the demand for timber to support the growing population continues to increase (Prescott 1998; Lewis et al. 2015). The demand for wood in Ghana for furniture and construction works is escalating at an alarming rate, such that the annual allowable cut (AAC) of 2.0 million m^3 comprising 0.5 million m^3 from forest reserves and 1.5 million m^3 from off-reserve areas is inadequate (Oduro 2016; Asamoah et al. 2020). The current estimate for timber harvesting in Ghana ranges from approximately 3.7 million m^3 to 6 million m^3, nearly double the AAC (Brown et al. 2022). The national and international demand for a limited number of principal timber species has led to their dangerous exploitation. Although many lesser-used timber species exist, they remain largely unexploited due to a lack of understanding of the strength of their sapwood and heartwood (Ewudzie et al. 2018; Tekpetey et al. 2008). Following the loss of forest cover in Ghana, which once stood at 8.2 million hectares, the country considered importing logs from Cameroon (Ewudzie et al. 2018). This situation has prompted reassessment of the impact of supply sustainability on the construction and furniture industries (Diaz-Maroto et al. 2017; McEwan et al. 2020). Promoting and utilizing lesser-used species (LUS) can help alleviate pressure on the few key species. For example, Dahoma (*Piptadeniastrum africanum*) is considered a promising alternative to Odum (Kwaku et al. 2022). Sustainable management of tropical forests is essential for preventing overexploitation of a limited number of commercial timber species, which contributes to forest degradation (Brod 2009). Utilizing a variety of timber species, such as *Azadirachta indica A. juss* (Neem) and *Siamese senna* (Cassia), can help reduce this pressure on the primary species.

Research from previous times has shown that Neem wood is aromatic and not particularly lustrous but easy to saw. It seasons well when stacked in open air and can work with both hand tools and machines (Koul et al. 1990; Thengane et al. 1995; Baranay 2014). Neem wood is durable even under prolonged exposure and exhibits low shrinkage. It is moderately heavy and resembles *Khaya ivorensis* (African mahogany) in appearance, with a working quality like that of oak (Antwi-Boasiako et al. 2017; Hummel et al. 2016). Cassia is a fast-growing tree that resembles *Mansonia altissima* (Mansonia). It is a medium-sized tree characterized by large heartwood that ranges from yellowish-brown to blackish-brown and pale-yellow sapwood, both of which are free from knots (Chauhan et al. 2020). The trunk naturally reaches approximately 1,800 cm in height and diameter (30 to 50 cm) (Smith, 2009; Pushpakumara et al. 2023). In Ghana's tropical regions, Neem and Cassia are some of the abundant yet underused trees found in both forest reserves and off-reserve areas across nearly 82,000 km² of timberland, representing approximately 34% of the country's total land area (Quartey et al., 2021). These species are not used for furniture or construction due to limited research on the strength properties of their sapwood and heartwood. According to Olorunnisola (2018), the knowledge of scientific data on the strength properties of sapwood and heartwood allows furniture manufacturers and builders to understand wood species behavior in different applications.

In healthy trees, the stem cross-section of mature trees consists of a lighter exterior layer known as sapwood and a darker internal layer called heartwood (Sathish 2020; Cai et al. 2024). Sapwood is formed from fresher growth rings with lively cells that facilitate sap transmission, conveying water from the roots to the leaves and often storing excess nutrients. In contrast, heartwood consists of older growth rings with inactive cells where stored reserves have been transformed (Ramage et al. 2017; Traoré et al. 2023). The formation of heartwood results from gradual transformation of the innermost growth rings of sapwood (Petit et al., 2023). This transformation involves complex chemical changes occurring in the transition zone between sapwood and heartwood (Hillis 2012). Factors such as soil, weather, and environmental disorders can influence the strength of heartwood and sapwood. Additionally, tree age, growth location, and density significantly affect the width of sapwood and heartwood (Domec et al. 2012). Heartwood naturally contains less cellulose and more lignin than sapwood, which have similar hemicellulose contents, leading to differences in their strength properties (Arisandi et al., 2023). Therefore, the strength of sapwood and heartwood should be considered when utilizing wood for furniture and construction. Laskowska et al. (2021) reported that sapwood samples of

Eucalyptus grandis exhibited greater strength than heartwood samples. Shanavas (2001) reported that the modulus of rupture and modulus of elasticity of blackened heartwood were greater than those of sapwood. Bardak et al. (2019) noted no significant differences in the strength properties of European oak heartwood and sapwood. (Hai et al. 2010). Quartey et al. (2021) studied the strength properties of Neem but did not explore the structural difference between its sapwood and heartwood. The purpose of the study was to determine the strength properties of sapwood and heartwood from Neem and Cassia by concentrating on the MOE, MOR, compression strength parallel to grain and shear strength parallel to grain to determine their suitability for furniture manufacturing and construction.

Materials and methods

Three mature Cassia and Neem trees were extracted based on their diameters ranging from 360 mm to 520 mm at a height of 250 mm from the ground, which is the usual harvesting diameter. Marking and sawing were carefully performed (Figure 1) to ensure that the heartwood and sapwood portions of each log were obtained. The logs were then sawn on a horizontal band saw into 75 mm × 200 mm × 2400 mm lumber. Approximately 48 pieces of lumber were obtained from the six logs. The beams were then seasoned to 12% moisture content, which is the average moisture content for furniture and construction works in Ghana. The test specimens were then prepared for determination of all the properties mentioned above. An Instron universal testing machine (100 kN) was used to perform the tests. Eighty specimens comprising sapwood and heartwood were tested for each property at the timber testing laboratory of the Centre for Scientific and Industrial Research of the Forestry Research Institute of Ghana (CSIR-FORIG), Fumesua-Kumasi of Ghana.

Bending strength test (MOE and MOR):

The test was performed according to the British Standard BS 373 (1957) standard. Twenty-five millimeter thick boards were ripped, planed and crosscut to 20 mm × 20 mm × 300 mm test specimens. Twenty samples were obtained for sapwood and heartwood from each tree for the MOE and MOR tests. The test (Figure 2) was performed on a 100 kN Instron universal testing machine.

The modulus of elasticity is computed by the following equation:

$$\frac{P'/L^3}{4\Delta'/bh^3} \text{ or } \frac{P L^3}{4bd^3\Delta}$$

where

P ' = Load at limit of proportionality (N)

L = Length of test piece (mm)

Δ' = Deflection at mid length at limit of proportionality (mm) b = Breadth of test piece (mm)

h = Depth of test piece (mm) or

h = Height of test piece (mm)

The MOR was determined using a similar test procedure as outlined for MOE. However, for the MOR test, the maximum load prior to rupture was recorded and computed by the following equation:

$$\frac{3PL}{2bh^3} \quad \text{or} \quad \frac{3PL}{2bh^2}$$

where:

P = Maximum load (N)

L = Length of test piece (mm)

b = Breadth of test piece (mm)

h = Depth of test piece (mm)

Parallel-to-the-grain compression strength test

The compression tests were performed on 60 mm × 20 mm × 20 mm specimens, as shown in Figure 3. The load that caused each wood sample to fail was recorded and calculated by the following equation:

$$\sigma cpl = \frac{W_{max}}{F} \text{ or } \frac{P}{A}$$

where

σcpl = Compression strength (MPa)

W_{max} = Maximum load at the break point (N)

F = Area of cross-section of a specimen on which force was applied.

P = maximum load in Newtons

A= area of cross-section of test piece in mm^2

Shear strength parallel-to-the-grain test

The shear strength test was carried out as shown in Figure 4 using 50 mm × 50 mm × 50 mm specimens. The load that caused each wood sample to fail was recorded. The formula used for the calculation of the shear strength parallel to the grain was:

P/bh

where

P = maximum load in Newtons

b = breadth of the test piece in mm

h = height of the test piece in mm

Results and discussion

Modulus of rupture (MOR)

Table 1 shows the MOR results for sapwood (SW) and heartwood (HW) from Neem and Cassia species at 12% moisture content (MC). The mixed analysis of variance (mixed ANOVA) test of the MOR values of sapwood and heartwood differed significantly between the two species ($p < 0.005$). When the data were evaluated on average, the heartwood from Neem obtained an MOR of 104.25 N/mm^2, while that from Cassia obtained an MOR of 85.69 N/mm^2. These values are greater than those of the sapwood (59.94 N/mm^2 and 58.28 $N/mm^{2,}$ respectively). These results are consistent with those of Hiziroglu (2016), who reported that, in general, depending on the species, wood has MOR values between 34.47 N/mm^2 and 103.42 N/mm^2. These results agree with published data by Bektas et al. (2020), who reported that the 48.2 N/mm^2 and 68.5 N/mm^2 of poplar and red pine sapwood were lower than those of heartwood (56.4 N/mm^2 and 80.9 N/mm^2, respectively). These results are comparable with those for *Aningeria altissima* (Asanfena) (130.00 $N/mm^{2)}$, *Milicia exelsa* (odds) (87.00 $N/mm^{2)}$ and *Piptadeniastrum Africanum* (Dahoma) (109.00 $N/mm^{2)}$ reported by Antwi (2014). The modulus of rupture of Neem heartwood was nearly 20% lower than that of Asanfena heartwood, approximately 17% greater than that of Odum heartwood and 4% less than that of Dahoma heartwood. However, Cassia is 34% lower than Asanfena, almost 2% lower than Odum and 21% lower than Dahoma, as shown in Table 4. When comparing the sapwood (Table 5) of Neem (59.94 $N/mm^{2)}$ and Cassia (58.28) to that of Asanfena, Odum and Dahoma, Neem was 54% lower than that of Asanfena, 31% lower than that of Odum and 45% lower than that of Dahoma. Cassia is 55% lower than Asanfena, 33% lower than Odum and nearly 47% lower than Dahoma. The MOR values obtained from the sapwood of the two species are, however, lower than those of several substantial timber species, such as *Cylicodiscus gabunensis* (Denya), with an MOR of 137 N/mm^2; *Nesogordonia papaverifera* (Danta), with an MOR of 137 N/mm^2; Celtis spp. (Essa), with 104 N/mm^2; *Sterculia rhinopetala* (Wawabima), with 127 $N/mm^{2;}$ and *Albizia ferruginea* (Albizia), with 102 $N/mm^{2,}$ which are acceptable for use in furniture and construction. (Appiah-Kubi et al. 2016). Therefore, these materials should be used for work, such as roofing small buildings; constructing doors, windows, hoardings, tables, cabinet doors and drawers etc. which require moderate loads.

Table 1
Results of MOR tests of sapwood and heartwood from Neem and Cassia at 12% MC

Wood Species	Wood Type	N	Mean N/mm^2	SD	SE	F value	Sig
Neem	SW	20	59.94	13.93	4.41	571.374	.000
	HW	20	104.25	11.90	3.76		
Cassia	SW	20	58.28	10.80	3.42	303.215	.000
	HW	20	85.69	11.28	3.57		

N: Number of samples, SW: Sapwood, HW: Heartwood, SD: Standard deviation, SE: Standard error, Sig: Significance.

Modulus of elasticity (MOE):

The MOE was assessed according to the data given in Table 2. The mixed ANOVA test showed a significant difference between the sapwood and heartwood values ($p < 0.005$). The heartwood MOE values of the Neem and Cassia trees were 11940.83 N/mm^2 and 13238.91 N/mm^2, respectively, and those of the sapwood were 7828.30 N/mm^2 and 8327.63 $N/mm^{2,}$ respectively. The heartwood values of the two species were greater than those of the sapwood. According to Hiziroglu (2016), in general, depending on the species, wood has an MOE ranging from 5515 N/mm^2 to 17,236.9 N/mm^2. The MOE values of Neem and Cassia (Table 2) are within the acceptable range for furniture manufacturing and construction. These results differ from those of a study by Bektas et al. (2020), in which the elasticity moduli of Eucalyptus and Scots pine sapwood were 7280.9 N/mm^2 and 6539.3 N/mm^2 greater than those of heartwood (5264.5 N/mm^2 and 5193.8 N/mm^2, respectively). Compared to Aningeria *altissima* (Asanfena), 11,100.00 N/mm^2; *Milicia exelsa* (Odum), 12,840.00 N/mm^2; and *Piptadeniastrum Africanum* (Dahoma), 11,200.00 N/mm^2 reported by (Antwi 2014). Cassia and Neem are closely related to these other species, and these two species are predicted to be suitable for furniture and construction. The bending strength (MOE) of Neem is 7% greater than that of Asanfena, approximately 7% lower than that of Odum, and 6% greater than that of Dahoma. However, Cassia is approximately 16% greater than Asanfena, nearly 7% greater than Odum and 15% greater than Dahoma, as indicated in Table 4. When comparing the sapwood of Neem 7828.30 N/mm^2 and Cassia 8327.63 to that of Asanfena, Odum and Dahoma, the sapwood of Neem was 29% lower than that of Asanfena, 39% lower than that of Odum and 30% lower than that of Dahoma. Cassia is nearly 25% lower than Asanfena, 35% lower than Odum and nearly 26% lower than Dahoma, as shown in Table 5. The classifications in Table 3 indicate that heartwood from Neem and Cassia are medium-quality wood, whereas their sapwood grades are low. The MOE (Fig. 5) was not significantly different among the five species.

Table 2
Results of the MOE test of sapwood and heartwood from the two species at 12% M.C.

Wood Species	Wood Type	N	Mean N/mm^2	SD	SE	F value	Sig
Neem	SW	20	7828.30	3126.08	988.55	40.10	.000
	HW	20	11940.83	617.41	195.24		
Cassia	SW	20	8327.63	3939.17	1245.68	27.264	.001
	HW	20	13238.91	801.23	253.37		

N: Number of samples, SW: Sapwood, HW: Heartwood, SD: Standard deviation, SE: Standard error, Sig: Significance.

Table 3
Assigning MOE grades to the results based on the timber export development board – Ghana

Value	Grade
19,000 N/mm^2 and more	Very High
14,000 N/mm^2 – 19,000 N/mm^2	High
11,000 N/mm^2 – 14,000 N/mm^2	Medium
Below 9,000 N/mm^2	Low

Table 4 Neem and Cassia heartwood specimens compared to other known timber species in N/mm^2

Species	MOR	MOE	Cllg	Shear llg
Azadirachta indica (Neem)	104	11,940	60.8	19.5
Senna. Siamea (Cassia)	85	13,238	64.4	18.9
Aningeria altissima (Asanfena)	93	11,100	57	9.5
Milicia exelsa (Odum)	87	12,840	54	14.1
Piptadeniastrum Africanum (Dahoma)	109	11,200	23	17.6
Terminarian ivorensis (Emire)	83	9,300	35	12.1
Antiaris toxicaria (Kyenkyen)	59	7,200	54	7.9
Cyclidiscus Gabunesis (Denya)	64	6,300	-	11.1
Canarium Schweinfurthii (Bediwonua)	41	6,200	-	6.4

Source: Antwi (2014)

Table 5 Neem and Cassia sapwood compared to other known timber species in N/mm^2

Species	MOR	MOE	Cllg	Shear llg
Azadirachta indica (Neem)	59	7,828	54.1	16.7
Senna. siamea (Cassia)	58	8,327	52.7	15.7
Aningeria altissima (Asanfena)	93	11,100	57	9.5
Milicia exelsa (Odum)	87	12,840	54	14.1
Piptadeniastrum Africanum (Dahoma)	109	11,200	23	17.6
Terminarian ivorensis (Emire)	83	9,300	35	12.1
Antiaris toxicaria (Kyenkyen)	59	7,200	54	7.9
Cyclidiscus Gabunesis (Denya)	64	6,300	-	11.1
Canarium Schweinfurthii (Bediwonua)	41	6,200	-	6.4

Source: Antwi (2014)

Compression strength parallel to the grain

According to the mixed ANOVA test (Table 6), there was a significant difference ($p < 0.005$) between the sapwood and heartwood of both species. The heartwood values for Neem (60.78 N/mm$^{2)}$ and Cassia (64.43 N/mm^2) were greater than the sapwood values of 54.09 N/mm^2 and 52.73 N/mm^2, respectively. These results differ from those of Bektas et al. (2020), who reported that the compression strength parallel to the grain of *Quercus cerris* sapwood (54.8 N/mm$^{2)}$ was greater than that of heartwood (51.6 N/mm$^{2)}$. When comparing the compression strength results of the heartwood from Neem and Cassia with those noted by Antwi (2014), from Asanfena (57.00 N/mm^2, Odum 54.00 N/mm$^{2)}$ and Dahoma 23.00 N/mm^2) (Table 4), the heartwood from Neem and Cassia performed better. The yield of Neem was approximately 6% greater than that of Asanfena, 11% greater than that of Odum and approximately 62% greater than that of Dahoma. Cassia is approximately 12% greater than Asanfena, 16% greater than Odum and approximately 64% greater than Dahoma. When comparing the sapwood of Neem 54.09 N/mm^2 and Cassia 52.73 to that of Asanfena, Odum and Dahoma, the sapwood of Neem was 5% lower than that of Asanfena, approximately 0.2% greater than that of Odum and 57% greater than that of Dahoma. Cassia is 7% lower than Asanfena, 2% lower than Odum and 56% higher than Dahoma (Table 5). The compressive strength of the species studied is comparable to that of traditional timber species used in furniture and construction.

Table 6
Results of compressive strength parallel to grain test of sapwood and heartwood from Neem and Cassia species at 12% MC

Wood Species	Wood Type	N	Mean N/mm^2	SD	SE	F value	Sig
Neem	SW	20	54.09	2.32	.734	21.591	.002
	HW	20	60.78	3.56	1.138		
Cassia	SW	20	52.73	5.67	1.79	310.153	.000
	HW	20	64.43	4.16	1.31		

N: Number of samples, SW: Sapwood, HW: Heartwood, SD: Standard deviation, SE: Standard error, Sig: Significance.

Shear parallel-to-the-grain test

The mixed ANOVA test showed a significant difference between the sapwood and heartwood results ($p < 0.005$). The heartwood values of Neem and Cassia trees at 19.50 N/mm^2 and 18.85 N/mm^2, respectively, were greater than those of the sapwood trees at 16.67 N/mm^2 and 15.67 N/mm^{2,} respectively (Table 7). It is understood that Neem displayed greater resistance to shear failure parallel to the grain than Cassia. These findings support the findings of Bektas et al. (2020), who noted that the shear strength of red pine sapwood (4.5 N/mm^2) was lower than that of heartwood (7.9 N/mm^2). However, they also observed that the shear strength values for heartwood were lower in Scots pine and

Poplar (4.2 N/mm² and 3.2 N/mm², respectively) than in their sapwood counterparts (6.3 N/mm² and 4.0 N/mm², respectively). When the shear strength of Neem and Cassia heartwoods was compared to that of Asanfena (9.50 N/mm²), Odum (14.10 N/mm²), and Dahoma (17.60 N/mm²), the two species demonstrated greater resistance to shear failure. Specifically, the shear strength of Neem heartwood is approximately 51% greater than that of Asanfena, 28% greater than that of Odum, and 10% greater than that of Dahoma. Similarly, Cassia's shear strength was approximately 50% greater than that of Asanfena, 25% greater than that of Odum, and nearly 7% greater than that of Dahoma.

Table 7
Results of shear strength parallel-to-grain tests of sapwood and heartwood from Neem and Cassia at 12% MC

Wood Species	Wood Type	N	Mean N/mm^2	SD	SE	F value	Sig
Neem	SW	20	16.67	1.17	.370	156.925	.000
	HW	20	19.50	.57	.179		
Cassia	SW	20	15.67	1.05	.332	1590.886	.000
	HW	20	18.85	.99	.314		

N: Number of samples, SW: Sapwood, HW: Heartwood, SD: Standard deviation, SE: Standard error, Sig: Significance

In terms of the sapwood, Neem 16.67 N/mm² and Cassia 15.67 N/mm², compared with Asanfena and Odum and Dahoma, Cassia is 43% stronger than Asanfena, 15% stronger than Odum, and 5% weaker than Dahoma. Similarly, Neem was approximately 39% stronger than Asanfena, 10% stronger than Odum, and nearly 11% weaker than Dahoma. The shear strengths of both the sapwood and heartwood from Neem and Cassia trees are comparable to those of *Aningeria altissima* (Asanfena), *Milicia excelsa* (Odum), and *Piptadeniastrum africanum* (Dahoma), which are well-regarded species for furniture and construction. This further supports the suitability of Neem and Cassia for furniture production and construction applications. These findings emphasize the importance of considering the differences in strength properties between sapwood and heartwood when utilizing these species in construction and furniture. Understanding the strength of sapwood and heartwood enables manufacturers and builders to make informed choices regarding wood selection for high-stress areas.

Conclusion

The MOR, MOE, compression and shear strength of sapwood and heartwood from Neem and Cassia trees fall within the acceptable strength range for wood for furniture and construction. The mixed ANOVA revealed a statistically significant difference between heartwood and sapwood for all the stated strength properties, with heartwood exhibiting higher values than sapwood for both species. These differences should be considered when using species in areas that require special attention in furniture and construction. Cassia and Neem can serve as effective substitutes for many primary timber species used in furniture manufacturing and construction. Their strength properties are comparable to those of Odum, Dahoma, and Asanfena, which are recognized as suitable species for furniture production, building construction and other structural applications.

Declarations

Conflict of interest statement

The authors have no conflicts of interest to declare.

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Author Contribution

J.L.N: Prepared the samples and the text, E.A.K: Performed the tests and L.K.N: Proofread

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Figures

Figure 1

The surface of each log was marked for sawing.

Figure 2

Setup for modulus of elasticity and rupture tests

Figure 3

Setup for the compression test parallel to the grain

Figure 4

Setup for the shear tests parallel to the grain

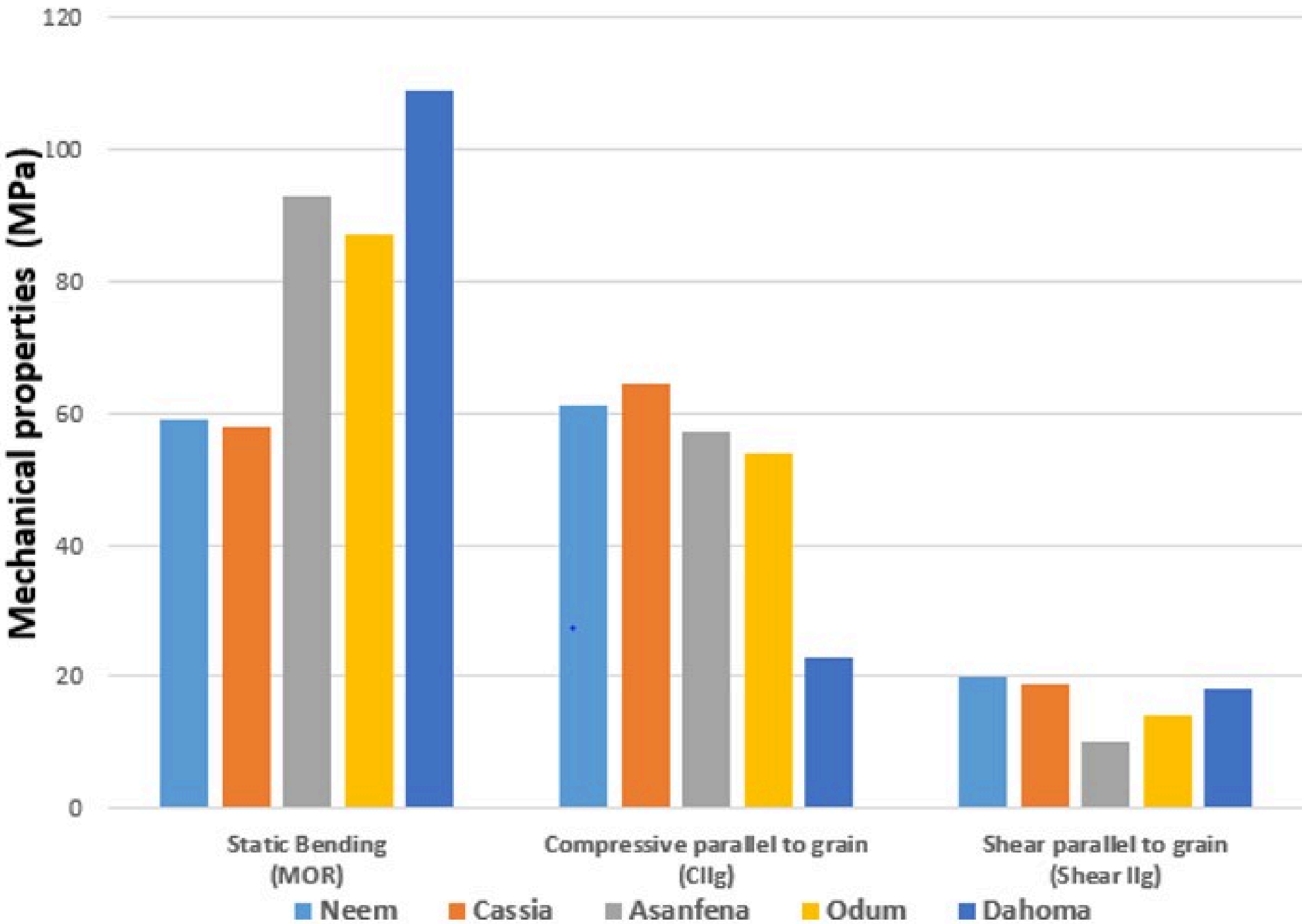

Figure 5

Comparative strengths of Neem, Cassia, Asanfena, Odum and Dahoma.