Journal of Tropical Forest Science 37(4): 404–414 (2025)
https://doi.org/10.26525/jtfs2025.37.4.404
ISSN: 0128-1283, eISSN: 2521-9847

GROWTH STRESS ATTRIBUTES OF FALCATA (*FALCATARIA FALCATA* [L.] GREUTER & R. RANKIN) IN DIFFERENT GROWTH ORIENTATIONS IN MINDANAO, PHILIPPINES

Rojo MJA[1, 3, *], Gilbero DM[2], Parlucha JA[1], Casas JV[1], Paquit JC[1], Lopez TMT[4], Casas VJM[4], Huervas R[4] & Tanong KJD[4]

[1]*College of Forestry and Environmental Science, Central Mindanao University, Musuan, Maramag, Bukidnon 8714 Philippines*
[2]*Sustainable Agro-Biomaterials Research Laboratory (SABRL), College of Agriculture, Agusan del Sur State College of Agriculture and Technology, San Teodoro, Bunawan, Agusan del Sur, 8506 Philippines*
[3]*Center for Natural Products Research Development and Extension, Central Mindanao University, Musuan, Maramag, Bukidnon 8714 Philippines*
[4]*Central Mindanao University, Musuan, Maramag, Bukidnon 8714 Philippines*

**mackyrojo@gmail.com*

Submitted October 2024; accepted March 2025

This study assessed growth stress in *Falcataria falcata* trees by measuring longitudinal Surface Released Strains (SRS) and Residual Released Strains (RRS) to evaluate the effects of growth orientation, location, age, and season on strain patterns. Kyowa strain meter and strain gauge were used for measurements. The SRS was taken at four cardinal directions on each tree, with three replications per factor. Quarter-sawn boards were prepared for RRS, with sampling points set from pith to bark. All SRS values were negative ranging from -1000% to 2100% on the average, indicating tensile stress near the bark. Multiple-factor analysis of variance showed that age and cardinal direction significantly affected SRS ($P < 0.05$). Younger trees (3–6 years old) have significantly higher strain values of -1600% compared to -1200% in older trees (7–10 years old). While the observation on cardinal direction showed that the highest strain values were on the east side since most of the trees lean towards the north western direction, resulting in the east side being under tensile stress. For RRS, compressive stress was found near the pith (+1000%) and tensile stress near the bark (-1500%), with age and channel position (from pith to bark) significantly influencing RRS ($P < 0.05$).

Keywords: Growth orientation, industrial tree plantation, residual released strains, strain pattern, Surface Released Strains

INTRODUCTION

Growth stress is a significant issue in forestry, affecting the yield and viability of timber leading to defects when trees are felled and processed into end products. This stress, which arises due to cell maturation, the weight of the growing tree, and growth orientation can cause severe mechanical problems prevalently splitting in felled logs (Gril et al. 2017). This is present in all standing timber and cut logs which is necessary to maintain a vertical position in standing trees (Cassens & Serrano 2004). Growth stress is usually impossible to measure directly. However, by measuring the strain, the stress can be calculated (Yang & Waugh 2001). There are three common methods for measuring surface strains as a consequence of stress release in trees viz., (a) the Nicholson technique which determine the average longitudinal strain within a volume of wood; (b) the CIRAD-Forêt method which gives a good estimate of the longitudinal surface strain and suits routine field measurements; and (c) by strain gauges measures the surface strain (in longitudinal or tangential directions) directly and more accurately than the other two methods (Yang et al. 2005).

When trees are felled and cut into logs and processed into lumber, the results of growth stresses being released, particularly in small diameter timber become evident (Cassens & Serrano 2004). The occurrence of radial cracks at a log end, or lumber crooking can be explained in relation to the residual stress distribution inside the log (Gril et al. 2017). These growth stress related defects caused a significant negative impact to local Industrial Tree Plantation (ITP) farmer-growers and sawmill operators. This study focused on measuring growth strains in *Falcataria falcata* (L.) Greuter & R. Rankin trees. *Falcataria falcata* is one of the fast-growing species favoured by local farmers because of its demand in plywood industry. Falcata tree farmer growers recently experienced odd market prices on logs because of these growth-related defects that depreciated the value of logs during marketing, and this attribute is also due to the low recovery of wood processing. Cross-cutting a log releases longitudinal growth stress, generating secondary radial and tangential tensile stresses at the cut end. If tangential stress near the pith exceeds the wood's tensile strength, splits form from the pith outward (Yang & Waugh 2001). Moreover, Alipon et al. (2016) observed that growth stresses in falcata often caused end splits and cracks, with diametrically cut lumber splitting through the pith and curving outward at both ends. While Moya and Tenorio (2021) observed that growth stresses in *Hieronyma alchorneoides* Allemão trees show high and negative effects on the lumber quality (increased warps and splits or checks). Other reports showed that splitting-related losses in South African sawmills exceeded 10% (Maree & Malan 2000).

Variations in growth orientation—such as whether trees are leaning or straight, crown balance, location, and age—can significantly affect stress distribution around the trunk, from pith to bark. Jullien et al. (2013) found that crown asymmetry leads to greater stress dissymmetry within trees. This study aims to address these challenges by systematically measuring growth stress in *F. falcata* across different growth orientations and ages, using Surface Released Strains (SRS) and Residual Released Strains (RRS) as key indicators. The SRS is used to assess surface stress observed in the outermost layer of the xylem, which is essentially equivalent to maturation stress, while RRS measures the residual stress remaining in the material or structure even after external forces, such as mechanical actions or gravity, have been removed (Gril et al. 2017). By evaluating the SRS and RRS influenced by growth orientation, location, age, and season, this research will provide valuable insights into how to minimise growth-related defects.

MATERIALS AND METHODS

Selection of *F. falcata* trees

The study was conducted in tree plantations located in Regions 10 and 13 in Mindanao, Philippines, where *F. falcata* is extensively planted. The experiment was replicated three times, with a total of 48 trees selected based on the following criteria: location (Regions 10 and 13), season (wet and dry), age (young: 3–6 years old and old: 7–10 years old), and growth orientation (straight and leaning).

Surface Released Strain (SRS) measurements

The SRS in *F. falcata* was measured using a Kyowa strain meter set 2022 (EDX-10B Compact Data Logger w/DCS-100A, EDX-11A Strain Measuring Unit, DBV-120A-8 One-touch Type Bridge Box 8ch/unit, U-126 Connector Cable and UN312-0520 AC Adapter for EDX-10B). For each standing tree, measurements were taken at four cardinal points (north, south, east, and west) at diameter at breast height (DBH). A strain gauge (electric-wire strain gauge, 10 mm length, KFG-10-120-C1-11L3M3R, Kyowa Co., Tokyo, Japan) was glued to the exposed secondary xylem along the longitudinal direction and connected to the strain meter. After the initial strain measurement, surface stress was released by making a groove using a handsaw at a depth of 5–10 mm and a distance of 3–5 mm from the edge of the strain gauge (Figure 1). The strain was then recorded and values from the four cardinal points were averaged for each factor (Paquit et al. 2024).

Residual Released Strain (RRS) measurements

After the SRS measurements, the trees were felled to measure the Residual Released Strain (RRS). A quarter-sawn board, 5 cm thick (with the centre at the pith) and a length equal to 2.5 times the DBH, was prepared from the north to south side of the stem, excluding the bark. Sampling points were established from the pith to the bark at the centre of the board's length (Figure 2). The sampling area of the board was

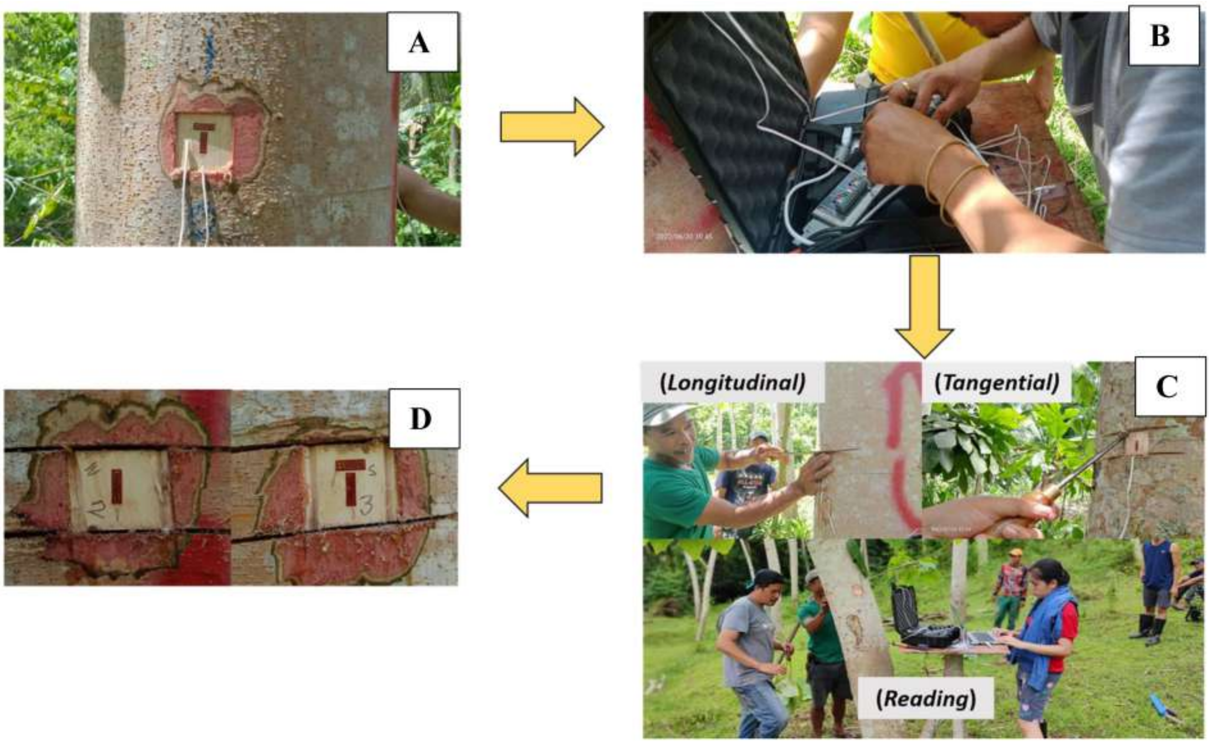

Figure 1 Strain gauge installation and measurement process: (A) placement of strain gauges in tangential and longitudinal orientations; (B) connection of the strain gauge to the strain meter; (C) release of longitudinal and tangential stress; and (D) grooves created to facilitate surface stress release

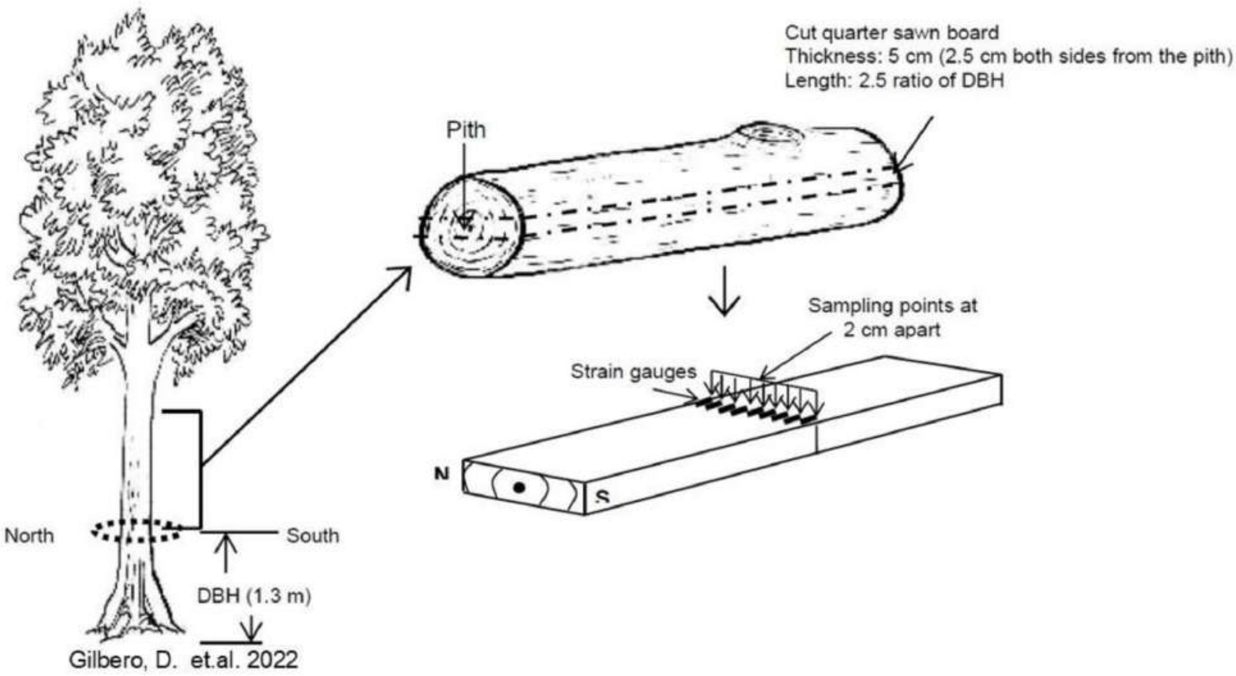

Figure 2 Sampling points of radial distribution patterns from the pith to north and south side of the quarter sawn board; length-to-diameter at breast height (DBH) ratio = 2.5

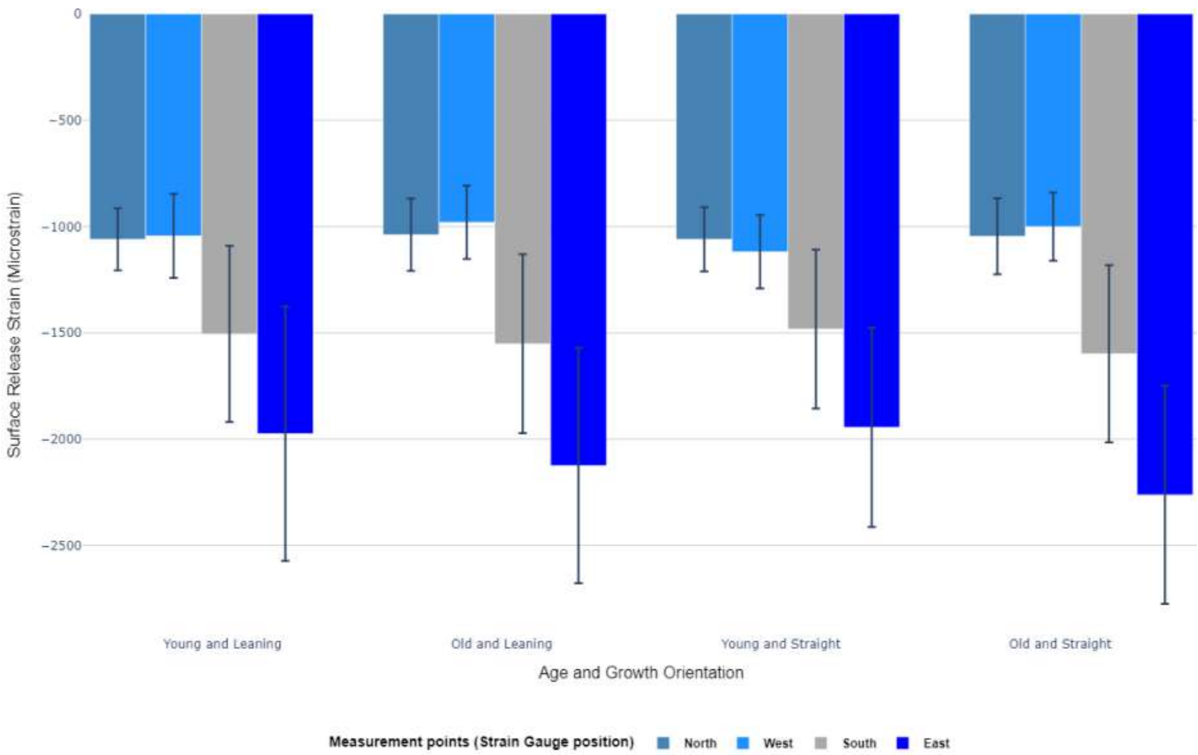

Figure 3 Surface Released Strain (SRS) of both leaning and straight trees of young (3–6 years old) and old (>7 years old) *Falcataria falcata*

prepared by sanding to ensure an even and smooth surface. The strain gauge was glued to the sampling points across the board and connected to the strain meter. After measuring the initial strain, the residual stress was released using a handsaw, and the strain was recorded.

Statistical analysis

Variations in SRS across the factors were analysed descriptively. The RRS patterns from the pith to the bark were also analysed descriptively. A multifactor ANOVA was performed using Statgraphics Centurion XVI.I software (2009) to determine whether growth orientation, location, season, and age significantly affect growth stress. Means were separated using Fisher's least significant difference (LSD) test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Surface Released Strain (SRS)

The percent SRS values are shown in Figure 3. For falcata trees exhibiting both leaning and straight growth orientations across the two regions in Mindanao, the results indicated that all SRS values were negative, confirming that tensile stress is present near the bark. Negative strain values indicate fibre contraction or compression. This shows that the fibres were initially stretched or under tensile stress before being released. Imagine a stretched rubber band—when cut, it contracts (or compresses), resulting in negative strain. Hence, negative SRS values indicate that the wood elements were under tensile stress prior to release. This is consistent with findings from previous study (Gril et al. 2017) which suggested that the newly formed xylem fibres experienced deformation in axial as a result of cell maturation and increasing tree weight.

The ANOVA showed that only age ($P < 0.001$) and cardinal direction ($P < 0.001$) significantly affected SRS. As shown in Figure 4, mean SRS values were significantly higher ($P < 0.001$) in the east side of the tree compared to other cardinal directions. This can be attributed to the fact that most of the trees lean towards the north western direction, resulting in the east side being under tensile stress. In angiosperms like *F. falcata*, reaction wood is called tension wood and it appears along the upper side of the inclined stem (Gril et al. 2017). As discussed in Ghislain et al. (2019), tension wood generates

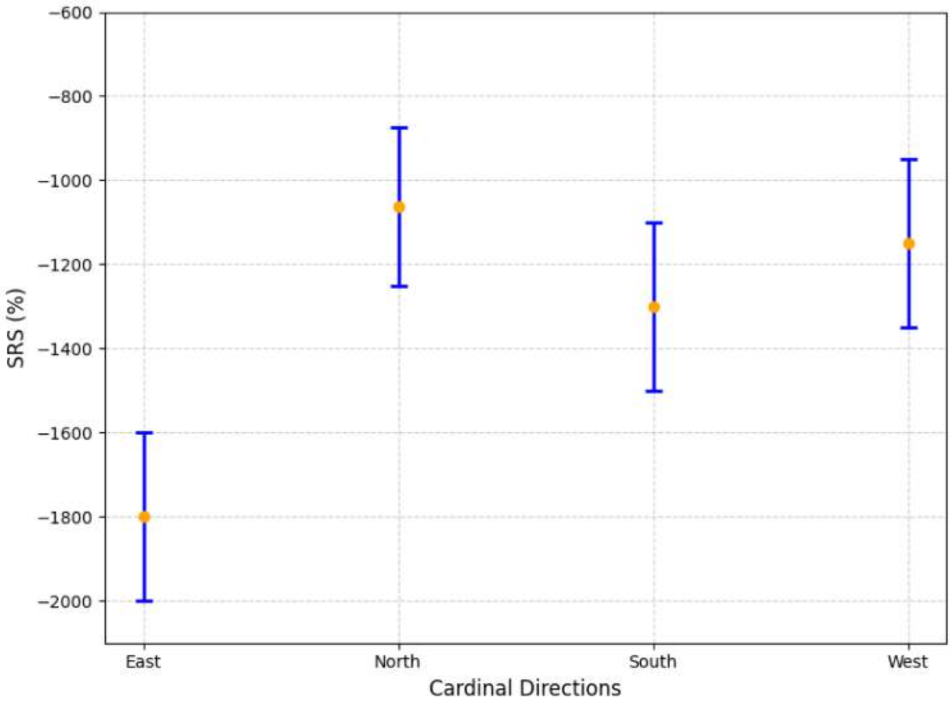

Figure 4 Mean Surface Released Strains (SRS) values with 95% LSD intervals across cardinal directions

Table 1 Distribution of tree samples by location, season, age, and growth orientation

Location	Total tree samples	Season	Samples per season	Age	Samples per age group	Growth orientation	Samples per growth orientation
Region 10	24	Dry	12	Young (3–6 years old)	6	Straight	3
						Leaning	3
				Old (7–10 years old)	6	Straight	3
						Leaning	3
		Wet	12	Young (3–6 years old)	6	Straight	3
						Leaning	3
				Old (7–10 years old)	6	Straight	3
						Leaning	3
Region 13	24	Dry	12	Young (3–6 years old)	6	Straight	3
						Leaning	3
				Old (7–10 years old)	6	Straight	3
						Leaning	3
		Wet	12	Young (3–6 years old)	6	Straight	3
						Leaning	3
				Old (7–10 years old)	6	Straight	3
						Leaning	3

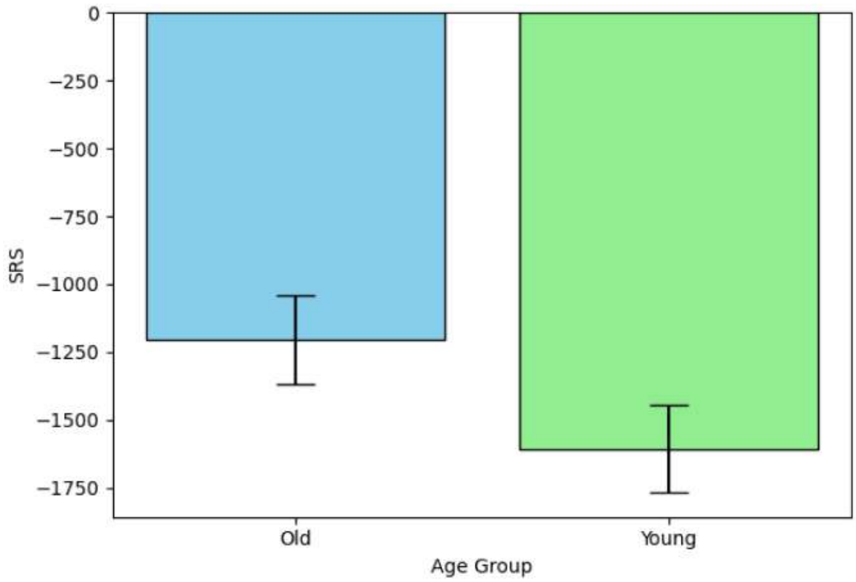

Figure 5 Mean Surface Released Strains (SRS) values with 95% LSD intervals between old and young *Falcataria falcata* trees

Table 2 ANOVA results identifying significant factors influencing Surface Released Strains (SRS) in *Falcataria falcata* trees

Source	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS				
A: Region	1	1.75354E6	2.30	0.1311
B: Age	1	6.97663E6	9.16	**0.0029**
C: Season	1	67379.1	0.09	0.7665
D: Growth Orientation	1	1.50051E6	1.97	0.1623
E: Cardinal Directions	3	4.89952E6	6.43	**0.0004**
RESIDUAL	163	761646		
TOTAL (CORRECTED)	170			

tensile forces during maturation that causes eccentric growth and a bending moment that straightens the stem, leading to high growth stress on the opposite side. It is surprising to observe that the SRS between straight and leaning trees did not vary significantly. This result is supported by Paquit et al. (2024) who observed higher SRS values in leaning trees compared to straight trees, but the difference was not significant. The observed higher strain values were also recorded in straight trees. However, these trees were planted in the rolling terrain and with unbalanced crowns.

This stress, as explained by Gril et al. (2017), results from the combined effects of increasing dead weight and cell wall maturation in growing trees. Furthermore, the newly differentiated xylem fibre tends to deform in its axial and transverse directions. These dimensional changes are restricted by the already-formed xylem. The restraint induces mechanical stress, or the so-called "maturation stress", at the outermost surface of the secondary xylem, located beneath the layer of differentiating xylem.

A significant difference in SRS variation was observed between older trees (>7 years) and younger trees (3–6 years). Younger trees exhibited significantly higher mean SRS values ($P < 0.05$) (Figure 5). This difference may be attributed to physiological variations between young and mature trees. Mature trees exhibit a reduced photosynthetic rate and less developmental plasticity compared to younger trees (Bond 2000). Additionally, falcata being a fast-growing species, may have contributed to the higher stress values observed. Maeglin (1987), as cited in Cassens and Serrano (2004), emphasised that younger trees contain a higher proportion of juvenile wood, reaction wood, and growth stress compared to older trees. According to Gilbero et al. (2019), some tested big-leaf mahogany (*Swietenia macrophylla* King) with small diameter exhibited high SRS levels, which they attributed to tension wood formation. They also concluded that the current cambium age is still producing juvenile wood, particularly in smaller-diameter trees.

Residual Released Strain (RRS)

The RRS values of falcata trees are shown in Figure 6. The graph follows an inverted U-shape where the horizontal axis represents the relative distance of the strain gauge from the pith. The results revealed a high strain near the bark and a positive percent strain near the pith. A negative strain indicates compression, while a positive strain indicates tension. However, these values were obtained after the stress was released. Thus, before the stress was released, the wood elements near the bark were under tensile stress, while those near the pith were under compressive stress. The opposite strains occurred after the stress was released. According to Cassens and Serrano (2004), in the longitudinal (L) direction, tensile stress near the periphery is compensated by compression in the centre. A similar pattern was also observed by Matsuo-Ueda et al. (2022) in sugi (*Cryptomeria japonica*) and Kameyama et al. (2023) in keyaki (*Zelkova serrata*) logs.

The ANOVA revealed that only the positions (strain gauge location from pith to bark) and age had significant effects on the RRS (Table 3). The variation in strain across different positions is expected, as strain measurements near the bark are under tensile stress, while those near the pith are under compression. Thus, there is a significant change in released strain from pith to bark as stress transitions from compression to tension. No significant difference was observed between the RRS of straight and leaning trees. This result is consistent with the SRS values presented above. However, since the growth pattern of the sample trees at a younger age is unknown, it is unclear whether they were initially leaning and later recovered to become fully straight. According to Cassens and Serrano (2004), growth stresses are important because they help reorient stems and branches. Reaction wood generally tends to exhibit high levels of longitudinal growth stresses that allow leaning

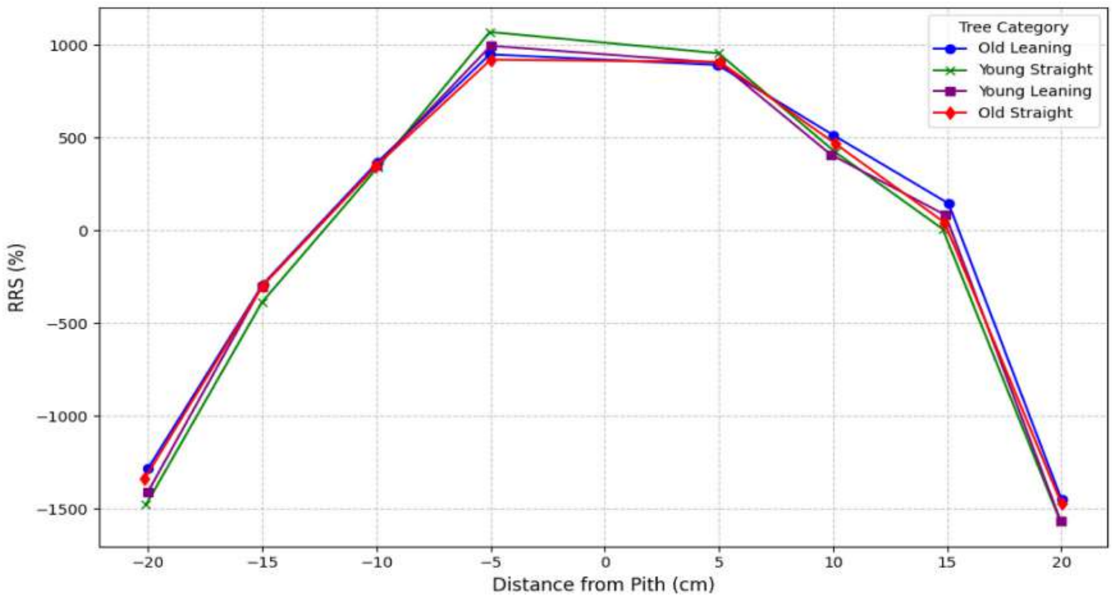

Figure 6 Residual Released Strain (RRS) of *Falcataria falcata* trees; x-axis shows the distance of the strain gauge from the pith (in cm) and y-axis represents the RRS (%)

Table 3 ANOVA results identifying significant factors influencing Surface Released Strains (SRS) in *Falcataria falcata* trees

Source	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS				
A: Region	1	1.79768E6	2.88	0.0908
B: Age	1	2.84603E6	4.55	**0.0335**
C: Season	1	1.86851E6	2.99	0.0847
D: Growth Orientation	1	7408.45	0.01	0.9134
E: Gauge position	7	3.90969E7	62.54	**0.0000**
RESIDUAL	369	625169		
TOTAL (CORRECTED)	380			

Figure 7 Occurrence of splitting after crosscutting and sawing logs into boards; a S-shaped metal plate is fixed to prevent further splitting

trees to regain a vertical position. In this study, the stresses that developed during the younger age of trees while they were leaning may have remained as residual stress. Furthermore, other factors such as location (Regions 10 and 13) and season (wet and dry), did not significantly affect the residual growth stress in falcata (Table 3).

The greater the difference between tensile and compressive stress, the more likely wood defects such as end checking and, in severe cases, splitting will occur. As emphasised by Gril et al. (2017), growth stress cannot be simply released when trees are cut down, but will remain as self-balanced residual stress. Thus, when a log or trunk is crosscut, the wood near the log end behaves as if it is subjected to the opposite of the pre-existing growth stress. This typically results in peripheral contraction and central expansion, leading to end checks and eventually splitting. In this study, upon crosscutting and sawing, several boards were observed to split, requiring a S-shaped steel plate to be nailed across the cross-section to stabilise the crack and prevent further splitting (Figure 7).

When compared to *Gmelina arborea*, the RRS pattern from pith to bark is much steeper in *F. falcata* than in *G. arborea* (Figure 8). This explains the more frequent occurrence of cracking or growth defects in *F. falcata* compared to *G. arborea*. Although *F. falcata* grows faster

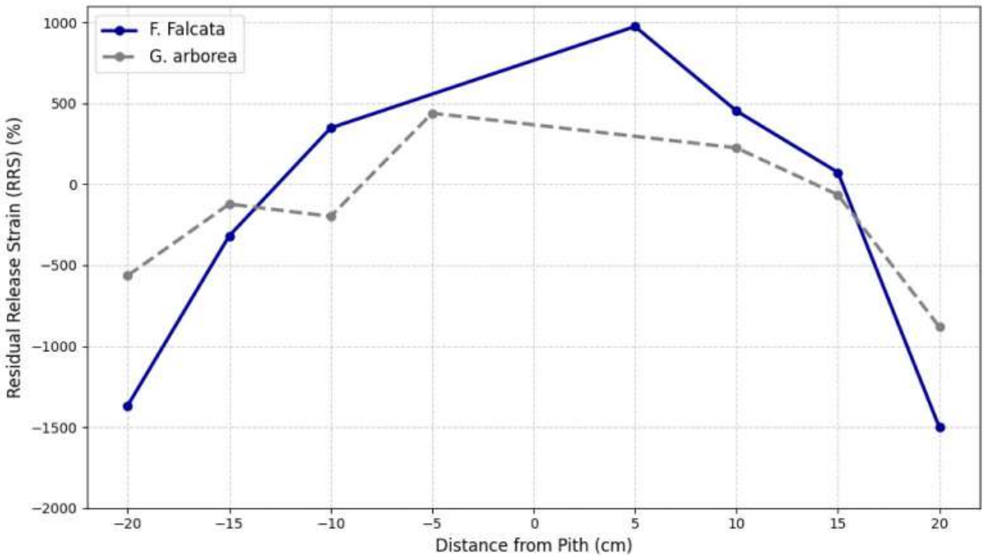

Figure 8 Comparing the Residual Released Strain (RRS) of *Falcataria falcata* and *Gmelina arborea*

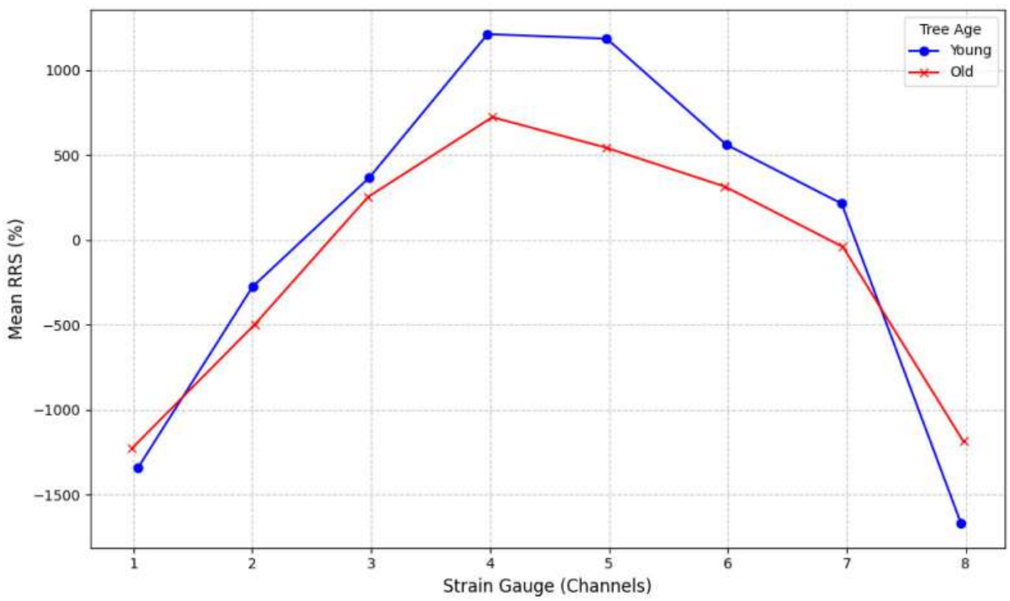

Figure 9 Mean Residual Released Strain (RRS) from pith to bark in young and old Falcataria falcata trees; pith is located between channels 4 and 5, and bark is near channels 1 and 8

than *G. arborea*, the latter is much denser, with a density of 345 to 620 kg m^{-3} (Sulaiman & Lim 1989) compared to 284 kg m^{-3} for *F. falcata* (Marasigan et al. 2022). This variation may have contributed to the differences in growth stress between the two industrial tree species.

Consistent with the SRS results, younger trees exhibited significantly higher released strain values ($P < 0.05$) compared to older trees (Figure 9). Boyd (1950), as cited by Cassens and Serrano (2004), emphasised that growth stresses are more severe in smaller logs from young, fast-growing trees due to steeper growth stress gradients. In this study, the presence of juvenile wood may have contributed to the higher growth stress in younger trees. As explained by Nawrot et al. (2007), juvenile wood is formed by young cambium within the living, active crown and develops in the shape of a cylinder surrounding the pith along its entire length. The transition from juvenile to mature wood can be determined by measuring fibre length and vessel element length from near the pith to near the bark (Kartikawati et al. 2024). Thus, trees that grow larger in diameter compared to others of the same species, depending on genotype, may produce more mature wood. The xylem maturation boundary for *S. macrophylla* was identified at diameters of 8.08, 17.36, 16.23 and 17.87 cm depending on fibre and vessel lengths, vessel width and xylem density, respectively (Gilbero et al. 2022). It is therefore, necessary to investigate the relationship between age and diameter (growth performance) in relation to growth stress. Additionally, the transition zone between juvenile and mature wood in falcata trees should be identified as a basis for determining the optimal harvesting period to minimise growth stress-related defects.

CONCLUSIONS

All SRS values were negative, indicating that fibres near the bark experience tensile stress. Multiple-factor analysis of variance revealed that only age and cardinal direction significantly affected SRS. Notably, SRS was significantly higher ($P < 0.001$) on the east side of the trees compared to other directions. This is likely due to the trees leaning north west, placing the east side under greater tensile stress. For RRS, the strain pattern follows an inverted U-shape, suggesting compressive stress near the pith, with tensile stress near the bark. Age and channel position (from pith to bark) were the only factors that significantly influenced RRS ($P < 0.05$). Older trees exhibited a more uniform strain distribution compared to younger, smaller-diameter trees, which had steeper gradients. Thus, younger, smaller-diameter trees are more prone to stress-related defects. It is recommended to conduct a study investigating the relationship between age, diameter (growth performance), and growth stress to determine the optimal diameter or rotation cycle for *F. falcata* to minimise growth stress-related defects.

ACKNOWLEDGEMENTS

This research project was supported by the Department of Science and Technology-Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD). The authors also wish to acknowledge the support of the Central Mindanao University Research Office for facilitating this project under research no. 416-236 Defects of Falcata. Furthermore, the authors recognise the contributions of the collaborating agencies: DENR-ERDB-Forest and Wetland Research, Development and Extension Center (FWRDEC), and Agusan del Sur State College of Agriculture and Technology (ASSCAT).

REFERENCES

Alipon MA, Alcachupas PL, Bondad EO & Cortiguerra EC. 2016. Assessing the utilization of Falcata [*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes] for lumber production. *Philippine Journal of Science* 145: 225–235.

Bond BJ. 2000. Age-related changes in photosynthesis of woody plants. *Trends in Plant Science* 5: 349–353. https://doi.org/10.1016/S1360-1385(00)01691-5

Cassens DL & Serrano JR. 2004. Growth stress in hardwood timber. Pp 106–115 in Yaussy DA, Hix DM, Long RP, Goebel PC (eds) *Proceedings of the 14th Central Hardwood Forest Conference*. 16–19 March 2004, Wooster, Ohio, USA.

Ghislain B, Alméras T, Prunier J & Clair B. 2019. Contributions of bark and tension wood and role of the G-layer lignification in the gravitropic movements of 21 tropical tree species. *Annals of Forest Science* 76: 107. https://doi.org/10.1007/s13595-019-0899-7

Gilbero DM, Abasolo WP, Matsuo M & Yamamoto H. 2022. Lateral growth affects xylem maturation properties of 8-year-old big-leaf mahogany (*Swietenia macrophylla*). *Journal of Tropical Forest Science* 34: 1–10.

Gilbero DM, Abasolo WP, Matsuo-Ueda M & Yamamoto H .2019. Surface growth stress and wood properties of 8-year-old planted Big-leaf mahogany (*Swietenia macrophylla* King) from different landrace provenances and trial sites in the Philippines. *Journal of Wood Science* 65: 35. https://doi.org/10.1186/s10086-019-1814-4

Gril J, Jullien D, Bardet S & Yamamoto H. 2017. Tree growth stress and related problems. *Journal of Wood Science* 63: 411–432. https://doi.org/10.1007/s10086-017-1639-y

Jullien D, Widmann R, Loup C & Thibaut B. 2013. Relationship between tree morphology and growth stress in mature European beech stands. *Annals of Forest Science* 70: 133–142. https://doi.org/10.1007/s13595-012-0247-7

Kameyama N, Matsuo-Ueda M, Chen S et al. 2023. Unique characteristics of residual stress distribution of large-diameter keyaki (*Zelkova serrata*) logs and examination of their measurement method. *Journal of Wood Science 69*: 16. https://doi.org/10.1186/s10086-023-02088-z

Kartikawati E, Bienitta, Prastiwi FW & Nugroho WD. 2024. Determination of the boundary between juvenile-mature wood of *Diospyros kaki* and their wood anatomical variations. *Journal of the Korean*

Wood Science and Technology 52: 191–203. https://doi.org/10.5658/WOOD.2024.52.2.191

Kojima M, Yamamoto H, Marsoem SN et al. 2009. Effects of the lateral growth rate on wood quality of *Gmelina arborea* from 3.5-, 7- and 12-year-old plantations. *Annals of Forest Science* 66: 507. https://doi.org/10.1051/forest/2009031

Maeglin RR. 1987. Juvenile wood, tension wood, and growth stress effects on processing hardwoods. Pp 100–108 in *Proceedings of the 15th Annual Hardwood Symposium of the Hardwood Research Council*. 10–12 May 1987, Memphis, TN.

Marasigan OS, Razal RA, Carandang WM & Alipon MA. 2022. Physical and mechanical properties of stems and branches of Falcata [*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes] grown in Caraga, Philippines. *Philippine Journal of Science* 151: 575–586. https://doi.org/10.56899/151.02.03

Maree B & Malan FS. 2000. Growing for solid hardwood products—a South African experience and perspective. Pp 319–327 in *The Future of Eucalypts for Wood Products: Proceedings of the IUFRO Conference*. 19–24 March 2000, Launceston, Tasmania, Australia.

Matsuo-Ueda M, Tsunezumi T, Jiang Z et al. 2022. Comprehensive study of distributions of residual stress and Young's modulus in large-diameter sugi (*Cryptomeria japonica*) log. *Wood Science and Technology* 56: 573–588. https://doi.org/10.1007/s00226-022-01360-7

Moya R & Tenorio C. 2021. Reduction of growth stresses in logs of *Hieronyma alchorneoides* Allemão from fast-growth plantations using steaming and heating: effects on the quality of lumber. *Annals of Forest Science* 78: 74. https://doi.org/10.1007/s13595-021-01090-z

Nawrot M, Pazdrowski W, Szymański M, Kupczyk G & Lubieński K. 2007. Volume and share of juvenile, maturing and mature wood in stems of Norway spruce (*Picea abies* [L.] Karst) grown in mixed mountain forest sites. *Acta Scientiarum Polonorum Silvarum Colendarum Ratio et Industria Lignaria* 6: 67–76.

Paquit JC, Rojo MJA, Parlucha JA & Gilbero DM. 2024. Surface release strain (SRS) and wood anatomy of young *Falcataria falcata* trees planted in Agusan del Norte, Philippines. *Journal of Tropical Forest Science* 36: 310–318.

Statgraphics Centurion XVI. 2009. *User Manual*. StatPoint Technologies Inc., Warrenton, VA, USA.

Sulaiman A & Lim SC. 1989. Some timber characteristics of *Gmelina arborea* grown in a plantation in peninsular Malaysia. *Journal of Tropical Forest Science* 2: 135–141.

Yang JL & Waugh G. 2001. Growth stress, its measurement and effects. *Australian Forestry* 64: 127–135. https://doi.org/10.1080/00049158.2001.10676176

Yang JL, Baillères H, Okuyama T, Muneri A & Downes G. 2005. Measurement methods for longitudinal surface strain in trees: a review. *Australian Forestry* 68: 34–43. https://doi.org/10.1080/00049158.2005.10676224

Yoshida M, Okuda T & Okuyama T. 2000. Tension wood and growth stress induced by artificial inclination in *Liriodendron tulipifera* Linn. and *Prunus spachiana* Kitamura f. *ascendens* Kitamura. Annals of Forest Science 57: 739–746. https://doi.org/10.1051/forest:2000156