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SENILE FRUIT-BEARING TREES AS POSSIBLE TIMBER ALTERNATIVE: PHYSICAL AND MECHANICAL PROPERTIES

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The physico-mechanical properties of five senile fruit-bearing trees, i.e., caimito (*Chrysophyllum cainito*), durian (*Durio zibethinus*), kalumpit (*Terminalia microcarpa*) rambutan, (*Nephelium ramboutan-ake*) and sampalok (*Tamarindus indica*) were tested using ASTM D143-52 (2014) standard, and their end-uses were determined. The samples were obtained from Laguna, Batangas and Butuan cities. Results showed that the *C. cainito* and *T. indica* had the lowest moisture content (MC) (64.7 and 55.1%, respectively) and highest relative density (RD) (0.737 and 0.747, respectively). On the other hand, *N. ramboutan-ake* and *T. indica* had the highest radial shrinkage (6.78 and 6.52%, respectively). *Tamarindus indica* also exhibited the highest longitudinal (2.01%) and volumetric shrinkage (16.7%). As for the mechanical properties, in green condition and at 12% MC, *C. cainito* had the highest modulus of rupture (MOR) (72.40 and 109.0 MPa, respectively), modulus of elasticity (MOE) (9.91 and 14.20 GPa, respectively), compression perpendicular-to-grain (6.37 and 11.10 MPa, respectively), shear (7.92 and 12.40 MPa, respectively), and hardness: end (7.42 kN in green condition). *Nephelium ramboutan-ake* showed the highest SPL (42.40 and 56.80 MPa, respectively) and compression parallel-to-grain (29.30 MPa, green condition). *Tamarindus indica* showed the highest hardness values: side (7.20 and 11.20 kN, respectively) and toughness (59.70 and 59.70 J/spec, respectively). Based on the properties obtained, the senile fruit-bearing tree species are suitable as alternative raw materials for various end-uses.

Keywords: Fruit trees, fruit-bearing trees, mechanical properties, physical properties, raw materials

INTRODUCTION

Fruit-bearing trees abound in the Philippines. According to the Philippine Statistics Authority PSA (2021), a total of 5717.18, 16,582.92 and 2207.47 ha are planted with *Nephelium ramboutan-ake*, *Durio zibethinus* and *Tamarindus indica*, respectively in various parts of the country. These amount to a total of 420,987.0, 1,341,526.0 and 124,360.0 trees, respectively. The huge numbers must have resulted from the government's National Greening Program (NGP) where fruit-bearing trees were among the priority species for planting (EO 26 2010). The NGP, which aimed to plant 1.5 B seedlings on 1.5 M ha of land from 2010–2016, has been extended until 2026 (EO 193 2016). Fruit trees remain on its priority species list.

In the Philippines, fruit-bearing trees are commonly used as windbreaks. They are also important components of the agroforestry system, mixed with annual crops such as maize, cassava and vegetables. This combination of crops helps promote an agroforestry system that can offer farmers long-term and diverse income sources through product diversification (Do et al. 2020).

Investing in fruit-bearing tree orchards has become an attractive business option among planters as it provides a regular income for many years without the need for reinvestment. The trees also help meet the planters' multiple household objectives, yielding food and other by-products and providing a protective cover in an environmentally fragile landscape (Snelder et al. 2007).

In the Philippines, senile and unproductive fruit-bearing trees are seen as alternative materials to commercial timber which are now in short supply. Alipon et al. (2022) reported that senile trees can be used for construction, carving, furniture, cabinets, pallets, crates and pulp and paper.

Knowledge on the physical and mechanical properties of wood is crucial in promoting the use of would-be substitutes for commercial or traditionally used timbers. Information on these properties would facilitate their utilisation as structural materials as well as substitute species for specific end-uses, and possible new wood applications. The more important physical properties of timber are related to wood quality, i.e., moisture content (MC), relative density (RD) and shrinkage. The RD is correlated with shrinkage, drying, machining and mechanical properties. Shrinkage, on the other hand, is associated with behavior such as warping, cupping, checking and splitting, resulting in major deformities in wood. Mechanical properties such as static bending, compression parallel-to-grain, compression perpendicular-to-grain, shear strength, hardness and toughness are equally important for wood used in structural applications and as indicators of the quality of sawn lumber.

In the Philippines, there is very limited information on the basic properties of fruit-bearing trees. To date, only the following fruit-bearing trees have been studied: pahutan (*Mangifera altissima*), durian (*Durio zibethinus*), santol (*Sandoricum koetijape*), bayabas (*Psidium guajava*), nangka (*Artocarpus heterophyllus*) and marang (*Litsea perrottetti*) (Alipon et al. 2005, 2022, Alipon & Bonded 2008). Results showed that these fruit-bearing trees can be used for construction, carving, furniture, cabinets, pallets, crates, and pulp and paper.

The basic properties and possible uses of *Mangifera indica, T. indica*, *Syzygium malaccense, Nephelium lappaceum* and *D. zibethinus* have been studied in Nigeria, Malaysia and Indonesia (Aiso et al. 2013, Aleru & David-Sarogoro 2016, Mohd-Jamil et al. 2020). The properties of the above species are at par with those of commercial hardwood trees, and they can be processed into furniture, moldings, framing, construction lumber, and pulp and paper.

Some senile fruit-bearing trees such as *M. indica* and *T. indica* have been used in the Philippines to make wooden trays, carvings, plates and furniture for both export and domestic markets. Moreover, investing in fruit-bearing trees has become attractive among planters because their fruits provide a regular source of income for many years (Alipon et al. 2022).

Utilising senile fruit trees for different wood applications could provide additional income to farmers and help augment the local wood industry's raw material shortage. Thus, this study aimed to determine the basic properties and provide recommended uses of various fruit-bearing species with potential for wood application such as caimito (*Chrysophyllum cainito*), durian (*D. zibethinus*), kalumpit (*Terminalia microcarpa*), rambutan (*N. ramboutan-ake*) and sampalok (*T. indica*).

MATERIALS AND METHOD

Preparation of samples

Three senile trees each of caimito (*C. cainito*), durian (*D. zibethinus*), kalumpit (*T. microcarpa*), rambutan (*N. ramboutan-ake*), and sampalok (*T. indica*) were collected from Butuan City, Batangas and Laguna Province, Philippines. The trees' diameter at breast height (DBH) was measured at 1.3 m above the ground and the total height was determined (Table 1). The trunks were then segmented into three (3) height levels, namely butt, middle and top portions. For each bolt, a disc approximately 152 mm thick and billets 2.14 m long were cut. The discs were assigned for physical properties determination, and billets were used for mechanical property determination (Alipon et al. 2017). Figure 1 shows the sampling scheme used.

Determination of physical properties

Physical properties were tested using ASTM D143-52: Standard Test Methods for Small Clear

Table 1 Experimental fruit-bearing trees

Species	DBH (cm)	Height (m)	Location
Chrysophyllum cainito	21.67	15.33	Butuan City, Caraga
Durio zibethinus	21.66	19.67	Butuan City, Caraga
Terminalia microcarpa	22.83	19. 57	Batangas, Region IV-A
Nephelium ramboutan-ake	21.43	12.33	Butuan City, Caraga
Tamarindus indica	21.16	17.67	Laguna, Region IV-A

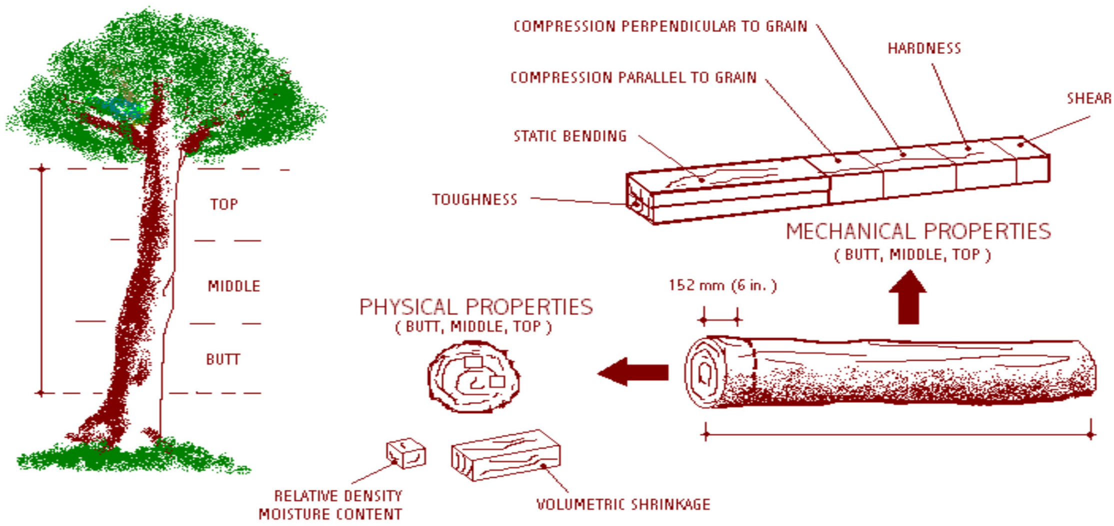

Figure 1 Sampling scheme for determination of the physical and mechanical properties of fruit-bearing trees

Specimens of Timber (ASTM 2014). A sample measuring 25 × 25 × 25 mm was cut from the disc for the analysis of the moisture content (MC) and relative density (RD). The volume of the samples was determined by the water displacement method and their weights were determined before and after oven drying at 103 ± 2 °C until a constant weight was attained. The difference in weight expressed as a percentage of the oven-dry weight was considered the specimen's MC. The RD of each sample was determined as the ratio of the oven-dried weight to its green volume. The MC and RD were calculated using the following equations:

$$MC\ (\%) = \left(\frac{W_i - W_o}{W_o}\right) \times 100 \quad (1)$$

$$RD = \frac{W_o}{W_d} \quad (2)$$

where MC is moisture content from green to oven-dried condition, RD is relative density, W_i is initial weight (g), W_o is oven-dried weight (g), W_d is weight of displaced water (g).

The shrinkage values from green to oven-dried conditions were determined from the blocks measuring 25 × 25 × 102 mm. The tangential, radial and longitudinal sections of each sample were marked and measured with a dial gauge with the least reading of 0.0254 mm. The shrinkage properties (i.e., directional and volumetric shrinkage) were calculated using the following equations:

$$Sa\ (\%) = \frac{D_i - D_o}{D_i} \times 100 \quad (3)$$

where S_a: shrinkage from green to oven-dried conditions, D_i: initial dimension (mm), and D_o: oven-dried dimension (mm).

Determination of mechanical properties

Samples for the mechanical properties were tested following ASTM D143-52: Standard Test Methods for Small Clear Specimens of Timber (ASTM 2014). Two sets of samples were prepared (i.e., green and 12% MC condition) and tested for static bending modulus of rupture (MOR), modulus of elasticity (MOE), stress at the proportional limit (SPL), compression perpendicular and parallel-to-grain, shear strength, hardness (side and end), and toughness. All tests were conducted using the 300 kN universal testing machine (UTM).

Statistical analysis

Statistical analysis was performed using the R Studio ver. 4.2.1 (R Core Team 2022). Analysis of variance (ANOVA) was used to determine whether or not the mean differences were significant in species, height levels, and their interaction. If the differences were significant, Tukey`s honestly significant difference (HSD) test was used to determine which of the means were significantly different from one another.

The relationship between physical properties was analysed using Pearson correlation analysis.

RESULTS AND DISCUSSION

Physical properties

Moisture content and relative density

The average values and results of Tukey`s HSD for the physical properties is shown in Figures 2 and 3 while Figure 4 shows the results of the correlation coefficient analysis between the physical properties of the fruit-bearing trees. The effect of species (S) and height levels (H) on the physical properties were significant except for the longitudinal shrinkage (LS) ($p = 0.527$) where the height levels were not a significant factor. A significant interaction between S × H was observed in MC ($p = 0.014$) and volumetric shrinkage (VS) ($p = < 0.001$), suggesting that this contributed to the variability in differences in the physical properties.

In the results obtained, the MC of the *T. microcarpa* (158.0%) was significantly higher while RD (0.430) was significantly lower than the other species. Conversely, the MC of *T. indica* (64.7%) and *C. cainito* (55.1%) were significantly lower but their RD (0.737 & 0.741, respectively) was significantly higher than the other fruit-bearing trees. A negative relationship between MC and RD was documented (Figure 4). The low MC and high RD observed in *T. indica* and *C. cainito* could probably be due to their thicker cell walls, lower vessel frequency, and narrower vessel diameter compared to other species (Escobin et al. 2015, Aiso et al. 2016, Shmulsky and Jones 2019). However, the relationship between the anatomical and physical properties of the senile fruit-bearing trees was not proven

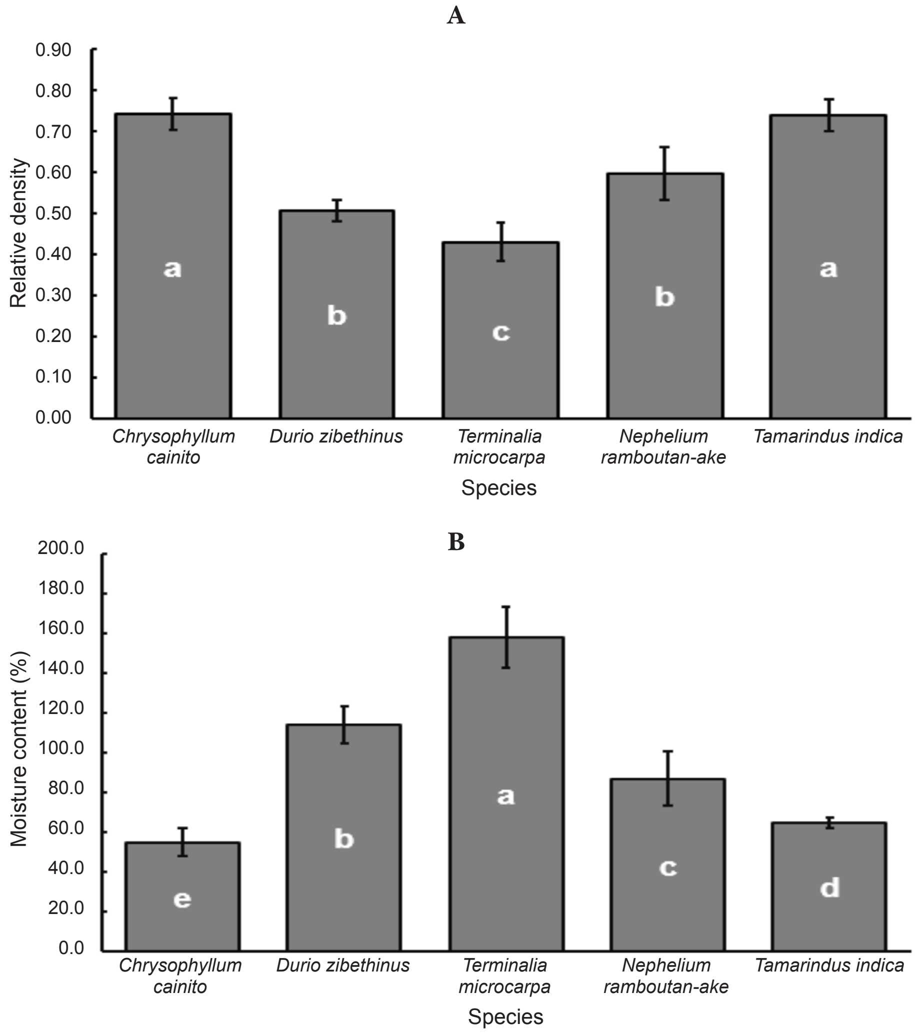

Figure 2 Relative density (A) and moisture content (%) (B) of fruit-bearing trees, means with the same letter are not significantly different, a–d = highest to lowest value

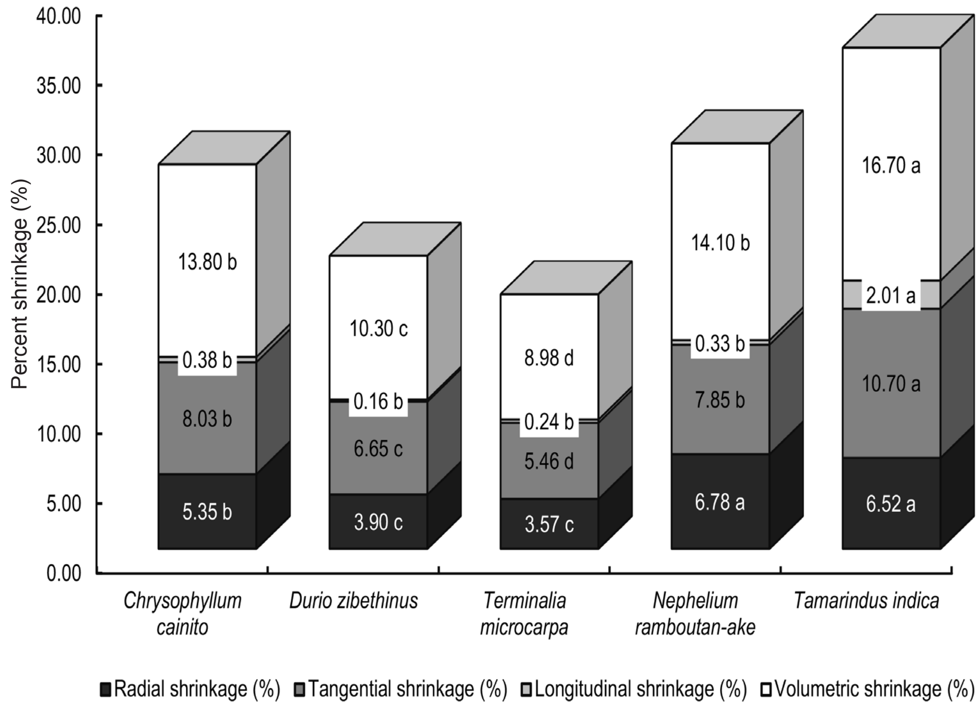

Figure 3 Shrinkage properties of fruit-bearing trees, means with the same letter are not significantly different, a–c = highest to lowest value

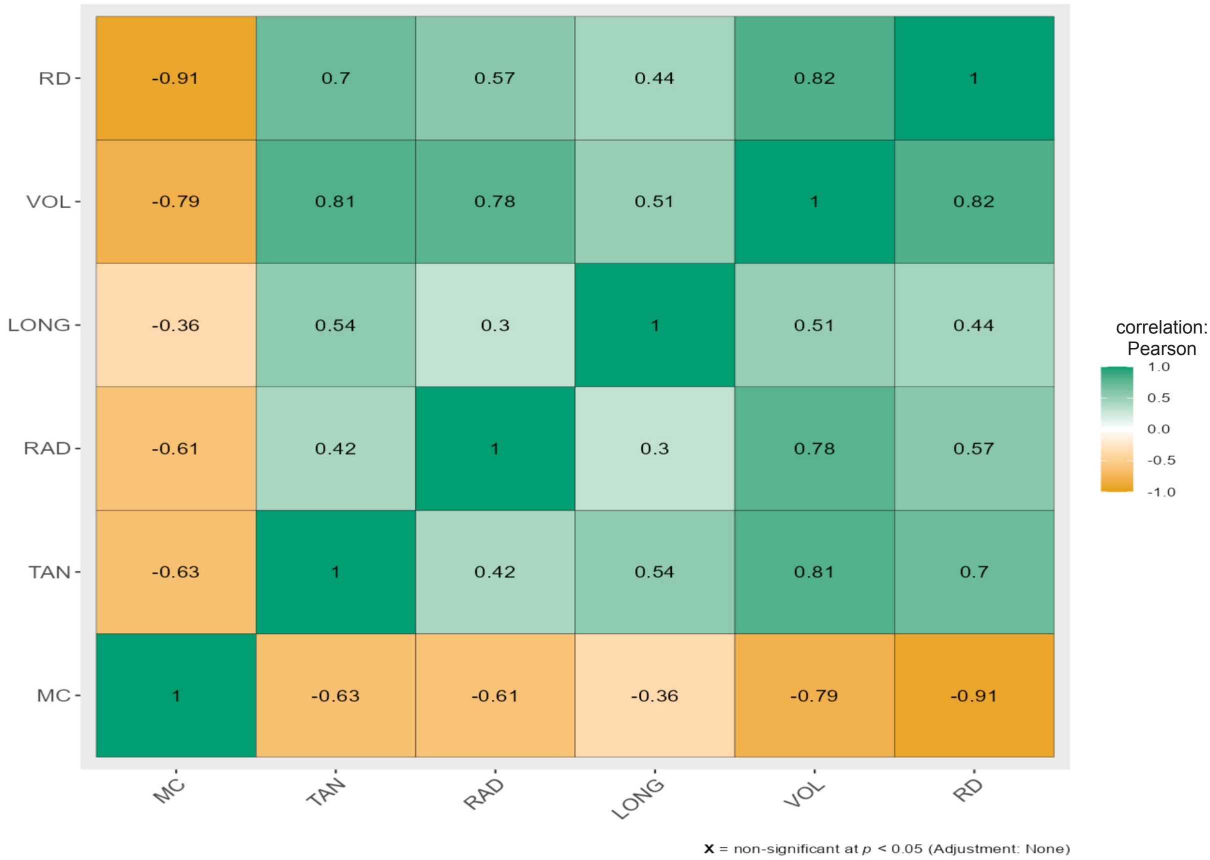

Figure 4 Correlation heatmap of the physical properties of fruit-bearing trees; RD = relative density, MC = moisture content, TAN = tangential shrinkage, RAD = radial shrinkage, LONG = longitudinal shrinkage, VOL = volumetric shrinkage

statistically in the present study, but this can be explored for future research. The results indicated that the mechanical properties of *T. indica* and *C. cainito* could probably be better than the other species.

Based on the RD, *C. cainito* and *N. ramboutan-ake* are classified as moderately high, higher than the RD of the Philippine mahogany group and commercially used timber species in the Philippines. *Tamarindus indica,* on the other hand, was classified as medium-high, comparable to the RD of *Parashorea malaanonan*, *Shorea negrosensis*, *Shorea contorta*, *Shorea polysperma*, *Swietenia macrophylla*, *Gmelina arborea* and *Acacia mangium.* The RD of *T. microcarpa* was similar to that of *Shorea almon*, *Shorea palosapis*, *Eucalyptus deglupta* and *Havea brasiliensis*, classified as moderately low. The *D. zibethinus* was classified as low, homogeneous with *Shorea ovata* and *Falcataria moluccana* (Alipon & Bondad 2008).

The variation in MC and RD of the fruit-bearing trees could probably be correlated to their anatomical properties (e.g., fibre length, fibre cell wall thickness and vessel diameter). Aiso et al. (2016) reported that the MC is positively and negatively correlated with the proportion of juvenile wood and fibre cell wall thickness, respectively. On the other hand, according to Hamdan et al. (2020), the fibre length, fibre wall thickness and small vessel diameter are directly related to the RD. Similar observations were also reported by Nordahlia et al. (2011) and Alia-Syahirah et al. (2019) where RD is positively correlated to fibre length, fibre wall thickness and vessel diameter. However, the present study did not assess the relationship between the fruit-bearing trees' anatomical and physical properties.

Shrinkage properties

Shrinkage properties among the species varied. For the radial shrinkage (RS) and tangential shrinkage (TS), the mean values of the *N. ramboutan-ake* (6.78 and 7.85%, respectively) and *T. indica* (6.52 and 10.7%, respectively) were significantly higher than the other species (Figure 3). The lowest RS and TS were observed in *D. zibethinus* (3.90 and 6.65%, respectively) and *T. microcarpa* (3.57 and 5.46%, respectively). For the longitudinal (LS) and volumetric shrinkage (VS), *T. indica* recorded the highest mean value (2.01 and 16.7%, respectively). This was followed by *C. cainito* (0.38 and 13.8%, respectively) and *N. ramboutan-ake* (0.33 and 14.1%, respectively).

The VS of the fruit-bearing trees was rated based on the classification of Alipon and et al. (2005). The *T. indica* was classified as high VS while *C. cainito* and *N. ramboutan-ake* were moderately high. The shrinkage of these species was higher compared to the Philippine mahogany group and commercially used timber species which belong to medium to low VS. On the other hand, the VS of *T. microcarpa* and *D. zibethinus* were moderately low, comparable to *S. ovata* and *A. mangium.*

The high shrinkage properties (i.e., directional and volumetric) observed in *T. indica, C. cainto* and *N. ramboutan-ake* can be associated with their high RD. This is supported by the significant positive correlation between shrinkage properties and RD as shown in Figure 4. The results of the present study indicated that shrinkage is highly dependent on RD. Wood with higher RD has higher shrinkage properties. This is in good agreement with Hamdan et al. (2020) and Fanny et al. (2018) who also reported a significant positive relationship between the RD and shrinkage properties of *Paraserianthes moluccana, Sapium baccatum, Macaranga gigantea, Endospermum malaccese, Melia azedarach, Azadiractha indica* and *Pinus pinaster,* respectively. According to Hamdan et al. (2020) and Okon (2014), the shrinkage properties of wood are also positively correlated with fibre length and fibre cell wall thickness. The high microfibril angle (MFA) and low extractive content can also contribute to the high shrinkage of the wood (Drozdzek et al. 2017, Shmulsky & Jones 2019). The effect of anatomical and chemical properties on the shrinkage properties of fruit-bearing trees can be considered in future studies.

Mechanical properties

Species and height levels had a significant effect on the mechanical properties of the fruit-bearing trees in both green and 12% MC conditions. However, for the green samples, height did not significantly affect the compression perpendicular-to-grain ($p = 0.159$) and shear ($p = 0.118$). On the other hand, stress at the proportional limit (SPL) ($p = 0.323$), compression parallel ($p = 0.830$) and perpendicular to the grain ($p = 0.257$), and hardness (end) ($p = 0.115$)

were not affected by the height at the 12% MC samples. Moreover, the SPL (p = 0.002), MOE (p = 0.010), and toughness (p = 0.031) were significantly affected by the interaction of S x H in the 12% MC condition.

In both conditions, the mean value of *C. cainito* was significantly higher than the other species in all mechanical properties except SPL and toughness (Table 2). In contrast, the strength of *D. zibethinus* was significantly lower than other species in most of the mechanical properties. For the green specimens, no significant difference was observed between *N. ramboutan-ake* and *C. cainito* in MOR, SPL and compression parallel-to-grain. On the other hand, MOR, SPL, shear and hardness (side & end) of *C. cainito* and *T. indica* did not significantly vary at the 12% MC condition. The highest toughness was recorded in *T. indica* in both conditions.

The variation in the mechanical properties of the fruit-bearing trees seemed to be affected by the RD. As shown in Figure 2 and Table 2, there was a direct relationship between RD and mechanical properties. Similar findings were also documented by Hamdan et al. (2020) and Nordahlia et al. (2014) in *P. moluccana, S. baccatum, M. gigantea, E. malaccense* and *Azadirachta excelsa*, respectively. Several studies also reported that the mechanical properties of wood are significantly affected by fibre length, fibre wall thickness and vessel diameter (Uetimane & Ali 2011, Adeniyi et al. 2013, Nordahlia et al. 2014, Hamdan et al. 2020).

All species documented an increase in strength after the wood samples were conditioned from green to 12% MC. *Tamarindus indica* recorded the highest increase in MOR (99%), SPL (85%), MOE (102%) and hardness [side (56%) and end (66%)] (Figure 5). On the other hand, *C. cainito* recorded the highest increase in shear (57%) and compression parallel-to-grain (95%), and *D. zibethinus* recorded the highest increase in compression perpendicular (109%). In contrast, all species observed a decrease in toughness. The highest decrease was observed in *N. ramboutan-ake* (28%) and the lowest in *D. zibethinus* (10%) and *T. indica* (10%). The decrease in toughness could probably be associated with the decrease in MC, making the wood brittle and easy to break (Shmulsky & Jones 2019). Thus, it is recommended to condition the MC of the wood to enhance all its strength parameters except toughness.

Based on the strength classification of Alipon and Bondad (2008), *C. cainito* is rated moderately high, higher than the Philippine mahogany group, and commercially used

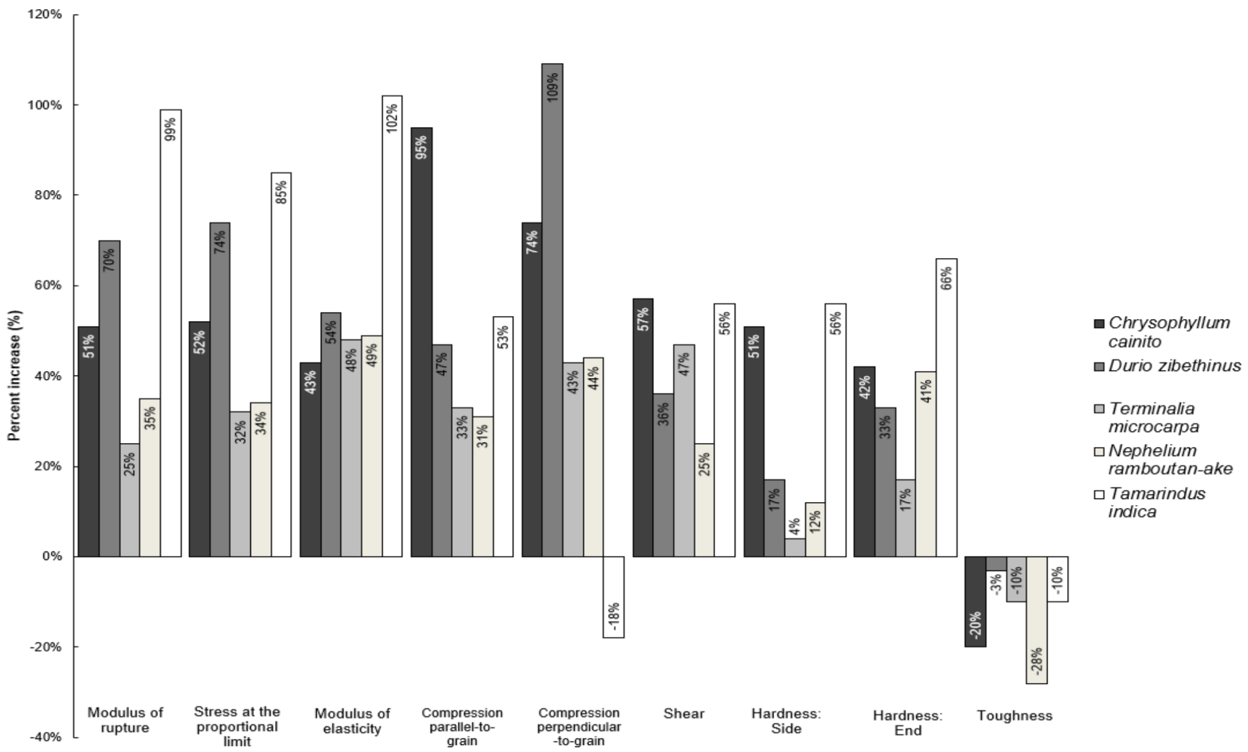

Figure 5 Percent change in mechanical properties of fruit-bearing trees after conditioning from green MC to 12% MC condition

Table 2 Mechanical properties of fruit-bearing trees at the green and 12% MC conditions

Species	Static bending						Compression strength (MPa)				Shear (MPa)		Hardness (kN)				Toughness (J/spec)	
	MOR (MPa)		MOE (GPa)		SPL (MPa)		Parallel-to-grain		Perpendicular-to-grain				Side		End			
	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC	Green	12% MC
Chrysophyllum cainito	72.40a (12.90)	109.00a (38.90)	9.91a (2.45)	14.20a (4.27)	27.30b (5.73)	41.40b (11.90)	27.30ab (5.64)	53.30a (21.60)	6.37a (1.44)	11.10a (3.30)	7.92a (0.78)	12.40a (5.47)	6.70a (0.91)	10.10a (2.83)	7.42a (0.54)	10.50a (1.96)	25.70c (11.60)	20.50c (8.64)
Durio zibethinus	35.70c (8.78)	60.80c (11.10)	4.49d (1.06)	6.90c (1.39)	22.70c (5.39)	39.60bc (6.52)	15.20d (2.73)	22.40c (3.12)	2.54c (0.42)	5.30c (1.72)	4.03d (0.56)	5.50c (0.90)	1.91d (0.44)	2.24c (0.59)	2.58e (0.42)	3.43c (0.32)	18.40c (9.75)	17.90c (6.08)
Terminalia microcarpa	49.00b (7.88)	61.10c (11.40)	5.65c (1.40)	8.38c (2.08)	25.30bc (3.09)	33.40c (7.81)	22.10c (2.35)	29.40c (5.88)	4.55b (0.57)	6.52bc (1.69)	5.37c (0.79)	7.87bc (1.16)	2.70c (0.41)	2.82c (0.64)	3.39d (0.65)	3.97c (0.93)	51.90b (4.08)	46.50b (6.62)
Nephelium ramboutan-ake	66.90a (8.65)	90.60b (14.70)	7.33b (1.09)	10.90b (2.37)	42.40a (6.29)	56.80a (8.12)	29.30a (3.78)	38.50bc (9.50)	5.26b (0.79)	7.60b (1.33)	6.76b (0.71)	8.47b (2.08)	5.02b (1.03)	5.62b (1.46)	5.30c (0.89)	7.47b (1.34)	23.80c (10.40)	17.20c (7.59)
Tamarindus indica	47.10b (7.23)	93.80ab (15.30)	3.52d (0.67)	7.11c (1.82)	28.20b (4.29)	52.30a 12.20)	25.40b (3.59)	38.80b (4.30)	5.76ab (1.21)	4.70d (1.58)	6.34b (0.84)	9.88ab (1.67)	7.20a (0.98)	11.20ab (1.77)	6.61b (1.01)	11.00a (1.40)	66.20a (8.30)	59.70a (14.30)

Values inside the parenthesis are standard deviations, means with the same letter are not significantly different, a–d = highest to lowest value, MOR = Modulus of rapture, MOE = Modulus of elasticity, SPL = Stress at the proportional limit, MC = Moisture content timbers. *N. ramboutan-ake, T. indica* and *T. microcarpa* fell under the medium strength which is similar to the Philippine mahogany group except for *S. ovata*. *Durio zibethinus,* on the other hand, was classified as low strength similar to *F. falcata and S. ovata*. The recommended uses for the fruit-bearing trees are shown in Table 3. The wood of *T. indica* is not recommended for structural application due to its uncertain durability against wood-decaying agents. In contrast, the wood of *N. ramboutan-ake* is durable against insect attacks but susceptible to fungal attacks (Lim et al. 2019). However, there are proper recommended preservative treatments that may be applied to prolong its service life such as the application of prophylactic treatment after harvesting, chemical preservatives (e.g., propiconazole, deltamethrin, tebuconazole, permethrin, disodium octaborate tetrahydrate, copper azole type) and heat or thermal modification treatment Mohd-Jamil et al. 2020.

Effect of height levels on properties

Physical properties

Various trends of the physical properties were observed along the height levels of the fruit-bearing trees (Figures 6 and 7). The MC decreased from the bottom to the middle and increased towards the top portion for *C. cainito, T. microcarpa* and *T. indica*. On the other hand, an increasing trend towards the top portion was observed in *N. ramboutan-ake,* and an increasing trend from bottom to middle and a decrease towards the top were observed in *D. zibethinus*. For the RD, the highest mean value was reported in the bottom, and the lowest in the middle portion of *C. cainito, D. zibethinus, T. microcarpa,* and *N. ramboutan-ake*. *Tamarindus indica,* on the other hand, showed a decreasing trend towards the top portion. However, the significant effect of the height level on the MC and RD was only documented in *N. ramboutan-ake*.

The variation in MC and RD along the height levels of the fruit-bearing trees could be due to the anatomical and chemical properties of the trees. According to Hussin et al. (2014), the variation in MC along the height levels was due to differences in RD which is ascribed to varied anatomical and chemical properties such as cell wall thickness, fibre length and extractive contents. This is supported by Aiso et al. (2016) and Van Duong and Matsumura (2018) who observed a direct relationship between anatomical properties and RD for *F. falcata* and *M. azedarach*. Additionally, the proportion of sap, heartwood, and early and late wood deviations along the height levels could also contribute to the variability of MC and RD (Shmulsky & Jones 2019). Drozdzek et al. (2017), on the other hand, found that the extractive has a positive correlation with the RD of selected tropical wood species.

For the shrinkage properties, a decreasing trend from top to bottom was recorded for RS, TS and VS of *D. zibethinus, N. ramboutan-ake* and *T. indica*. *Tamarindus microcarpa* also showed a decreasing trend for its RS and VS. Likewise, *C. caimito* RS decreased, while its bottom TS and VS gave the highest mean, and the middle TS and VS gave the lowest. Height levels significantly affected the TS, RS and VS of *N. ramboutan-ake* and *T. indica*. Likewise, VS of *T. microcarpa* significantly varied along the height levels. For LS, an increasing trend from the bottom to the top portion was observed in *C. cainito* and *T. microcarpa*. The bottom and middle portions exhibited the highest and lowest LS in *D. zibethinus, N. ramboutan-ake,* and *T. indica*.

The high TS, RS and VS in the bottom portion of the fruit-bearing trees may be due to the properties' strong positive correlation with their RD (Figure 4). The results agree with Marsoem and Pujiwinarko (2006) and Alipon and Bondad (2015) who reported a positive relationship between RD and shrinkage properties along the height levels of *F. falcata*. According to Marsoem and Pujiwinarko (2006), the increase in shrinkage at the bottom portion of the stem is due to its thick fibre wall. On the other hand, the variation in the trees' LS may be associated with the differences in microfibril angle (MFA) at the S_2 layer (Shrmulsky & Jones 2009). The results of the present study in *D. zibethinus, N. ramboutan-ake* and *T. indica* agree with the findings of Donaldson (2008) and Ogunjobi et al. (2018) that the high LS is due to high MFA.

Mechanical properties

The fruit-bearing trees exhibited varied mechanical properties along their height levels at the green condition and 12% MC (Tables 4 & 5). Significant differences were observed in *C. cainito* (MOR, MOE, compression parallel-to-grain and toughness) and *N. ramboutan-ake*

Table 3 Strength classification of the fruit-bearing trees, Philippine mahogany group and commercially used timber species, and their recommended uses

Strength classification	Fruit-bearing trees	Philippine mahogany group	Commercially used timber species in the Philippines	Recommended uses	References
Moderately high	*Chrysophyllum cainito*			Medium-heavy construction such as heavy-duty furniture, cabinets, medium-grade beams, flooring, door panels, frames, tool handle, veneer, and plywood production	Alipon & Bondad 2018, Lim et al. 2019
Medium	*Nephelium ramboutan-ake*	*Parashorea malaanonan*	*Swietenia macrophylla*	General construction, doors, framing, paneling, flooring, planking, medium-grade furniture, cabinet, veneer, and plywood (face & core).	Alipon & Bondad 2008, Escobin et al. 2015, Lim et al. 2019, Mohd-Jamil et al. 2020
	Tamarindus indica	*Shorea negrosensis*	*Gmelina arborea*		
	Terminalia microcarpa	*Shorea contorta*	*Acacia mangium*		
		Shorea polysperma			
Moderately low		*Shorea almon*	*Eucalyptus deglupta*	For pulp and paper production, wood carving and sculpture, conventional furniture, drafting boards, toys, venetian blinds, crates, pallets, form wood, and shingles.	Alipon & Bondad 2008
		Shorea palosapis	*Havea brasiliensis*		
Low	*Durio zibethinus*	*Shorea ovata*	*Falcataria falcata*	Light construction where strength hardness and durability are not critical requirements such as door and panel cores, moldings, ceiling, pulp and paper, and core veneer. It can also be used for interior construction, cheap types of furniture, window frames (treated), flooring, planking, and packing cases.	Alipon & Bondad 2008, Ella et al. 2008, Escobin & Conda 2018, Lim et al. 2019

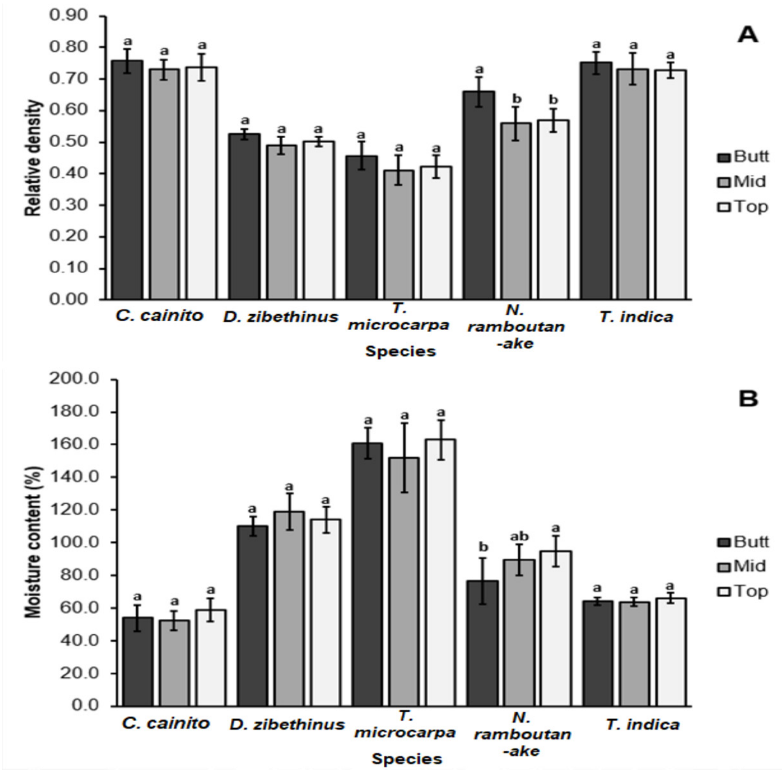

Figure 6 Relative density (A) and moisture content (B) of fruit-bearing trees at different height levels, mean with the same letter are not significantly different, a–b = highest to lowest value

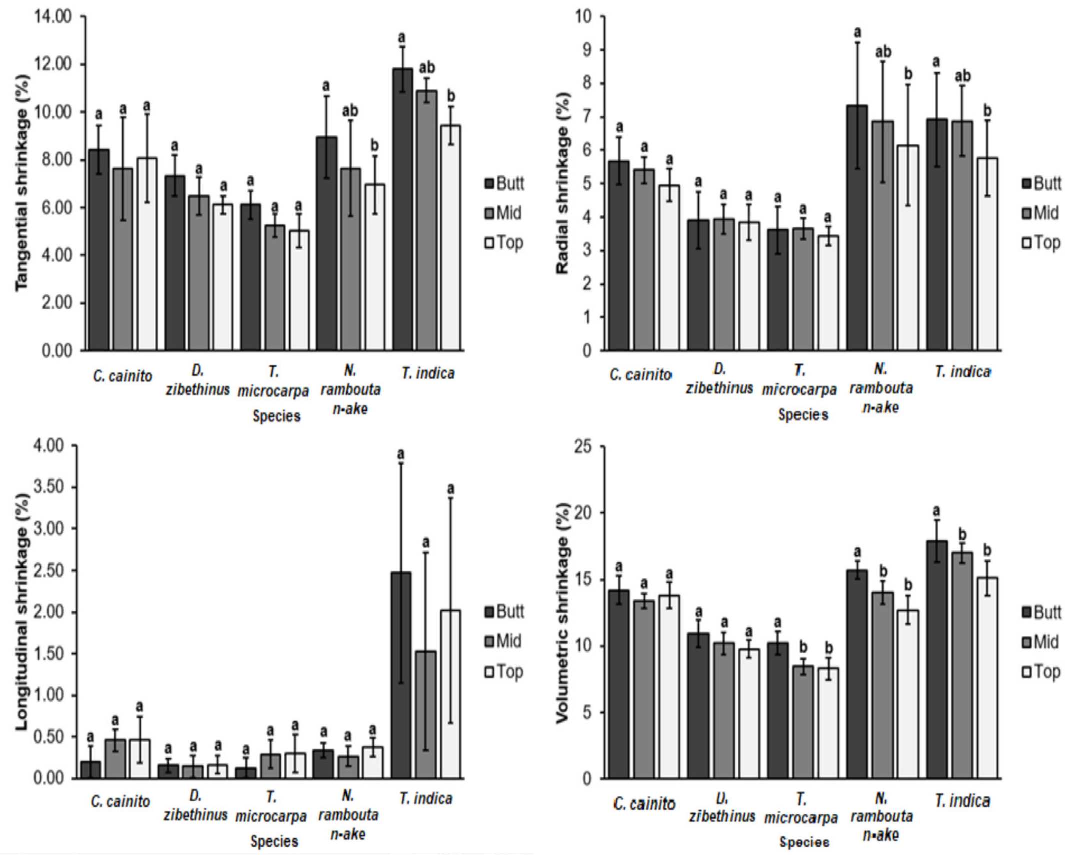

Figure 7 Shrinkage properties of fruit-bearing trees at different height levels, mean with the same letter are not significantly different

Table 4 Mechanical properties of fruit-bearing trees in the green condition at different height levels

Species	Height levels	Static bending			Compression strength		Shear (MPa)	Hardness (kN)		Toughness (J/spec)
		Modulus of rupture (MPa)	Stress at the proportional limit (MPa)	Modulus of elasticity (GPa)	Parallel-to-grain (MPa)	Perpendicular-to-grain (MPa)		Side	End	
Chrysophyllum cainito	Butt	76.00ab (7.63)	26.20 a (5.06)	8.45 b (1.64)	24.20 b (4.61)	6.00 a (1.63)	8.17 a (0.96)	7.17 a (0.66)	7.42 a (0.29)	36.40 a (11.90)
	Mid	80.30a (10.00)	29.80 a (4.69)	12.40 a (1.42)	32.90 a (2.35)	5.93 a (0.75)	8.05 a (0.63)	6.33 a (0.82)	7.55 a (0.43)	18.90 b (4.73)
	Top	60.90b (12.50)	25.90 a (7.23)	8.86 b (2.05)	24.80 b (4.97)	7.17 a (1.64)	7.53 a (0.62)	6.58 a (1.12)	7.29 a (0.82)	21.80 ab (9.31)
Durio zibethinus	Butt	39.20 a (5.07)	24.80 a (2.61)	4.79 a (0.62)	17.10 a (1.25)	2.75 a (0.38)	4.49 a (0.24)	2.02 a (0.56)	2.79 a (0.10)	23.20 a (12.30)
	Mid	33.10 a (11.70)	21.90 a (7.67)	4.80 a (1.16)	16.10 a (2.35)	2.47 a (0.53)	3.63 a (0.52)	1.83 a (0.33)	2.35 a (0.59)	16.80 a (8.88)
	Top	34.90 a (8.69)	21.50 a (5.06)	3.90 a (1.20)	12.40 a (1.93)	2.41 a (0.31)	3.96 a (0.54)	1.88 a (0.46)	2.60 a (0.36)	15.30 a (7.13)
Terminalia microcarpa	Butt	52.30 a (7.37)	27.80 a (3.42)	5.84 a (1.62)	22.80 a (3.09)	4.58 a (0.66)	5.70 a (0.60)	2.88 a (0.32)	3.81 a (0.71)	49.40 a (5.65)
	Mid	52.40 a (1.58)	24.20 a (3.18)	6.05 a (0.95)	22.00 a (1.94)	4.55 a (0.40)	5.81 a (0.82)	2.87 a (0.37)	3.42 a (0.32)	51.00 a (1.25)
	Top	42.30 a (8.64)	24.00 a (0.09)	5.07 a (1.58)	21.50 a (2.08)	4.52 a (0.71)	4.61 a (0.23)	2.34 a (0.31)	2.94 a (0.60)	55.30 a (0.72)
Nephelium ramboutan-ake	Butt	77.00 a (0.90)	49.60 a (1.17)	8.37 a (0.45)	33.60 a (2.04)	6.01 a (1.00)	6.65 a (1.06)	6.24 a (0.27)	6.20 a (0.47)	32.80 a (13.70)
	Mid	64.10 ab (2.42)	41.50 ab (2.35)	7.04 a (0.93)	28.80 ab (0.88)	4.80 a (0.30)	6.50 a (0.55)	4.34 b (0.76)	5.02 ab (0.26)	21.70 ab (4.10)
	Top	59.70 b (7.28)	36.00 b (4.03)	6.59 a (0.97)	25.50 b (2.07)	4.97 a (0.05)	7.14 a (0.22)	4.47 b (0.48)	4.67 b (0.93)	16.90 b (1.89)
Tamarindus indica	Butt	48.10 a (5.08)	27.30 a (4.59)	3.11 a (0.51)	26.50 a (3.90)	4.77 a (1.20)	6.40 a (0.86)	7.75 a (1.15)	7.28 a (0.75)	68.20 a (6.39)
	Mid	44.30 a (8.19)	27.80 a (4.99)	3.68 a (0.73)	24.70 a (3.96)	5.87 a (0.96)	6.34 a (1.25)	6.76 a (0.71)	6.15 a (1.29)	66.60 a (4.71)
	Top	48.90 a (8.39)	29.50 a (3.66)	3.78 a (0.66)	25.00 a (3.26)	6.64 a (0.71)	6.28 a (0.23)	7.10 a (0.89)	6.41 a (0.63)	63.60 a (12.60)

Values inside the parenthesis are standard deviations, means with the same letter are not significantly different, a–d = highest to lowest value

Table 5 Mechanical properties of fruit-bearing trees in the 12% MC condition at different height levels

Species	Height levels	Static bending			Compression strength		Shear (MPa)	Hardness (kN)		Toughness (J/spec)
		Modulus of rupture (MPa)	Stress at the proportional limit (MPa)	Modulus of elasticity (GPa)	Parallel-to-grain (MPa)	Perpendicular-to-grain (MPa)		Side	End	
Chrysophyllum cainito	Butt	132.00 a (15.00)	45.50 a (11.30)	17.30 a (3.23)	51.60 a (4.33)	10.60 a (1.62)	10.60 a (0.83)	9.74 a (1.81)	10.10 a (0.94)	22.50 a (6.14)
	Mid	98.60 b (29.30)	35.70 a (10.60)	11.70 b (4.33)	52.90 a (17.80)	12.40 a (3.71)	11.70 a (2.74)	9.75 a (0.73)	10.70 a (1.23)	14.10 a (9.82)
	Top	96.20 b (55.40)	43.10 a (13.40)	13.70 ab (3.68)	55.50 a (35.20)	10.40 a (4.19)	14.90 a (9.04)	10.80 a (4.76)	10.70 a (3.21)	25.10 a (6.31)
Durio zibethinus	Butt	64.10 a (9.51)	41.50 a (6.19)	6.62 a (1.38)	23.90 a (2.21)	6.04 a (1.72)	6.31 a (0.44)	2.94 a (0.22)	3.56 a (0.17)	22.10 a (7.16)
	Mid	62.20 a (15.00)	39.90 a (8.17)	7.31 a (2.03)	20.50 a (1.81)	4.02 a (0.93)	5.14 a (1.12)	1.77 a (0.33)	3.40 a (0.16)	14.90 a (4.08)
	Top	56.30 a (8.17)	37.30 a (5.36)	6.77 a (0.47)	22.70 a (4.25)	5.85 a (1.80)	5.04 a (0.29)	2.01 a (0.34)	3.32 a (0.50)	16.60 a (4.88)
Terminalia microcarpa	Butt	62.10 a (10.40)	38.60 a (6.07)	9.46 a (2.44)	31.70 a (5.58)	7.83 a (1.13)	8.53 a (0.65)	3.13 a (0.58)	4.46 a (0.43)	46.90 a (2.79)
	Mid	70.50 a (8.11)	34.30 a (6.14)	8.89 a (1.78)	31.60 a (5.80)	6.91 a (0.84)	7.50 a (0.84)	3.14 a (0.50)	4.61 a (0.51)	40.30 a (6.66)
	Top	50.70 a (5.45)	27.20 a (7.30)	6.80 a (0.96)	25.00 a (4.15)	4.82 a (1.42)	7.57 a (1.63)	2.17 a (0.24)	2.83 a (0.36)	52.50 a (2.85)
Nephelium ramboutan-ake	Butt	102.00 a (7.14)	61.60 a (5.41)	12.30 a (1.33)	33.70 a (13.60)	7.71 a (0.56)	9.00 a (1.07)	7.30 a (0.84)	8.82 a (0.55)	23.70 a (2.64)
	Mid	92.30 a (10.00)	58.80 a (6.77)	11.40 a (2.48)	40.80 a (4.79)	6.97 a (1.17)	8.54 a (2.54)	5.20 b (0.68)	6.68 a (0.37)	14.80 a (9.93)
	Top	76.90 b (13.80)	50.10 a (7.94)	8.92 a (2.00)	41.10 a (7.47)	8.12 a (1.88)	7.87 a (2.51)	4.36 b (0.76)	6.91 a (1.55)	13.10 a (3.55)
Tamarindus indica	Butt	87.10 a (17.40)	45.80 a (8.48)	6.60 a (1.48)	36.70 a (3.87)	5.52 a (1.21)	8.98 a (0.73)	12.20 a (2.12)	11.30 a (1.64)	70.80 a (0.61)
	Mid	92.80 a (12.80)	48.10 a (8.65)	6.80 a (1.44)	37.50 a (2.35)	4.02 a (1.49)	9.93 a (0.56)	10.80 b (1.73)	10.70 a (1.57)	50.50 b (17.30)
	Top	101.00 a (14.30)	62.90 a (12.30)	7.92 a (2.40)	42.20 a (4.66)	4.57 a (1.85)	10.70 a (2.62)	10.70 b (1.26)	11.00 a (1.15)	57.80 ab (11.80)

Values inside the parenthesis are standard deviations, means with the same letter are not significantly different, a–d = highest to lowest value

(MOR, SPL, compression parallel-to-grain, hardness and toughness) at green condition. For *C. cainito*, the middle portion recorded the highest MOR, MOE and compression parallel-to-grain. For toughness, the top of *C. cainito* gave the highest value while its bottom portion gave the lowest. For *N. ramboutan-ake*, the bottom portion was significantly higher MOR, SPL, compression parallel-to-grain, hardness and toughness compared to the other portions.

At 12% MC, significant differences were documented in *C. cainto* (MOR and MOE), *N. ramboutan-ake* (MOR and hardness: side) and *T. indica* (hardness: side and toughness). The bottom of the said species performed significantly better than the other portions. However, no significant variation between the bottom and top portions was observed in *C. cainito* (MOR) and *T. indica* (toughness). Moreover, no significant difference between the bottom and middle portions was noticed in the MOR of *N. ramboutan-ake*. The results indicated that the wood along the height levels of the *D. zibethinus, T. indica* (green condition) and *T. macrocarpa* can be utilised without significant reduction in strength properties compared to *C. cainito* and *N. ramboutan-ake*.

The variation in mechanical properties along the height levels may be attributed to differences in RD (Figure 6). Similar observations were also reported in *F. falcata*, *Pterocarpus erinaceus, Eucalyptus gomphocephala, E. cladocalyx* and *E. grandis x camaldulensis* where the portions with the highest RD gave the highest mechanical properties (Alipon et al. 2016, Wessels et al. 2016, Antwi-Boasiako et al. 2018, Marasigan et al. 2022). A positive relationship between RD and strength properties along height levels was also shown by Dinwoodie (2000). Other properties such as fibre cell wall thickness, fibre length, vessel frequency and diameter may also account for differences in strength properties across the bottom, middle and top portions (Sseremba et al. 2016, Lundqvist et al. 2017).

CONCLUSION

Senile trees of *C. cainito, N. ramboutan-ake* and *T. indica* showed the lowest MC and highest RD and shrinkage properties. While*, T. microcarpa* and *D. zibethinus* showed the opposite results. The strength of the *C. cainito* was classified as moderately high which is higher than the regularly used timber woods. *Nephelium ramboutan-ake, T. indica* and *T. microcarpa* were classified as medium strength, and *D. zibethinus* was classified as low. With that, the senile trees of *C. cainito, N. ramboutan-ake, T. indica* and *T. microcarpa* are suitable for construction, furniture, cabinets, beams, flooring, panels, frames, tool handle, face veneer and plywood production. On the other hand, *D. zibethinus* is also suitable for light construction, panel cores, moldings, ceiling, pulp and paper, and core veneer. The RD negatively correlated with MC but positively correlated with shrinkage and mechanical properties. The results showed that the RD is a good indicator for predicting shrinkage and mechanical properties. Generally, the senile trees of *C. cainito, N. ramboutan-ake, T. indica, T. microcarpa* and *D. zibethinus* are promising alternative materials that can be considered by the local wood industry to augment the supply of commercial timber.

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