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ARTÍCULO

Variation in specific gravity and shrinkage of tapped rubberwood

Ighoyivwi Onakpoma[1] https://orcid.org/0009-0001-1076-5862♠
Olukayode Ogunsanwo[2] https://orcid.org/0000-0003-0492-3673
Oghenekevwe Ohwo[3] https://orcid.org/0000-0001-6449-6197
Laurence Schimleck[1] https://orcid.org/0000-0003-1958-6059
Scott Leavengood[1] https://orcid.org/0000-0002-2938-2220
Finto Antony[4]

[1]Oregon State University. Department of Wood Science and Engineering. Oregon, USA.
[2]University of Ibadan. Department of Forest Production and Products. Ibadan, Nigeria.
[3]Delta State University. Department of Forestry and Wildlife. Abraka, Nigeria.
[4]Warnell School of Forestry and Natural Resources, University of Georgia, Georgia, USA.

♠Corresponding author: onakpomi@oregonstate.edu

Abstract:
Hevea brasiliensis (rubber tree), a major source of natural rubber, could also be an important source of lumber as senescence occurs. However, latex collection is known to affect *Hevea brasiliensis* (rubber tree) wood formation and consequently, wood properties. The impact tapping (cutting made in the bark of the tree for latex harvest) has on the tree and the way the tree responds after tapping is often overlooked. Knowledge on wood properties of tapped rubber trees in Nigeria would enhance its sustainable utilization which is especially important in developing countries where lumber is limited. Variation in specific gravity and shrinkage of rubberwood wood due to tapping duration was examined. Tapping duration had significant effect in specific gravity and longitudinal shrinkage of rubberwood but had no effect on tangential and radial shrinkage. The specific gravity (SG) of rubberwood ranged from 0,55 - 0,59. Longitudinal shrinkage (average 1,42 %) was higher than typically observed for mature wood. Average tangential shrinkage for rubberwood of all the ages was 5,37 % while radial shrinkage ranged from 2,87 % to 3,84 %. decrease in SG observed in trees tapped for 20 years may indicate the initiation of senescence. Tapped rubberwood could be used in areas not exposed to high moisture as well as in other wood composites.

Keywords: *Hevea brasiliensis*, rubberwood, lumber, specific gravity, tapping duration, wood shrinkage.

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Introduction

Rubber tree (*Hevea brasiliensis* (Mull. Arg.) generally referred to as rubber tree or para rubber is native to the Amazon Forest of Brazil and is now widely established as a plantation species in approximately 20 countries for latex production (Teoh *et al*. 2011). Countries in southeast Asia are the leading producers (Teoh *et al*. 2011) with more than 75 % of rubber plantations located in Indonesia, Thailand, and Malaysia (Balsiger *et al*. 2000). Rubberwood plantations are also found in various locations in Nigeria particularly in the southern region of the country. It is estimated that about 18 million hectares (ha) of land are suitable for cultivation of natural rubber in Nigeria, though only about 247000 ha are being used for that purpose (Omo-Ikerodah *et al*. 2011, Binang *et al*. 2017). The plantations were established to supply latex for rubber production within and outside the country. As a result of the oil boom in Nigeria, agriculture has diminished in importance which has resulted in a decline in rubber production and utilization locally, as well as for export. Thus, rubberwood is now used mainly for fuelwood and charcoal production, and while this provides a cheap source of energy in rural communities, it undermines the value of the timber which could be used for higher value products (Onakpoma 2019).

In Nigeria, the demand for wood and wood products is rising due to an increasing population and the corresponding increase in residential buildings (UNEP 2015, Vitalis and Oruonye 2021). To meet demand for wood, plantation forests will become increasingly important (Emerhi 1992, Payn *et al*. 2015). The area of planted forest has increased globally (Payn *et al*. 2014) and such forests not only serve to supply wood but also provide a variety of ecosystem services. Rubber plantations are productive for approximately 30 years, but as trees begin to approach senescence, productivity declines (Balsiger *et al*. 2000). Ratnasingam *et al*. (2011) reported that plantation grown rubberwood, which is effectively an agricultural tree as it is planted to produce a non-wood product (latex) on relatively short rotations, could be an important raw material for sawmills to produce lumber.

The latex collection process involves cutting through the bark of the tree at an angle of 30 degrees to the horizontal in a spiral around the stem near the base of the tree for convenience during tapping. These cuts expose the lactiferous vessels of the inner bark from where the latex oozes out. Care is taken during the tapping process not to damage the vascular cambium (FAO 1977) though damage invariably occurs. Tapping is mostly done in the morning every 3 days or biweekly and this involves reopening previous cuts.

Tapping causes injury and this process may affect wood quality as the tree is placed under stress owing to the wound (Kainulainen 2007). The process of tapping leads to stimulation of physiological reactions to the injury and production of cells capable of cushioning the effect of the stress. Every tree species has its own way of responding to stress. For instance, in conifers, injured trees form traumatic resin ducts in the new wood grown around the edges of the injury forming a barrier zone. In hardwoods, the process differs as trees seal wood rays and tangential series of parenchyma cells with phenolic substances and there may also be the extensive deposition of tyloses in vessels (Metzler and Hecht 2014). Further, discoloration owing to compartmentalization can occur in both hardwoods and softwoods (Smith 2015). Xylem and ray parenchyma shift to stress metabolism after each wound and produce toxic phenols and waterproofing lipids (Smith 2015). As bark damage continues to increase, the timber quality is invariably affected due to the formation of callus (Metzler and Hecht 2014). Many of the effects of cambial wounding are not realized for many years after an injury occurs.

Previous studies on the effect of tapping on rubberwood have focused on woody biomass production and growth. Norton (1998) and Annamalainathan *et al*. (2001) reported tapping to have a negative correlation with biomass production. Silpi *et al*. (2006) found tapping to drastically reduce radial growth by a factor of two when compared with untapped rubber trees illustrating the level of stress induced by tapping.

In Nigeria, research in rubberwood has largely focused on the latex yield from plantation trees and oil extracted from rubber tree seed (Nwokolo 1996). Exceptions are the work of Tembe *et al*. (2010) who examined variation in fiber length of rubberwood grown in South-eastern Nigeria. Mean fibre length of sampled trees was 1,59 mm and variation in fiber length was significant both in terms of cardinal directions and between trees. Ogunsanwo *et al*. (2005) studied the strength properties of wood from tapped rubber trees. Similarly, research on anatomical, strength and chemical properties of rubberwood in southeast Asia have been documented by Naji *et al*. (2011), Zaki *et al*. (2012), Majumdar *et al*. (2014), and Naji *et al*. (2014) however, none of these studies examined the influence of duration of tapping on wood properties.

While growth is clearly impacted by tapping and the associated stress it causes, the affect that tapping duration has on wood quality or on how properties differ amongst plantation trees of different ages requires examination. Therefore, this study aims to study the variation in specific gravity and shrinkage of tapped rubberwood.

Materials and methods

Wood samples were harvested from intensively managed rubber plantations in Ughelli North Local Government Area (05º 30ˈN - 5º 48ˈN and longitude 05º 58ˈE - 6º 70ˈE) of Delta State, Nigeria in 2016. A picture of a rubber tree tapped for latex production is shown in Figure 1.

Figure 1: Rubber tree showing several cuts made during tapping.

Five ramets of the same clone at four different durations of latex extraction (5, 10, 15, 20 years of tapping) were felled. Since tapping begins 5 years after planting, the actual ages of the trees were (10, 15, 20 and 25 years). The felled trees were cut into bolts 600 mm long from 10,0 % and 90,0 % of merchantable height of the tree with these heights selected to represent the base and top of the tree. From the bolts, wood blocks of 20 mm (radial) x 20 mm (tangential) x 600 mm (longitudinal) were obtained and represented zones adjacent to the pith (corewood), and bark (outerwood) and a zone representing the midpoint between corewood and outerwood (referred to as midwood). The blocks were replicated five times and were stacked and air-dried for 1 week and trimmed in length to 60 mm. The blocks were oven dried at 103 ºC ± 2 until constant weight was obtained and stored in an airtight bag until tested. Samples were immersed in water for 48 h to get them saturated for specific gravity and shrinkage determination. A total of 600 samples were used for each of the property assessed in this study.

Data collection

Determination of specific gravity

Specific gravity was determined gravimetrically and calculated as Equation 1.

$$Specific\ Gravity = \frac{1}{\frac{m_1 - m_2}{m_2} + \frac{1}{1.53}} \quad (1)$$

Where m_1= saturated weight of wood in g; m_2 = oven dry weight of wood in g

Shrinkage

Dimensional shrinkage (longitudinal, radial, and tangential) were evaluated from green condition to oven dry. Wood samples both in green and oven dry condition were measured using a slide calliper, and shrinkage was calculated as Equation 2.

$$Shrinkage\ (\%) = \frac{d_1 - d_2}{d_2} \times 100 \qquad (2)$$

Where d_1= Dimension of saturated wood in cm; d_2 = Dimension of oven dry wood in cm

Data analysis

A nested experimental design was utilized where replicates (5) are from 3 radial positions (inner, middle, outer) each, 2 heights (base, top) and 4 ages (10, 15, 20, 25 years). Analysis of variance (ANOVA) was performed by mixed model to test the significance of age, height, and radial position effects Equation 3.

$$Y_{ijk} = \mu + A_i + H_j + R_k + AH_{ij} + AR_{ik} + HR_{jk} + AHR_{ijk} + e_{ijk} \qquad (3)$$

where: Y_{ijk} is the response variable, μ is the intercept of the model, A_i is the effect of tapping duration, H_j is the height effect, R_k is the effect of the radial position, $(AH)_{ij}$ is the interaction effect between tapping duration and height, $(AR)_{ik}$ is the interaction between tapping duration and radial position, $(HR)_{jk}$ is the interaction between the height and radial position, $(AHR)_{ijk}$ is the interaction between the tapping duration, height and radial position, and e_{ijk} is the error introduced by the replicates. All statistical analysis of the measurement data was performed using R software version 4.2.2 (R Core Team 2022).

Results and discussion

Variation in specific gravity of tapped *Hevea brasiliensis* wood

The specific gravity (SG) of rubberwood ranged from 0,55 - 0,59 with an average of 0,56. Mean SG was 0,55 (5 years), 0,56 (10 years), 0,58 (15 years) and 0,54 (20 years) as shown in Figure 2. SG increased significantly as the trees aged and tapping duration increased (Table 1, $p = 0{,}0309$). SG was also significantly higher at the top of the tree than the base ($p < 0{,}001$). Radially, SG at 10 % height decreased from corewood to midwood and increased to outerwood for each tapping age except for 20 years where it slightly increased to midwood and then slightly declined to outerwood (Figure 3) with no observed significant difference. The SG at 90 % height remained constant from corewood to midwood for most tapping ages, except for tapping duration of 15 years with a slight decrease (0,61 to 0,60).

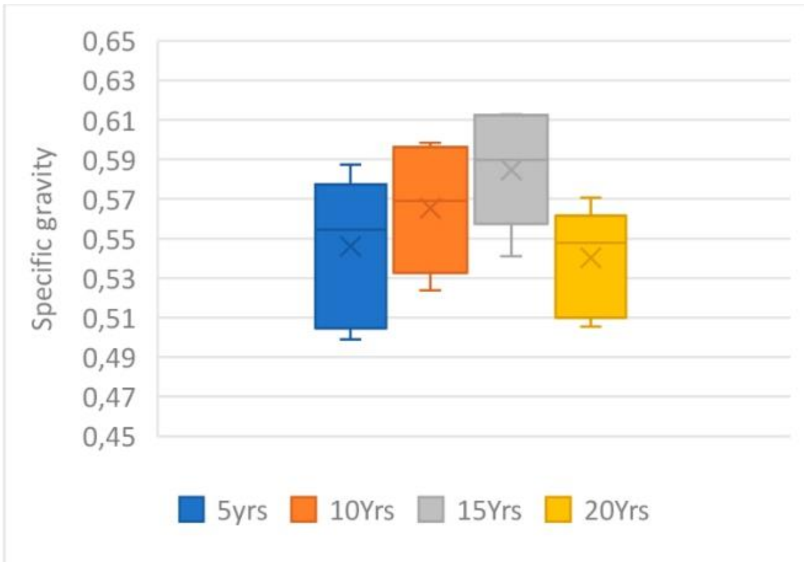

Figure 2: Variation in average specific gravity of tapped rubberwood for 5, 10, 15 and 20 years of tapping duration. Error bars = Confidence Interval.

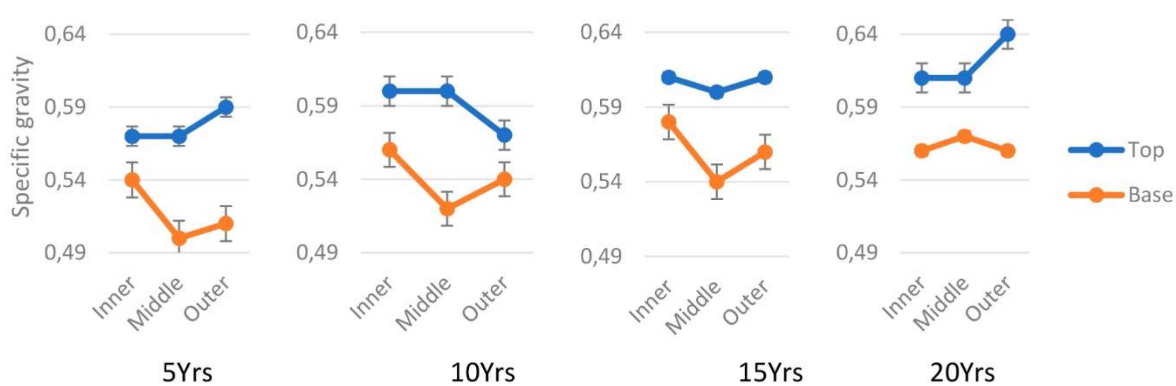

Figure 3: Radial specific gravity variation of tapped rubberwood trees at 10 and 90 % of total tree height and for different duration of tapping (5, 10, 15 and 20 years). Error bars represent Confidence Interval.

The range of specific gravity values obtained from this study were higher than those reported by Chudnoff (1980) with values of 0,46 - 0,52. However, the mean values obtained in this study compare favourably with those of Lee (1982), Roslan (1998) and Mohd Shukari (1999) who reported values of 0,56 - 0,65; 0,61 and 0,56 - 0,58 respectively. Teoh *et al*. (2011) reported the approximate value of specific gravity of rubberwood as 0,56, and earlier studies of Reghu *et al*. (2006), Norul Izani and Sahri (2008) reported values ranging from 0,51 - 0,57 and 0,58 - 0,60 respectively. Naji *et al*. (2012) reported an increase in SG of *Hevea* from the pith and a decrease towards the bark due to early maturation of trees.

Variation in longitudinal shrinkage of tapped *Hevea*. *brasiliensis* wood

Average longitudinal shrinkage of rubberwood samples was 1,42 %. Mean values of longitudinal shrinkage increased from 5 years of tapping to 10 years, decreased to 15 years, and increased at 20 years. Tapping duration did not significantly affect longitudinal shrinkage of rubberwood ($p > 0,05$) as shown in Table 1. Wood samples obtained near the top of the stem had a mean longitudinal shrinkage of 1,15 % and were significantly different ($p = 0,0189$) from the base (1,68 %). Longitudinal shrinkage showed inconsistent variation (Figure 4 and Figure 5) across the bole as it increased from corewood (0,73 - 2,87 %) to midwood (0,57 - 2,37 %) and then decreased for outerwood (0,82 - 1,70 %). No interaction terms were significant.

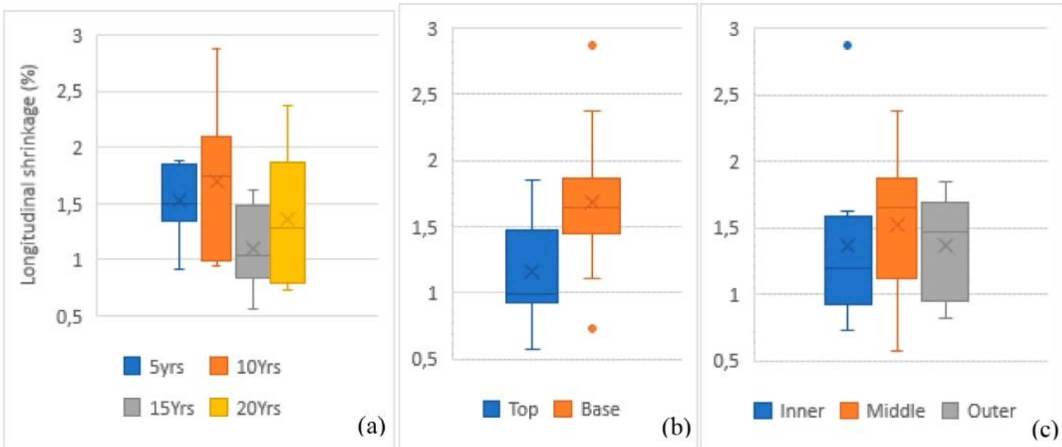

Figure 4: Variation in average longitudinal shrinkage of tapped rubberwood for (a) different tapping durations (b) axial position and (c) radial position. Error bars = Confidence Interval.

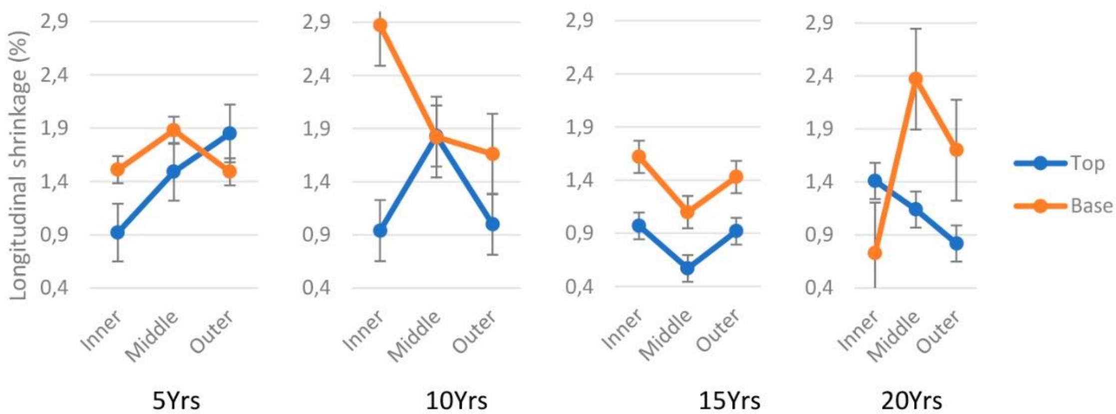

Figure 5: Longitudinal shrinkage variation of tapped rubberwood trees at 10 (base) and 90 (top) % of total tree height and for different duration of tapping (5, 10, 15 and 20 years). Error bars = Confidence Interval.

Rubberwood from this study exhibited excessive longitudinal shrinkage which is likely to be a concern in utilisation of the wood. According to Bauer (2003) and Wengert (2006), maximum longitudinal shrinkage of wood should not exceed 0,3 % and when this occurs, it is normally ignored because its influence is negligible. As a result of the high longitudinal shrinkage observed, attention should be paid to the wood when using it in designs where longitudinal stability is important especially in exterior uses. Longitudinal shrinkage is often associated with the age of wood, presence of reaction wood, microfibril angle (MFA) and specific gravity which are oftentimes interrelated (Kretschmann and Cramer 2007). MFA, which is the angle of cellulose microfibrils in the S2 layer of the cell wall, relative to the axis of the cell typically decreases radially and it has been reported to be positively correlated to longitudinal shrinkage, however in rubberwood, the relationship between MFA and longitudinal shrinkage with respect to age has not been reported high MFA is certainly possible near the pith and at the top of the tree due to the presence of juvenile wood.

Excessive shrinkage in rubberwood has also been linked to the age of the trees as they are mostly composed of juvenile wood (Khoo *et al*. 2019). However, previous studies have reported longitudinal shrinkage to reduce as the tree ages. This is not the case in this study as there was inconsistent variation in longitudinal shrinkage as tree age and tapping duration increased. Ratnasingam *et al*. (2010) opined that rubberwood would have higher longitudinal swelling compared with other species owing to presence of reaction wood (tension wood). Tension wood is commonly found in hardwoods in branches and leaning stems. Ring shapes are usually eccentric in tension wood on the upper side of the stem. However, Lim *et al*. (2003) reported that Malaysian rubberwood logs contained tension wood that are different from the conventional pattern of tension wood formation. They reported tension wood to be concentric or crescent-shaped and randomly distributed across the cross section of the stem. Previous studies have shown reaction wood to have high longitudinal shrinkage with samples obtained from the base of the tree being the poorest in terms of the quality of wood produced (Xu *et al*. 2009). Sik *et al*. (2009) reported that longitudinal shrinkage in rubberwood containing tension wood was as high as 0,67.

Table 1: Effect of tapping duration, height and radial position on Specific Gravity and Shrinkage.

Source of variation	numDF	denDF	Specific gravity		Longitudinal shrinkage		Tangential shrinkage		Radial shrinkage	
			F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
Tapping duration	3	89	3,097	0,0309	1,28387	0,2849	0,983	0,4045	4,605	0,0048
Height	1	89	52,339	<0,001	5,71705	0,0189	4,4377	0,038	1,0492	0,3085
Radial	2	89	1,274	0,2847	0,23585	0,7904	0,1255	0,8822	0,7666	0,4676
Tapping duration Height	3	89	0.794	0,5005	0,34733	0,7912	1,2312	0,3032	0,6094	0,6106
Tapping duration Radial	6	89	0,554	0,7657	0,68305	0,6637	0,2796	0,9452	1,3986	0,224
Height Radial	2	89	3,153	0,0475	0,05168	0,9497	0,3909	0,6776	2,5279	0,0855
Tapping duration Height Radial	6	89	1,843	0,0997	1,25562	0,2861	0,4027	0,8755	0,4228	0,862

numDF= numerator degree of freedom; denDF= denominator degree of freedom

Tangential and radial shrinkage of tapped *Hevea*. *brasiliensis* wood

The mean value for tangential shrinkage of rubberwood for all the ages was 5,37 %. The mean values of tangential shrinkage increased from 5 years of tapping to 10 years, decreased to 15 years, and increased again after 20 years (Figure 6). Table 1 shows that tangential shrinkage was not significantly affected by tapping duration (p > 0,05) or radial position with average tangential shrinkage values of 5,30 % for corewood, 5,34 % for midwood and 5,48 % for outerwood. Tangential shrinkage values along the bole were significantly higher (p = 0,038) at the base (5,73 %) than the top (5,01 %) of the tree.

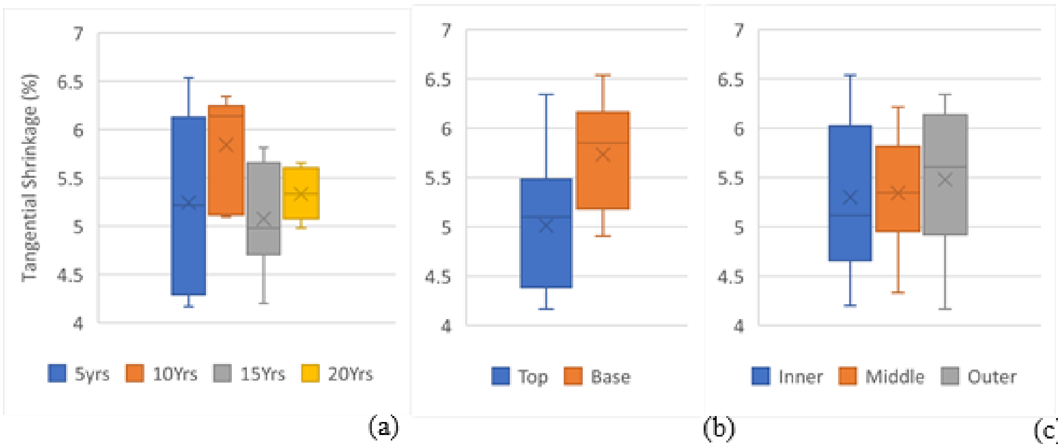

Figure 6: Variation in average tangential shrinkage of tapped rubberwood for a) different periods of time, (b) longitudinal position and (c) radial position. Error bars = Confidence Interval.

The mean radial shrinkage of rubberwood ranged from 2,87 % to 3,84 % for the various tapping ages. The mean values were highest at 10 years of tapping (3,84 %) and lowest at 5 years of tapping (2,87 %) as presented in Figure 7. Radial shrinkage showed no consistent variation with years of tapping but was strongly significantly affected by tapping duration as shown in Table 1 ($p = 0,0048$). Radial shrinkage along the bole was 3,52 % at the base and 3,32 % at the top of the tree. The radial shrinkage across the bole was 3,58 %, 3,36 % and 3,32 % for the core, mid and outerwood respectively.

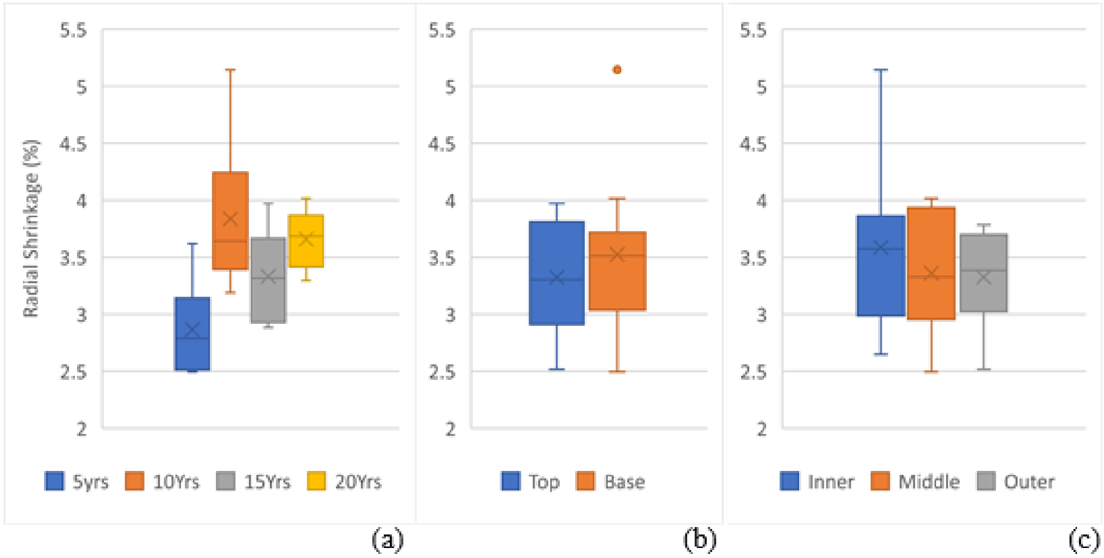

Figure 7: Variation in average radial shrinkage of tapped rubberwood for (a) different periods of time, (b) longitudinal position and (c) radial position. Error bars = Confidence Interval.

The range of values obtained in this study for tangential and radial shrinkage of rubberwood agreed well to the Chudnoff (1980) reported values of 5,1 and 2,3. The tangential and radial shrinkage values are higher than those reported by Roslan (1998) who obtained values of 2,13 and 0,99 respectively for 10-year-old rubberwood, and 0,69 for the radial shrinkage of 22-year-old rubberwood. In a later study Majumdar *et al*. (2014) recorded mean values of 4,85 and 2,40 for tangential and radial shrinkage of rubber tree (*Hevea brasiliensis* (Mull. Arg.). The ratio between tangential shrinkage and radial shrinkage in this study was 1,57 and this supports the report of Bodig and Jayne (1993) and Panshin and de Zeeuw (1980) that the tangential shrinkage is greater than the radial shrinkage by a factor between 1,5 and 3,0. The 1:1,57 % radial-tangential shrinkage reported in this study is low which indicates the wood is less likely to deform during seasoning.

Specific gravity (SG) is the best index of predicting the wood quality, strength and how the wood will behave in service. It was observed to increase radially for tapping periods of 5 to 15 years and then decrease after the trees were tapped for 20 years. Whether the decrease is due to tapping duration can't be stated with confidence as we lacked a control and the typical pattern of radial variation for rubber tree (*Hevea brasiliensis* (Mull. Arg.) is unknown. However, it is recognized that rubber tree (*Hevea brasiliensis* (Mull. Arg.) plantations are typically replaced after 30 years owing to their decline in productivity (Balsiger *et al*. 2000) and the decrease in SG observed in trees tapped for 20 years may indicate the initiation of this process. Similar declines in ring SG with age have been observed in conifers such as black spruce (*Picea mariana* (Mill.) B.S.P.) (Xiang *et al*. 2014). Xiang *et al*. (2014) hypothesized that the decreasing trend in SG arose as tree vigor declined.

Raw data for SG was quite variable amongst sampled ramets as was the shrinkage data. Other authors (Roslan 1998, Reghu *et al*. 2006) have observed considerable variability in rubber tree (*Hevea brasiliensis* (Mull. Arg.) wood properties and for any future studies we recommend sampling a large number of individuals, as opposed to this work were the sampling intensity per ramet was high compared to the number of ramets sampled.

Another potential source of variation among ramets was the response of individual ramets to tapping. Clatterbuck (2017) and Smith (2015) report that compartmentalization of injured locations in trees arise as a result of uncommon events such as mechanical abrasion, lightning strikes or fires which occurs infrequently during the life of a tree. For these injuries, the trees are able to adapt unlike tapping which is a continuous process that gives the tree little or no time to recover. In tapping rubber, cuts are carefully made on a tree biweekly resulting in the tree expending more energy in protecting itself from insect attacks and infection than in growth. If the cambium is damaged proper development of the secondary xylem (and its properties) may be affected. The resources expended in response to tapping could be responsible for the reduced growth observed by Silpi *et al*. (2006) where radial growth of tapped rubber trees was negatively affected by half when compared with untapped trees within two weeks after tapping resumed and the effect persisted throughout the growing season.

Conclusions

In this study, the specific gravity and longitudinal shrinkage of rubber tree (*Hevea brasiliensis* (Mull. Arg.) wood varied significantly with tapping duration. Specific gravity of the ramets sampled were within the range of a medium density wood, however longitudinal shrinkage was excessively high.

The longitudinal shrinkage should have little effect in the utilisation of rubberwood when the wood is seasoned as wood tends to remain stable when not exposed to areas with high moisture content (for example indoor settings). Research on the effect of MFA on longitudinal shrinkage as affected by tapping age is required to better understand the high longitudinal shrinkage of rubberwood.

Use of rubber tree (*Hevea brasiliensis* (Mull. Arg.) wood as a composite material would help to reduce the effect of high longitudinal shrinkage. The physical properties of rubber tree (*Hevea brasiliensis* (Mull. Arg.) wood were higher at the top of the sampled ramets (90 % of total height) than the base (sampled at 10 % of total height) which concurs with earlier studies where wood properties have been reported to improve from the base to the top of trees.

Authorship contributions

I. O.: Investigation, Resources, methodology, data curation, writing -original draft. O. Y. O.: Conceptualized the research, resources, project administration, supervision. O. O.: Writing-review and editing. L. S.: Visualization, resources, writing-review and editing. S. L.: Visualization, resources, writing-review and editing. F. A.: Formal analysis and validation.

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