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PHYSICAL AND MECHANICAL PROPERTIES OF THIRTEEN SENILE FRUIT-BEARING TREES IN THE PHILIPPINES AND THEIR POTENTIAL USES

Marasigan OS*, Alipon MA, Bondad EO, Hopia KA & Mundin MAM

Physics and Mechanics Section, Material Science Division, Forest Products Research and Development Institute (FPRDI), Department of Science and Technology (DOST), College, Laguna 4031, Philippines

**oliver.marasigan@fprdi.dost.gov.ph*

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The possible utilisation of the thirteen senile fruit-bearing trees were determined based on their physical and mechanical properties. The trees consisted of manggang kalabaw (*Mangifera indica L.*), manggang pahutan (*Mangifera altissima* Blanco), guyabano (*Annona muricata* L.), atis (*Annona squamosa* L.), avocado (*Persea americana* Mill.), lansones (*Lansium domesticum* Correa), santol (*Sandoricum koetjape* (Burm.f.) Merr.), nangka (*Artocarpus heterophyllus* Lam.), marang (*Artocarpus odoratissimus* Blanco), duhat (*Syzygium cumini* (L.)), bignai (*Antidesma bunius* (L.) Skeels), pomelo (*Citrus maxima* (Burm.)), and chico (*Manikara zapota* (L.) R. Royen). The tests were done using the ASTM D143-2014 standard and the tree samples were obtained from Laguna and Butuan City. Results showed that lansones (79.54%), duhat (60.77%), and chico (58.74%) had the lowest green moisture content (MC) and the highest relative density (RD) (0.66, 0.73, and 0.79, respectively). On the other hand, duhat and lansones had the highest tangential shrinkage (TS) (10.12% and 10.17%, respectively). Lansones also recorded the highest radial (RS) (7.80%) and volumetric (VS) (17.15%) shrinkage. For longitudinal shrinkage (LS), manggang pahutan (1.26%), and bignai (1.31%) displayed the highest value. For the strength properties, lansones recorded MOR (76.10 MPa), SPL (40.25 MPa), MOE (8.01 GPa), compression parallel-to-grain (32.05 MPa), and shear strength (7.06 MPa). Chico achieved higher compression perpendicular-to-grain (8.36 MPa), hardness: side (7.27 kN), and hardness: end (7.49 kN) than the other species. Based on the properties obtained, the 13 senile fruit-bearing trees are feasible alternatives that the local wood sector may consider to increase the supply of commercial lumber.

Keywords: Fruit trees, fruit-bearing trees, mechanical properties, physical properties, senile, utilisation

INTRODUCTION

The Philippines' need for wood continues to surge with the residential, commercial, and public construction projects combined with the falling production of timber and other wood products. According to Tamayo (2018), the local demand for wood increased by 216% between 2003 and 2014. As a result, imported forestry products have become a popular alternative source for wood users. In 2021, the Foreign Agricultural Service (FAS) reported a 15% increase in wood imports (Del Castillo 2021). In the search for alternative wood sources, timber from senile fruit-bearing trees has been named among the potential sources. As many of these old and unproductive fruit-bearing trees are uprooted every time the country is hit by a powerful storm or are being tapped simply for fuel and charcoal, they can help to meet the country's huge wood demand.

A total of 144,000, 41,000 and 22,000 ha in the country are planted with manggang kalabaw (*Mangifera indica*), maggang pahutan (*Mangifera altissima*), and lansones (*Lansium domesticum*) (PSA 2021). This translates to around 7,000,000, 2,000,000 and 2,000,000 trees, respectively. Moreover, the National Greening Program (NGP) which the Philippine government initiated in 2010, aims to reforest 1.5 million ha of land by planting 1.5 billion trees, including fruit-bearing species. Intercropping of fruit-bearing trees like rambutan (*Nephelium ramboutan-ake*) was started in one of the NGP sites in Pangasinan. Likewise, fruit trees including the guyabano (*Annona muricata*) and pomelo (*Citrus maxima*) were planted in Bataan as raw materials for pulp and paper, furniture, and other products (PhilForest 2015).

In recent years, the Department of Science and Technology's Forest Products Research and Development Institute (DOST-FPRDI) has received several inquiries about the strength characteristics of fruit-bearing trees. Customers wanted to know if these trees can be blended with other wood and non-wood forest products for diverse uses, utilised for construction, or both. Finding ways to use wood from old and unproductive fruit-bearing tree species could assist the wood industry in meeting its substantial raw material needs.

To encourage the use of potential replacements for traditionally used timbers, knowledge of the physical and mechanical qualities of alternative wood species is essential. Knowing about these characteristics would make it easier to employ these substitute species for particular end uses and new wood applications. For example, shrinkage causes warping, cupping, checking, and splitting which results in significant abnormalities in wood. On the other hand, mechanical properties are important for wood used in structural applications and as a gauge of the quality of sawn lumber.

There is currently scant knowledge on the fundamental wood characteristics of fruit-bearing trees in the Philippines. Only a few fruit-bearing trees have been studied by wood researchers so far: pahutan (*Mangifera altissima* Blanco), durian (*Durio zibethinus* Murray), santol (*Sandoricum koetijape* (Burm. F.) Merr.), bayabas (*Psidium guajava* L.), nangka (*Artocarpus heterophyllus* Lamk.), and marang (*Litsea perrottetti* (Blume) F. Vill.) (Alipon et al. 2005, 2022, Alipon & Bondad 2008). These fruit-bearing trees have been found promising for making pulp and paper, furniture, pallets, crates, and even construction materials. Moreover, wooden trays, carvings, plates, and furniture have been produced from some senile *M. indica* trees for both domestic and export markets (Alipon et al. 2022).

Studies on the potential uses of fruit-bearing trees including *M. indica* (Areo et al. 2015, Zziwa et al. 2016), *A. heterophylus*, *Syzygium* spp. (Hossain & Abdul Awal 2012, Ruwanpathirana 2014), and *S. koetjape* (Chhouk 2017) have been conducted in Nigeria, Uganda, Malaysia, Sri Lanka, and Cambodia. The above species can be used to make furniture, moldings, framing, construction timber, pulp and paper, and their qualities are comparable to those of commercial tree species.

Senile fruit-bearing trees could be used for a variety of wood projects, which could help to alleviate the local wood industry's raw material deficit and generate additional revenue. The goal of this study was to identify the physical and mechanical characteristics and suggest applications for 13 senile fruit-bearing tree species in the Philippines.

Wood characteristics of the fruit-bearing trees

Manggang kalabaw (*Mangifera indica* L.)

This wood has mediocre strength. It can be used for rough furniture, planking, packing boxes, shoe heels, toys, and boat building due to its moderate weight and hardness. If treated with preservatives, it can be used for construction, construction materials, and doors and windows. Additionally, it produces quality veneers for plywood manufacturing (Hossain & Abdul Awal 2012).

Manggang pahutan (*Mangifera altissima* Blanco)

Its heartwood is pale in colour with a yellowish tinge and has a very thick sapwood. The grain is straight. It has hefty, hard, and solid timber. Typically, it is utilised for regular building tasks, sheathing, ceilings, door panels, flooring, furniture, cabinetry, veneer, and ornate gunstocks (Escobin et al. 2015).

Guyabano (*Annona muricata* L.)

It is a thin, evergreen tree that typically grows to a height of 5 to 10 m and has a diameter of 15 cm. Straight and the trunk is grey or grey-brown in colour. The sapwood of this tree is pale, while the heartwood is dark. Although it is soft, light, unreliable, and hardly utilised as timber, the wood has been employed to make animal yokes (Orwa et al. 2009).

Atis (*Annona squamosa* L.)

A tiny, semi-evergreen tree that grows between 3 to 7 m in height. The wood is soft, light in weight and weak, with light-yellow sapwood and brownish heartwood. Additionally, the wood is a useful source of firewood (Orwa et al. 2009).

Avocado (*Persea americana* Mill.)

The wood is used for interior paneling, furniture, general carpentry, closets, and cabinets, as well as glue boards and glue lams for indoor frameworks (Fuentes-Talavera et al. 2011). Additionally, it is used for light construction, furniture, cabinet making, agricultural tools, carving, sculpting, musical instruments, paddles, small items like pen and brush holders, as well as house building (particularly for house posts). Additionally, it produces plywood and good-quality veneer. However, it is fragile and prone to termite infestation (Orwa et al. 2009).

Lansones (*Lansium domesticum* Correa)

A 10 to 15-m tall upright tree with reddish-brown or yellow-brown bark. The wood is fine-grained, medium-hard, and light brown in colour. It is durable, pliable, and robust. It weighs 840 kg m^{-3} on average. It is used for small utensils, tool handles, rafters, and house posts (Orwa et al. 2009).

Santol (*Sandoricum koetjape* (Burm.f.) Merr.)

The wood is light brown to pinkish brown in tone. It is also moderately soft and light. Its wood is frequently substituted in butcher's blocks, household tools, wood carvings, and house construction. Additionally, it is utilised in the production of furniture, construction of cabinets, joinery, interior decoration, paneling, planking, boat decking and packaging. Alternatively, it can be utilised as raw wood for veneer, plywood, pulp and paper (Escobin et al. 2015).

Marang (*Artocarpus odoratissimus* Blanco)

The wood has a slightly crossed grain and is light to grayish brown in colour. It is mildly soft to mildly light. The material is frequently employed for carving, sculpting and pattern-making (Escobin et al. 2015)

Nangka (*Artocarpus heterophyllus* Lam.)

The wood may be easily sawed, machined or carved, and is robust, firm and long-lasting. It has a light to medium yellow colour. It is employed in the creation of fine furniture, as well as in the manufacture of utensils, boats, cabinets, musical instruments like the violin, and house construction like doors, windows and roof rafters, for example (Hossain & Abdul Awal 2012).

Duhat (*Syzygium cumini* (L.) Skeels)

It is a timber that is fairly robust and medium-dense. However, it can shrink significantly. It may be used for doors, windows and furniture, and is a good construction timber because of its weight. It is also appropriate for making carts, railway sleepers and boats (Hossain & Abdul Awal 2012).

Bignai (*Antidesma bunius* (L.) Spreng.)

Small, durable wood pieces are used for fuel, temporary buildings, poles, posts, fences, and small things like walking sticks and tool handles. For the production of hardboard, wood chips are combined with other species (Escobin & Conda 2018).

Pomelo (*Citrus maxima* (Burm.) Merr.)

The tree is between 5 and 15 m tall and has a somewhat bent trunk. It has strong, robust and fine-grained wood that is ideal for manufacturing tool handles (Orwa et al. 2009).

Chico (*Manikara zapota* (L.) R. Royen)

It is a large, evergreen forest tree that grows up to 1.5 m in diameter and is over 30 m tall. Its wood is very hard, strong, tough, dense, resistant and long-lasting, and is deep red in colour. Heavy construction, furniture, joinery, and tool handles are all appropriate uses (Orwa et al. 2009).

MATERIALS AND METHODS

Preparation of materials

Thirteen senile fruit-bearing trees namely manggang kalabaw (*Mangifera indica* L.), manggang pahutan (*Mangifera altissima* Blanco), guyabano (*Annona muricata* L.), atis (*Annona squamosa* L.), avocado (*Persea americana* Mill.), lansones (*Lansium domesticum* Correa), santol (*Sandoricum koetijape* (Burm. F.) Merr.), marang (*Artocarpus odoratissimus* Blanco), nangka (*Artocarpus heterophyllus* Lam.), duhat (*Syzygium cumini* (L.) Skeels), bignai (*Antidesma bunius* (L.) Spreng.), pomelo (*Citrus maxima* (Burm.) Merr.) and chico (*Manikara zapota* (L.) R. Royen) were collected from Laguna and Butuan City. These species belong to nine families *viz.* Anacardeaceae, Annonaceae, Lauraceae, Meliaceae, Moraceae, Myrtaceae, Phyllantaceae, Rutaceae, and Sapotaceae (Table 1). Three senile trees per species were felled at 15 cm above the ground. From the bottom

Table 1 Information about the 13 senile fruit-bearing trees

Common name	Scientific name	Family name	Collection site
Manggang kalabaw	*Mangifera indica* L.	Anacardiaceae	Laguna
Manggang pahutan	*Mangifera altissima* Blanco		Laguna
Guyabano	*Annona muricata* L.	Annonaceae	Laguna
Atis	*Annona squamosa* L.		Butuan city
Avocado	*Persea americana* Mill.	Lauraceae	Butuan city
Lansones	*Lansium domesticum* Correa	Meliaceae	Laguna
Santol	*Sandoricum koetjape* (Burm.f.) Merr.		Butuan city
Marang	*Artocarpus odoratissimus* Blanco	Moraceae	Butuan city
Nangka	*Artocarpus heterophyllus* Lam.		Butuan city
Duhat	*Syzygium cumini* (L.) Skeels	Myrtaceae	Laguna
Bignai	*Antidesma bunius* (L.) Spreng.	Phyllanthaceae	Laguna
Pomelo	*Citrus maxima* (Burm.) Merr.	Rutaceae	Butuan city
Chico	*Manikara zapota* (L.) R. Royen	Sapotaceae	Butuan city

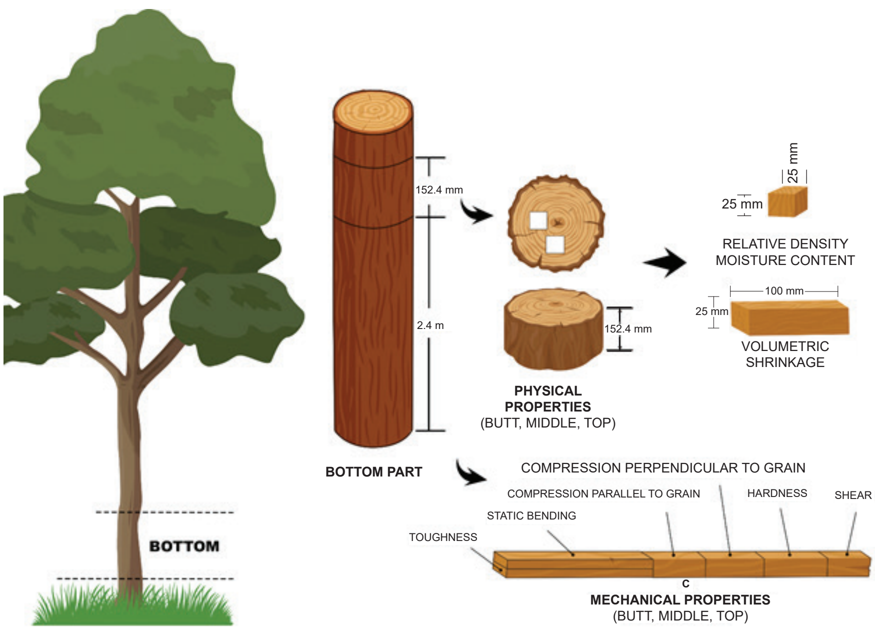

Figure 1 Sampling scheme used in the study

portion of the stem, a disc of approximately 152.4 mm in thickness and billets of 2.4 m in length were cut from the bottom portion of the stems (Figure 1) (Tan et al. 2010). Research on the physical qualities was conducted using discs, while a study of the mechanical properties was conducted using billets.

Physical properties determination

Physical properties were tested using ASTM D143-52: Standard Test Methods for Small Clear Specimens of Timber (ASTM 2014). A sample measuring 25 × 25 × 25 mm was cut from the disc for the analysis of moisture content (MC) and relative density (RD). The volume of the samples was determined by water displacement method and their weights were determined before, and after oven drying at 103 ± 2 ºC until a constant weight was attained. The difference in weight expressed as a percentage of the oven-dry weight was considered as the specimen MC. The RD of each sample was determined as the ratio of the oven dry weight to its green volume. The MC and RD were calculated using the following equations:

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

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

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

The shrinkage values from green to oven-dry 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:

$$S_a\ (\%) = \left(\frac{D_i - D_o}{D_i}\right) \times 100 \qquad (3)$$

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

Determination of mechanical properties

ASTM D143-52: Standard Test Methods for Small Clear Specimens of Timber was used to test samples for their mechanical qualities (ASTM 2014). Static bending, compression perpendicular and parallel to the grain, shear, hardness (side and end), and toughness were investigated. The 300 kN Universal Testing Machine was used for all testing (UTM).

Statistical analysis

R Studio version 4.2.1 was used to conduct the statistical analysis (R Core Team 2022). The significance of mean differences across species was assessed using a one-way analysis of variance (ANOVA). The Tukey's honestly significant difference (HSD) test was performed to discover which of the means were substantially different from one another if the differences were significant. Using the Pearson correlation analysis, it was determined how physical and mechanical attributes relate to one another.

RESULTS AND DISCUSSION

Physical properties

Moisture content and relative density

The green moisture content (MC) for 13 senile fruit-bearing trees varied significantly ($p = < 0.0001$) with values ranging from 58.74 to 218.54%. Atis recorded the highest MC, followed by marang (188.19%), while duhat and chico (60.77 and 58.74%, respectively) had the lowest MC (Figure 2). Relative density (RD) also differed substantially ($p = < 0.0001$), ranging from 0.30 to 0.79, with chico recording the highest and atis the lowest value. The results indicated that the MC and RD showed strong negative correlation ($p = < 0.001$).

The findings suggest that fruit trees with high green MC, such as atis, marang, guyabano, and manggang kalabaw, may have longer drying than species with a lower green MC (Cuaresma 2022). However, because of their high RD, the chico (0.79), duhat (0.73), and lansones (0.66) may have better mechanical properties than the other species.

Based on their RD, lansones, duhat, bignai, and chico were classified higher than the Philippines mahogany group and commercial timber in the Philippines (Alipon & Bondad 2008). On the other hand, manggang kalabaw, manggang pahutan, santol, nangka, and pomelo had moderately high RD. Avocado had medium RD similar to *Parashorea malaanonan*, *Shorea negrosensis*, *S. contorta*, *S. polysperma*, *Swietenia macrophylla*, *Gmelina arborea*, and *Acacia mangium*. On the other hand, guyabano and marang had moderately low RD, the same as *S. almon, S. palosapis, Eucalyptus deglupta*, and *Hevea brasiliensis*. The RD of atis was low and similar to *S. ovata* and *Falcataria moluccana*.

The anatomical and chemical properties of the senile fruit-bearing trees could explain the variance in their green MC and RD. Chico and duhat may have thicker cell walls, fewer vessels, and narrower vessel diameters, which may have resulted in their low MC and high RD (Shmulsky and Jones 2019, Aiso et al. 2016, Escobin et al. 2015). Hamdan et al. (2020) found a positive correlation between RD and fibre length, fibre wall thickness, and vessel diameter. In studies where RD is connected with fibre length, fibre wall thickness and vessel diameter, Alia-Syahirah et al. (2019), Hussin et al. (2014) and Nordahlia et al. (2011) reported similar results.

Furthermore, according to Aiso et al. (2016) and Van Duong and Matsumura (2018), MC is positively and negatively correlated with the amount of juvenile wood and fibre wall thickness, respectively. On the other hand, Drozdzek et al. (2017) reported that the presence of extractives is positively and negatively associated with RD and MC, respectively. The association among the anatomical, chemical, and physical characteristics of the senile fruit-bearing trees, however, was not statistically demonstrated in the current study and may be the subject of future research.

Shrinkage properties

The 13 tree species notably differed in directional shrinkage (i.e., tangential, radial, and longitudinal) and volumetric shrinkage ($p = < 0.001$). Compared to the other trees, lansones exhibited significantly higher tangential (TS) (10.17%), radial (RS) (7.80%), and volumetric (VS) (17.15%) shrinkage (Figure 3). On the other hand, manggang pahutan (3.98%), marang (4.56%), nangka (4.54%), and manggang kalabaw (4.51%) showed the lowest TS. The RS of santol (2.23%), marang (2.13%), and atis (2.43%) were noticeably lower than those of other species. For VS, the lowest values were recorded in manggang pahutan (7.27%), santol (7.05%), and marang (6.59%).

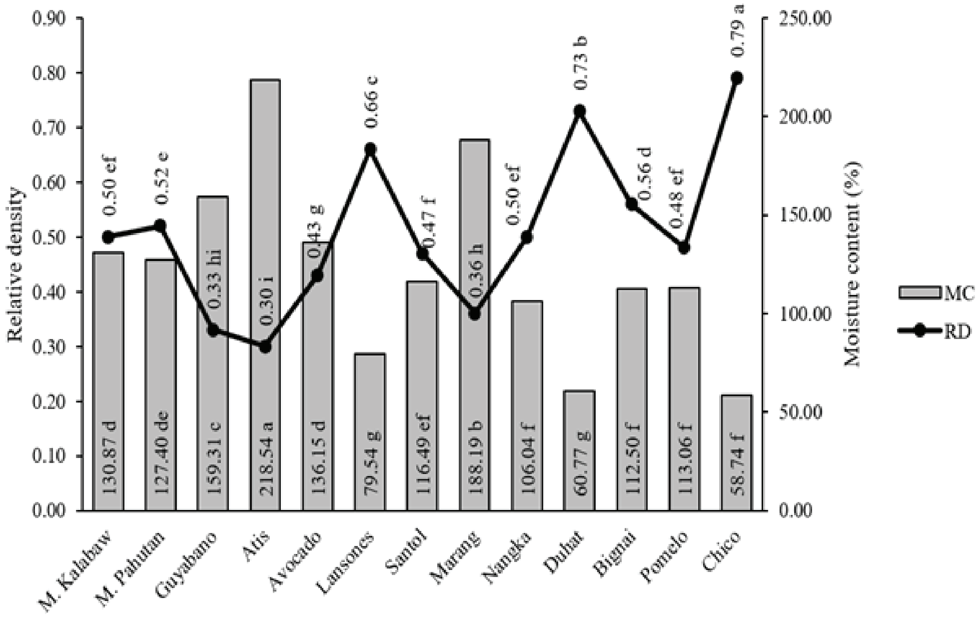

Figure 2 Relative density (RD) and green moisture content (MC) of the 13 senile fruit-bearing trees

Compared to other tree species, bignai (1.31%) and manggang pahutan (1.26%) had notably higher LS, while atis (0.18), nangka (0.15), and avocado (0.15) gave the lowest values.

Based on the classification by Alipon et al. (2005), manggang pahutan, atis, santol, marang, nangka, and pomelo had low VS, similar to *S. macrophylla* and *H. brasiliensis*. Duhat and guyabano, on the other hand, had moderately high, and lansones had a higher VS than that of the Philippine mahogany group and commonly used timber species. Bignai and chico's VS fell under the medium group, similar to the VS of the *Gmelina arborea, S. egrosensis, S. contorta, S. polysperma, S. almon*, and *S. palosapis*. Manggang kalabaw and avocado, on the other hand, had moderately low VS, comparable to *S. ovata* and *A. mangium*.

It is possible that lansones' high RD was responsible for its high TS, RS and VS. This is supported by Figure 4, which shows a strong positive correlation between RD and shrinkage properties. Wood with higher RD had greater shrinkage characteristics. Also, shrinkage was negatively correlated with green MC. A notably positive relationship was also found between directional and volumetric shrinkage. In general, the RD and MC of the 13 species greatly influenced their shrinkage properties, and high TS and RD typically exhibited high VS.

The findings of this study are consistent with those of Hamdan et al. (2020) and Fanny et al. (2018), who also noted 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. The shrinkage characteristics of wood are also positively correlated with fibre length and fibre wall thickness, according to Hamdan et al. (2020) and Okon (2014). The high microfibril angle (MFA) of the species may be the cause of the high LS seen in some fruit-bearing trees (Shmulsky & Jones 2019). Future research can take into account the impact of anatomical characteristics and other wood properties on the shrinkage of senile fruit-bearing trees.

The results of the present study suggest that it is necessary to dry wood materials to the environment's equilibrium moisture content (EMC) for species, particularly lansones and duhat that have high shrinkage qualities. It is anticipated that wood with MC equivalent to the

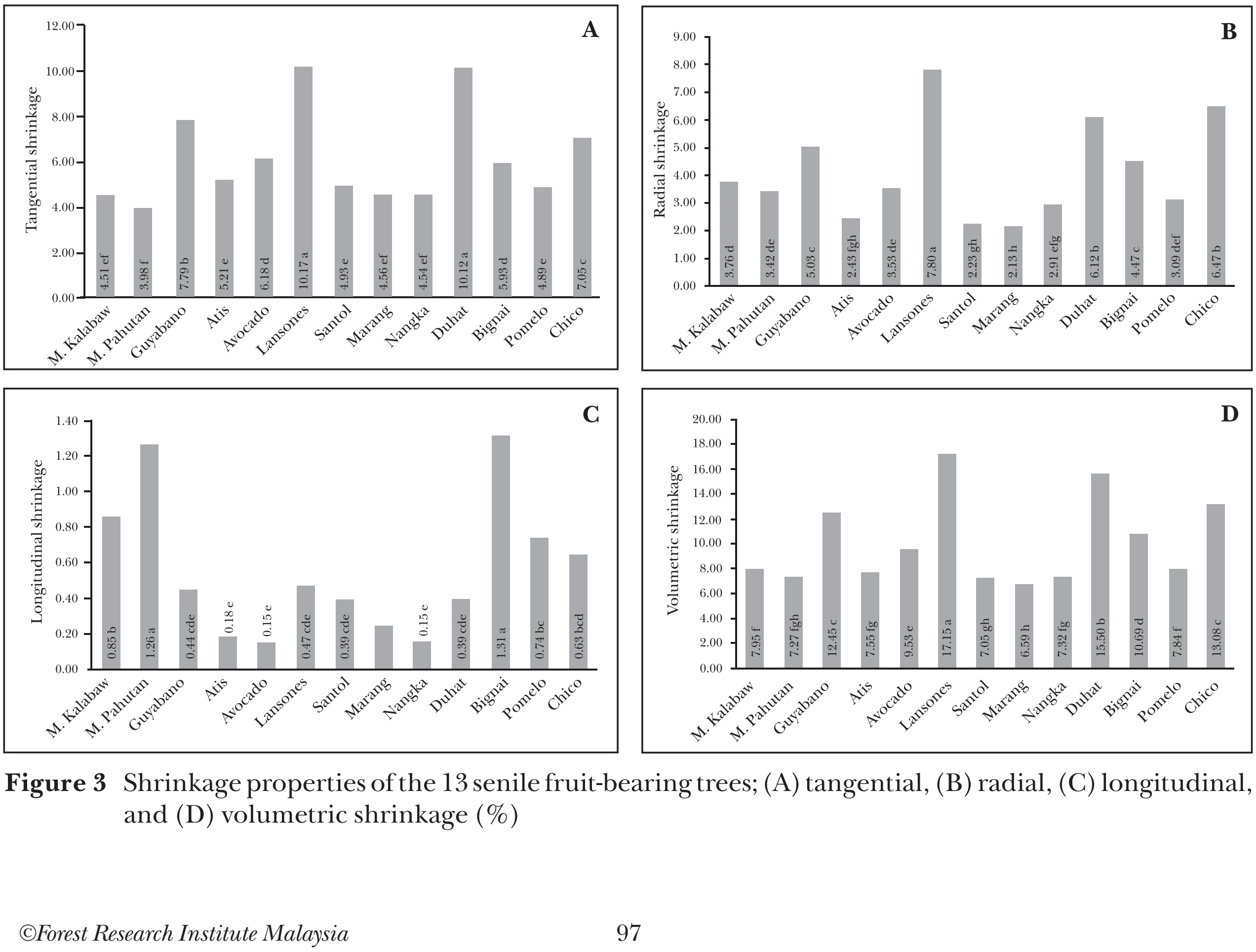

Figure 3 Shrinkage properties of the 13 senile fruit-bearing trees; (A) tangential, (B) radial, (C) longitudinal, and (D) volumetric shrinkage (%)

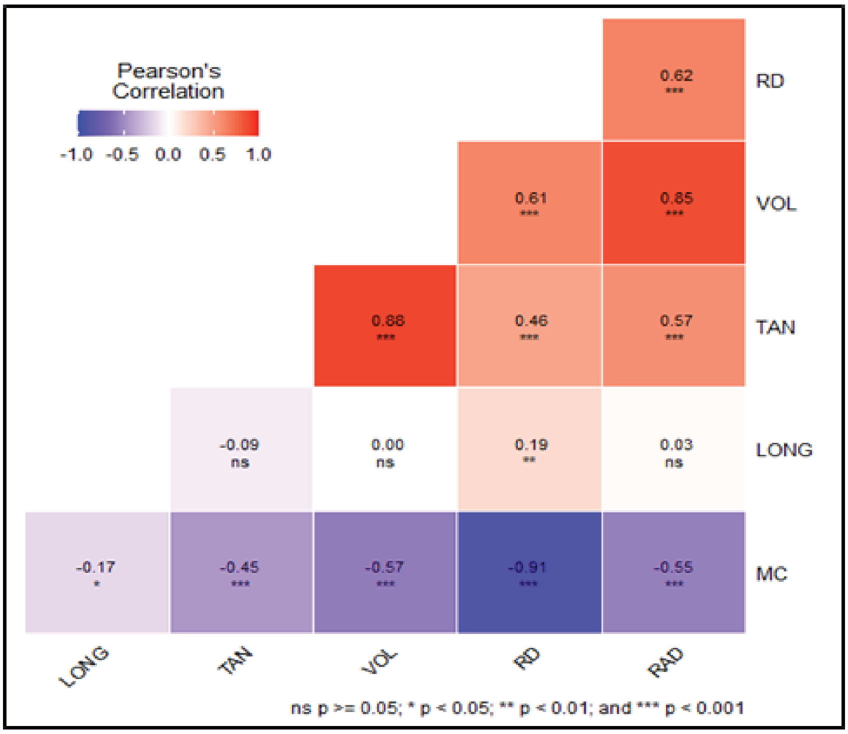

Figure 4 Correlation heatmap of physical properties of the 13 senile fruit-bearing trees MC = moisture content, RD = relative density, VOL = volumetric shrinkage, TAN = tangential shrinkage, RAD = radial shrinkage, and LONG = longitudinal shrinkage

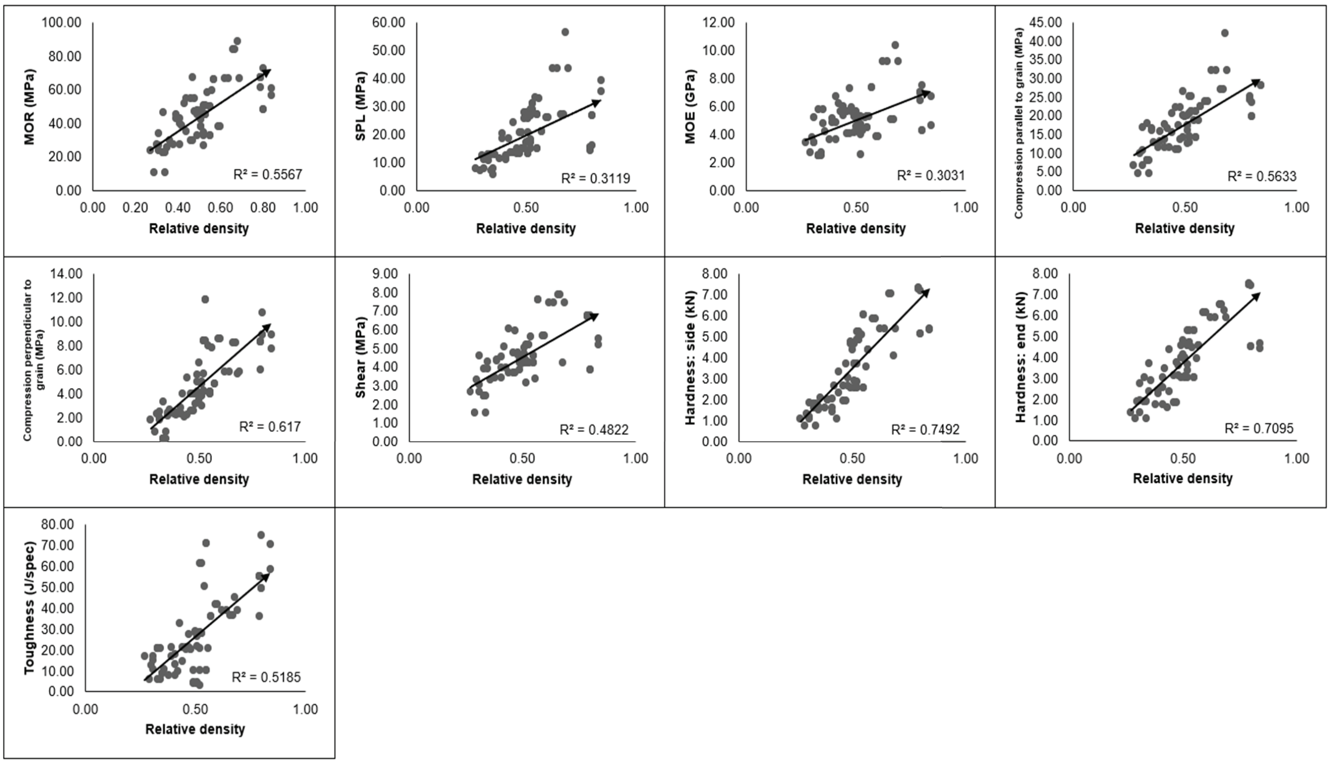

Figure 5 Relationship of relative density and mechanical properties of the 13 senile fruit-bearing trees

EMC will be dimensionally stable. Additionally, species with high VS are more likely to display drying flaws such as checking, warping, and splitting (Alipon et al. 2000). To reduce the likelihood of drying problems, an appropriate drying schedule for each species must be followed. Based on the RS and LS of the fruit-bearing trees during lumber manufacturing, the present study's findings can offer an estimation of a better shrinkage allowance.

Mechanical properties

The green mechanical properties of the senile fruit-bearing trees differed significantly between species ($p = < 0.001$). The strength of lansones was considerably higher than that of other species in terms of modulus of rupture (MOR) (76.10 MPa), stress at the proportional limit (SPL) (40.25 MPa), modulus of elasticity (MOE) (8.01 GPa), compression parallel-to-grain (32.05 MPa), and shear strength (7.06 MPa). Atis and guyabano, on the other hand, recorded significantly lower values than the other species for the aforementioned strength attributes (Table 2).

Chico gave significantly higher values than the other species for compression perpendicular-to-grain (8.36 MPa), hardness (side) (7.27 kN), and hardness (end) (7.49 kN). On the other hand, guyabano and atis obtained the lowest result for compression perpendicular-to-grain (0.22 and 1.58 MPa, respectively). Nonetheless, atis recorded significantly lower hardness side and end (1.04 and 1.43 kN, respectively).

In terms of toughness, bignai (58.13 J/spec), chico (55.38 J/spec), and duhat (49.90 J/spec) displayed significantly higher values than the other species. In these species, no significant differences in toughness were found. On the other hand, although having substantially lower toughness values than the other fruits, manggang kalabaw (4.02 J/spec), pomelo (10.27 J/spec), marang (10.86 J/spec) and atis (12.40 J/spec) gave strength values which did not statistically vary from one another.

The RD appeared to have an influence on the variation in mechanical characteristics of the fruit-bearing trees. There was a direct correlation between RD and mechanical parameters (Figure 5). Nordahlia et al. (2011) and Hamdan et al. (2020) both reported on related findings in *P. moluccana, S. baccatum, M. gigantea, E. malaccense,* and *Azadirachta excelsa*.

Several studies also reported that the mechanical properties of wood are significantly affected by fibre length, fibre wall thickness and vessel diameter (Hamdan et al. 2020, Uetimane & Ali 2011, Nordahlia et al. 2014, Adeniyi et al. 2013). Additionally, a number of studies revealed that the vessel diameter, fibre length and fibre wall thickness had a substantial impact on the mechanical properties of wood (Hamdan et al. 2020, Nordahlia et al. 2014).

The MOR and MOE of *M. indica* in the present study were lower than the findings of Zziwa et al. (2016) who reported of the values 63.50 MPa and 5.62 GPa, respectively. However, compared to the findings of Kumar et al. (2015) (29.1 MPa and 4.32 GPa, respectively), the MOR and MOE values of the present study were higher. Additionally, compression parallel- and perpendicular-to-grain and shear strength of the present study were lower than the findings of Kumar et al. (2015) and Chhouk (2017). For nangka, the MOE and MOR results of the present study were higher compared to those of Prihatmaji et al. (2012) (4.48 GPa and 60.80 MPa, respectively). However, the shear strength and compression parallel and perpendicular values were lower than the findings of Hossain and Abdul Awal (2012) and Chhouk (2017). The compression parallel and perpendicular, MOR, and shear strength values of duhat and santol in the present study were also lower than the findings of Hossain and Abdul Awal (2012) and Chhouk (2017). The difference in values may be associated with differences in the age and location of the trees. As tree plantations are located all over the Philippines, it may be helpful to carry out future studies on how age and location affect the wood characteristics of fruit-bearing trees.

Based on the classification of Alipon and Bondad (2008), lansones and chico are rated moderately high in strength, higher than the Philippine mahogany group and commercially used timbers. Nangka and duhat fell under medium strength, similar to the Philippine mahogany group, except for *S. ovata*. Manggang

Table 2 Mechanical properties of the 13 senile fruit-bearing trees at green condition

Species	Static bending			Compression		Shear (MPa)	Hardness		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 (kN)	End (kN)	
Manggang kalabaw	40.44^{def}	20.39^{d}	4.60^{de}	19.30^{de}	4.81^{c}	4.02^{de}	4.21^{d}	3.98^{e}	4.02^{h}
	(8.12)	(6.79)	(1.09)	(4.11)	(0.81)	(0.46)	(0.53)	(0.31)	(0.46)
Manggang pahutan	45.99^{d}	26.77^{c}	4.68^{de}	20.50^{cd}	8.43^{a}	4.31^{cde}	4.74^{cd}	4.58^{d}	28.18^{c}
	(0.65)	(5.10)	(0.51)	(0.63)	(3.18)	(0.16)	(0.19)	(0.22)	(0.29)
Guyabano	22.62^{g}	12.69^{ef}	2.47^{g}	8.11^{h}	0.22^{f}	2.44^{f}	1.80^{g}	1.88^{g}	20.70^{cdef}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Atis	20.49^{g}	9.00^{f}	3.25^{fg}	7.14^{h}	1.58^{ef}	2.46^{f}	1.04^{h}	1.43^{h}	12.40^{efgh}
	(7.69)	(2.24)	(0.43)	(2.64)	(0.64)	(0.75)	(0.23)	(0.39)	(5.11)
Avocado	33.55^{f}	12.75^{ef}	4.39^{de}	11.98^{g}	2.37^{de}	3.64^{e}	1.76^{g}	1.86^{g}	17.66^{defg}
	(9.43)	(0.95)	(0.88)	(1.72)	(0.20)	(0.21)	(0.43)	(0.25)	(9.46)
Lansones	76.10^{a}	40.24^{a}	8.01^{a}	32.05^{a}	6.63^{b}	7.06^{a}	5.72^{b}	6.14^{b}	39.20^{b}
	(10.33)	(11.23)	(2.34)	(5.51)	(1.25)	(1.39)	(1.16)	(0.31)	(3.08)
Santol	42.38^{de}	19.25^{d}	4.79^{de}	14.01^{fg}	3.33^{cd}	4.58^{cd}	2.57^{f}	2.97^{f}	21.08^{cde}
	(4.18)	(1.39)	(0.67)	(1.55)	(1.02)	(0.28)	(0.46)	(0.53)	(3.10)
Marang	35.60^{ef}	9.92^{ef}	5.52^{cd}	16.42^{ef}	2.59^{de}	4.20^{de}	1.68^{g}	2.90^{f}	10.86^{fgh}
	(8.78)	(2.54)	(0.73)	(1.60)	(0.42)	(0.32)	(0.23)	(0.46)	(4.12)
Nangka	60.68^{bc}	19.50^{d}	6.56^{bc}	21.24^{bcd}	4.50^{c}	6.12^{b}	3.51^{e}	3.93^{e}	26.88^{cd}
	(6.48)	(3.87)	(0.87)	(2.05)	(0.56)	(1.26)	(0.77)	(0.67)	(7.65)
Duhat	55.14^{c}	32.38^{b}	5.06^{de}	22.25^{bcd}	8.40^{a}	4.58^{cd}	4.94^{c}	4.42^{d}	49.90^{a}
	(5.71)	(4.95)	(0.93)	(4.57)	(0.59)	(0.98)	(0.68)	(0.24)	(16.40)
Bignai	46.23^{d}	27.37^{bc}	4.26^{ef}	23.39^{bc}	7.00^{ab}	5.16^{c}	5.73^{b}	5.55^{c}	58.13^{a}
	(6.28)	(1.31)	(0.31)	(1.76)	(2.33)	(0.50)	(0.38)	(0.45)	(13.36)
Pomelo	33.03^{f}	15.17^{de}	5.24^{de}	14.37^{fg}	3.85^{cd}	4.23^{de}	2.49^{f}	3.09^{f}	10.27^{gh}
	(2.83)	(1.86)	(0.61)	(1.25)	(0.58)	(0.56)	(0.21)	(0.20)	(0.29)
Chico	67.01^{b}	15.15^{de}	6.99^{ab}	24.41^{b}	8.36^{a}	6.73^{ab}	7.27^{a}	7.49^{a}	55.38^{a}
	(3.51)	(0.60)	(0.33)	(0.48)	(1.49)	(0.00)	(0.05)	(0.03)	(12.25)

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

Table 3 Strength classification of the 13 fruit-bearing trees, Philippine mahogany group, and commercially used timber species and their recommended uses (Lim et al. 2019, Alipon & Bondad 2008)

Strength classification	Fruit-bearing trees	Philippine mahogany group	Commercially used timber species in the Philippines	Recommended uses
Moderately high	Lansones (*Lansium domesticum*) Chico (*Manikara zapota*)			Medium-heavy construction such as heavy-duty furniture, cabinets, medium-grade beams, flooring, door panels, frames, tool handle, veneer, and plywood production
Medium	Nangka (*Artocarpus heterophyllus*) Duhat (*Syzygium cumini*)	Bagtikan (*Parashorea malaanonan*) Red lauan (*Shorea negrosensis*) White lauan (*Shorea contorta*) Tanguile (*Shorea polysperma*)	Mahogany (*Swietenia macrophylla*) Yemane/Gmelina (*Gmelina arborea*) Mangium (*Acacia mangium*)	General construction, doors, framing, paneling, flooring, planking, medium-grade furniture, cabinet, veneer, and plywood (face & core).
Moderately low	Manggang kalabaw (*Mangifera indica*) Manggang pahutan (*Mangifera altissima*) Bignai (*Antidesma bunius*) Santol (*Sandoricum koetjape*)	Almon (*Shorea almon*) Mayapis (*Shorea palosapis*)	Bagrass (*Eucalyptus deglupta*) Para-rubber (*Havea brasiliensis*)	For pulp and paper production, wood carving and sculpture, conventional furniture, drafting boards, toys, venetian blinds, crates, pallets, form wood, and shingles.
Low	Guyabano (*Annona muricata*) Atis (*Annona squamosa*) Avocado (*Persea americana*) Marang (*Artocarpus odoratissimus*) Pomelo (*Citrus maxima*)	Tiaong (*Shorea ovata*)	Falcata (*Falcataria moluccana*)	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.

kalabaw and pahutan, bignai and santol, on the other hand, were classified under moderately low, homogenous with *S. almon*, *S. palosapis*, *E. deglupta,* and *H. brasiliensis.* Guyabano, atis, avocado, marang, and pomelo had low strength, similar to *F. falcata and S. ovata.* Based on the strength classification, the recommended uses for the fruit-bearing trees are shown in Table 3.

According to Ruwanpathirana (2014), the wood of nangka can be seasoned easily, besides being easy to saw, work and finish. His study also showed that the smell of manggang kalabaw and pahutan attracted fruit flies and other insects (e.g., termites) when the samples were being prepared. Termites attacked the pith of the lansones tree as it aged and caused harm to the wood. This shows that timely harvesting, appropriate seasoning, and preservative treatments are important to extend the service life of wood materials. Examples of such treatments include application of prophylactic methods after harvesting, chemical preservatives (e.g., propiconazole, deltamethrin, tebuconazole, permethrin, disodium octaborate tetrahydrate, copper azole type), and heat or thermal modification treatment.

CONCLUSION

Among the 13 senile fruit trees studied, chico and duhat displayed the lowest MC and highest RD, bignai and manggang pahutan showed the highest LS, while lansones had the highest TS, RS and VS. Lansones and chico were rated moderately high-strength, higher than the mahogany group and commercial timber species. On the other hand, nangka and duhat were rated as medium strength, while pahutan, bignai, santol and manggang kalabaw were categorised as moderately low-strength. Guyabano, atis, avocado, marang and pomelo were all included under low strength.

Results indicated that the senile fruit-bearing trees are suitable for construction, furniture, cabinets, beams, flooring, panels, frames, tool handles, face veneers, and plywood production. However, this excludes guyabano, atis, avocado, marang and pomelo, which are only suitable for light construction, panel cores, moldings, ceiling, pulp and paper, and core veneer.

The RD value is negatively correlated with MC but positively correlated with mechanical characteristics and shrinking. In contrast to MC, VS is favourably correlated with TS, RS and LS. The current findings demonstrated that the RD is a reliable predictor of mechanical characteristics and shrinking. The 13 senile fruit-bearing trees are generally feasible alternatives that the local wood sector can consider to increase the supply of commercial lumber.

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