RESPONSE OF CAMBIUM GROWTH TO MECHANICAL INJURIES IN TREE SPECIES

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The major objective of the study was to understand regrowth after an injury in 11 tropical tree species such as *Albizia lebbeck, Azadirachta indica, Delonix regia, Lannea coromandelica, Madhuca longifolia, Pongamia glabra, Peltophorum pterocarpum, Terminalia catappa, Senna siamea, Syzygium cumini* and *Terminalia arjuna*. The study was conducted from January 2019 to January 2020 at the Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, India. In the experiment, wood incision with a dimension of 15 cm × 15 cm was made on the outside of the tree trunks and its growth was calculated by graph paper drawing method. The results indicated that *Lannea coromandelica* which has no timber value, exhibited the fastest cambial growth compared to the other tree species.

Keywords: Trees, wood incision, cambium growth, horizontal growth, vertical cambium growth

INTRODUCTION

Multi-utility tropical trees are the pillars of social and farm forestry. They are grown either singly or in groves because of their potential use in crop production and environmental importance. The trees have important roles in the livelihood of farmers. Generally, these trees are grown for their multiple benefits such as food, fuel, fodder and feed besides other direct and indirect benefits derived from the wood (Swaminathan et al. 2017). Generally, farmers use sharp farm tools like sickle, hoe, axe and shear harvesting, soil work and tree maintenance. Frequently, these tools may injure or harm the trees in the farmlands and thus, the trees suffer due to biotic and abiotic stresses including secondary infection by pest and disease. While trees in groves or communities are protected and less vulnerable to such injuries, solitary trees and avenue trees planted along roadsides are open to injuries caused by the public. A common phenomenon is to use stand-alone trees in public places as a pole to nail a billboard.

A wound tree has notable visible stage as in the discoloration process and may lead to decay of the tree stem or entire trunk. The breaking of branches due to strong wind and mechanical injuries to the stem are the types of wounds most commonly associated with decay and the death of trees. However, not all wounds cause extensive decay because minor physical injuries are repaired by the trees themselves over time. In contrast, deeper wounds cause greater damage and can affect the inner wood, leading to the tree death in the long term. Injuries that kills the vascular cambium in some portion of the stem affects translocation, causes wood discoloration and encourages wood-destroying fungi infections (Shigo 1984, Smith 2006). In addition, there are significant physiological changes in a tree due to the impact of injury and infection (Smith 2015). These changes lead to the formation of oxidised pigments in wounded sapwood that may stain and reduce hardwood value. Furthermore, damage to trees from farm equipment during field traffic can occur due to carelessness of personnel or improper management of vehicles and equipment. However, most of these damages are preventable and often associated with a lack of attention by the caretakers. The degree of regrowth in tree species following such injuries will enable us to understand the resilience of various multi-utility trees commonly grown in farmlands, community lands, ecoparks and along avenues. The major objective of this study was to examine regrowth stage after an injury in 11 multi-utility tree species such as *Albizia lebbeck, Azadirachta indica, Delonix regia, Lannea* *coromandelica*, *Madhuca longifolia*, *Pongamia glabra*, *Peltophorum pterocarpum*, *Terminalia catappa*, *Senna siamea*, *Syzygium cumini* and *Terminalia arjuna*.

MATERIALS AND METHODS

Tree species

Eleven multi-utility tree species such as *Albizia lebbeck*, *Azadirachta indica*, *Delonix regia*, *Lannea coromandelica*, *Madhuca longifolia*, *Pongamia glabra*, *Peltophorum pterocarpum*, *Terminalia catappa*, *Senna siamea*, *Syzygium cumini* and *Terminalia arjuna* were selected from their natural stands for the study. Trees had various uses and any mechanical injury caused to tree trunk or stem would create greater impact on the quality of timber at the time of maturity. The details of the multiple-utility trees (Chaturvedi et al. 2017) employed in this study were provided in Table 1.

Wood incision

A wood incision with a dimension of 15cm 15cm was made by using a sharp knife on the outer surface of tree stems or trunks of the 11 different trees species at 2 m height from the ground in January 2019. Observations on the growth and spread of cambium was made after 12 months' period on January 2020. The recovery was measured by using a scale and calculated by graph paper drawing method.

Graph paper drawing method

The graph paper used for measurement had a dimension of 24 cm × 18 cm with 432 grid boxes of 1.0 cm^2 each. The injured area with a dimension of 15 cm × 15 cm on the wood was photographed and the image was traced over the graph paper. The grids on the graph paper covered by the fresh cambium growth were counted and added to quantify the area covered by fresh cambium growth or callus formation after the injury. The method gave accurate measurement of growth in the injured portion of each tree species.

Weather monitoring

The local weather conditions such as mean maximum and minimum temperatures, mean annual rainfall, pan evaporation, relative humidity, sunshine hours and wind velocity at the experimental location were recorded during the duration of the experiment.

Statistical analysis

The results for each characterisation data were obtained from the mean procedure and statistical analysis was performed using a complete randomized design and 10 trees of each species with one incision per tree. The data on various parameters studied during the investigation were statistically analysed by procedures suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Trees were prone to mechanical injuries caused by natural and artificial factors. Abiotic factors and various pests and pathogens naturally attack trees could also cause injuries. In addition, tree injuries were also cause by human activities

Table 1 List of trees species for the study and their uses

Sample number	Common name	Scientific name	Family	Significant uses
1.	Indian siris	*Albizia lebbeck*	Fabaceae	Timber
2.	Neem	*Azadirachta indica*	Meliaceae	Timber, Medicinal oilseed.
3.	Gulmohar	*Delonix regia*	Fabaceae	Ornamental
4.	Indian Ash Tree	*Lannea coromandelica*	Anacardiaceae	Ornamental
5.	Madhuka	*Madhuca longifolia*	Sapotaceae	Oilseed
6.	Indian beech	*Pongamia glabra*	Fabaceae	Oilseed
7.	Yellow Flame	*Peltophorum pterocarpum*	Fabaceae	Ornamental
8.	Indian almond	*Terminalia catappa*	Combretaceae	Timber
9.	Cassod tree	*Senna siamea*	Fabaceae	Ornamental
10.	Black plum	*Syzygium cumini*	Myrtaceae	Timber, NTFP
11.	Arjuna Tree	*Terminalia arjuna*	Combretaceae	Timber

during pruning and logging operations. Trees tended to heal themselves from an injury by forming secondary xylem.

Wood or secondary xylem formation was a five-step process. The process included cell division; cell expansion with elongation as well as radial amplification; cell wall thickening (which involved cellulose and hemicelluloses, cell wall proteins with lignin biosynthesis and deposition), planned cell death and hardwood formation (Chaffey 1999, Mellerowicz et al. 2001). Bark thickness, basic density and heartwood percentage were important quality traits in stem and wood (Bon et al. 2020). Hence, injuries to tree trunks could affect the normal growth and the lowered the economic value of timber. In hardwood species, mechanical injury to the trunk or bole killed a part of the vascular cambium. They consisted of a thin layer of cells beneath the bark which divided to form new cells to increase the stem girth.

Vascular cambium which has the secondary xylem on the inside and secondary phloem on the outside matured to become wood and inner bark, respectively. In the present investigation, the trees selected were injured for numbering and left uncared and later observed for the recovery on the injured portion after 12 months. The mean horizontal growth was higher at 2.73 cm than the vertical growth of cambium at 0.87 cm, which was three times greater in all the species studied. Among the 11 species, the maximum horizontal growth of 8.00 cm was observed in *L. coromandelica,* which also had higher vertical growth at 3.80 cm of cambium (Table 3 & Figure 2). The observation was followed by *A. indica* and *T. arjuna.* Almost all tree species showed progressive horizontal growth but the vertical growth of cambium was comparatively poor or absent in most of the tree species except for *Lannea coromandelica.* A similar trend was also observed in the monthly growth rate of cambium. Generally, external factors played a significant role in affecting the physiological changes in trees in that way affecting the cambial activity (Rajput et al 2008) and such activity remained active under tropical climates throughout the year (Rajput and Rao 2001). The weather parameters recorded during the period were presented in Table 2. The mean maximum and minimum temperatures were 35.12 °C and 18.46 °C, respectively. The mean annual rainfall was at 979.00 mm with 62 rainy days. The mean pan evaporation was at 5.30 mm, relative humidity was at 77.96%, sunshine hours were 6.60 day^{-1} and wind velocity was at 17.64 m s^{-1}. Furthermore, the climatic variations between seasons would also influence cambium growth. In the present study, it was evident that monsoon seasons received maximum rainfall with a greater number of rainy days with minimum temperature compared to the summer season while winter season received no rainy days. Such seasonal variations in temperature and rainfall between seasons would naturally influence cambium growth and a dynamic change was observed in *Eucalyptus grandis* cambial zone due to seasonal variations (Budzinski et al. 2016). provided Previous research supported that trees had the amazing ability to adjust their growth rate to adverse and favorable seasonal environmental conditions and the basis for tuning of wood to seasonal growth rate was by the regulation of cambial stem cell activity (Bhalerao et al. 2017). The recovery of living cambium in the injured portion of the trunk was vital. The cambium played a significant role in the diametric growth in the shoots and roots of gymnosperm and angiosperm, predominantly in the tree wood that was produced due to cambial activity (Christophe et al. 2001). The cambium was responsibility for the covering and closing of wound surfaces through the configuration of

Table 2 Seasonal weather data during the study period

Month	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)	Rainy days	Pan evaporation (mm)	Sunshine (hours day^{-1})	Wind velocity (m s^{-1})
Winter	32.3	12.85	4.8	0	4.6	9.15	33.95
Summer	37.6	15.4	100.6	4	6.4	8.0	23.2
Monsoon	35.6	21.0	524.0	23	5.3	5.5	11.1
Retreating monsoon	33.8	21.8	354.0	18	4.6	4.8	9.96

callus tissue along with the boundary layer of the wound. In principle, there were two strategies on wound closure. The first was the formation of a lateral callus and the second was the formation of a surface callus (Stobbe et al. 2002). When a wound occurred, the cambium would experience greater cell division activity. It would lead to quick and fast growth of the callus, which would cover more of the original wound surface. In some tree wounds, a lateral callus was observed to cover of the entire wound surface and leaving a thin, axially oriented central cleft (Uwe et al. 2016). The formation of surface callus covering the wound surface was initiated and triggered when living phloem or cambium and also differentiating xylem was present on the wound surface.

A close observation of the cambial growth or also known as callus formation in terms of spread area indicated the fast-growing nature of *L. coromandelica,* which had no timber value compared to all other tree species (Figure 1 & Figure 2). The lateral callus growth shown by the species was superior and indicated the ability of the tree species to cover the injured area at a faster rate of 13.51%, which protected the tree trunk and saved the tree from secondary infection. In contrast, *D. regia* showed very slow cambial growth at 0.10 cm^2 with a meager 0.04% recovery.

In general, callus formation due to living cambium in the tree species of this study showed progressive latitudinal growth of cambium than altitudinal growth. The observation might be due to the natural genetic characteristic of the tree species family and the cyclic environmental conditions and factors such as and wet seasons which played key role in the vegetative growth of any tree species. The tree to tree variations in wood properties within a species was large and might be reflected through the variation in anatomical and physical properties. The more severe the environment, the greater the control it had on wood properties relative to inherited differences (Swaminathan 2012). The leafless nature of the trees like *D. regia* for almost one-fourth of the year would affect the growth and photosynthetic activity and was reflected in the cambium growth. The healthy wood was lost from injured parts of the tree even after full recovery (Wiedenbeck et al. 2019). Furthermore, the cambial activities like dormancy and activation were influenced by temperature, photoperiod or aging (Christophe et al. 2001) and a wood cell underwent significant morphological changes from cambium to heartwood formation (Song et al. 2011). However, at certain times the opposing injured wood ribs might meet and thereby forming a bark joint without restoration of circumferential connections. Overall, the study on cambium growth following injury revealed that among different tree species, *L. coromandelica* trees was faster in closing the injured trunk as compared to the other tested trees.

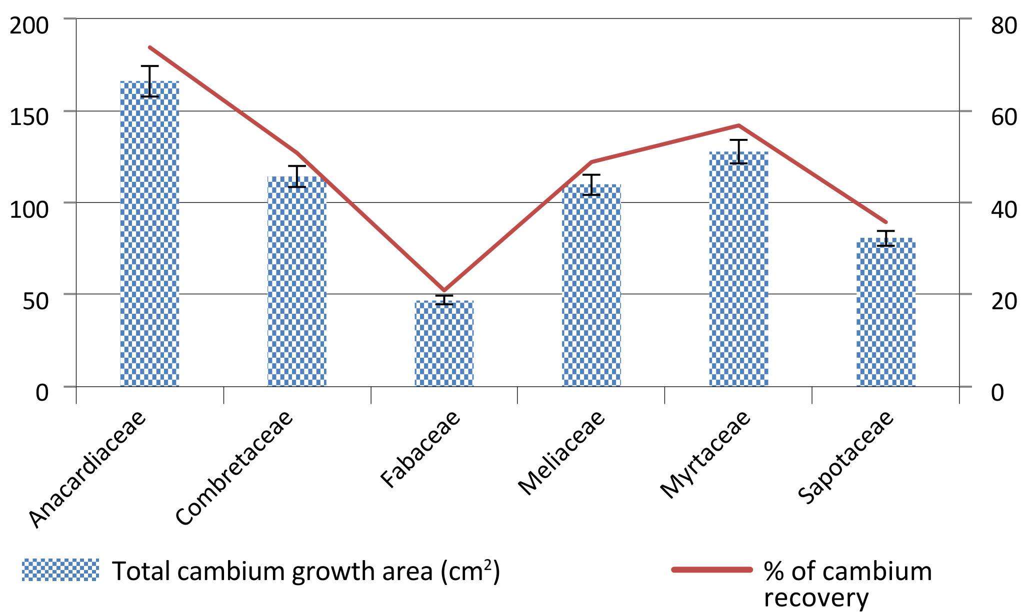

Figure 1 Total cambium growth (cm^2) and % of cambium recovery based on plant family

Table 3 Wood injured area (cm^2), vertical cambium growth area (cm), horizontal vertical cambium growth (cm), total cambium growth area (cm^2) and % of cambium recovery in 12 months

Species No.	Tree species	Family	Wood injured area (cm^2)	Vertical cambium growth area (cm)	Horizontal vertical cambium growth (cm)	Total cambium growth area (cm^2)	The monthly growth rate of cambium closure (cm^2 $month^{-1}$)	Percent of cambium recovery (%)
1.	*Albizia lebbeck*	Fabaceae	225	0.59 ± 0.12	2.83 ± 0.24	84.66 ± 0.18	7.06 0.15	37.62
2.	*Azadirachta indica*	Meliaceae	225	1.23 ± 0.12	3.32 ± 0.18	109.65 ± 0.10	9.14 ± 0.16	48.73
3.	*Delonix regia*	Fabaceae	225	0.1 ± 0.03	1.0 ± 0.25	34.44 ± 0.14	2.87 ± 0.03	15.30
4.	*Lannea coromandelica*	Anacardiaceae	225	3.80 ± 0.07	8.0 ± 0.10	165.91 ± 0.08	13.83 ± 0.06	73.73
5.	*Madhuca longifolia*	Sapotaceae	225	0.39 ± 0.05	2.07 ± 0.23	80.57 ± 0.14	6.71±0.09	35.80
6.	*Pongamia glabra*	Fabaceae	225	0.2 ± 0.12	1.25 ± 0.03	40.35 ± 0.07	3.36 ± 0.04	17.93
7.	*Peltophorum pterocarpum*	Fabaceae	225	0	1.52 ± 0.42	16.93 ± 0.21	1.41 ± 0.01	07.52
8.	*Terminalia catappa*	Combretaceae	225	0.92 ± 0.33	2.95 ± 0.74	100.37 ± 0.53	8.36 ± 0.15	44.60
9.	*Senna siamea*	Fabaceae	225	0	2.10 ± 0.01	59.12 ± 0.002	4.93 ± 0.11	26.27
10.	*Syzygium cumini*	Myrtaceae	225	0.50 ± 0.004	1.80 ± 0.032	127.68 ± 0.02	10.64 ± 0.14	56.74
11.	*Terminalia arjuna*	Combretaceae	225	1.85 ± 0.37	3.25 ± 0.31	128 ± 0.34	10.67 ± 0.01	56.88

Data were presented in mean values with (±) standard error

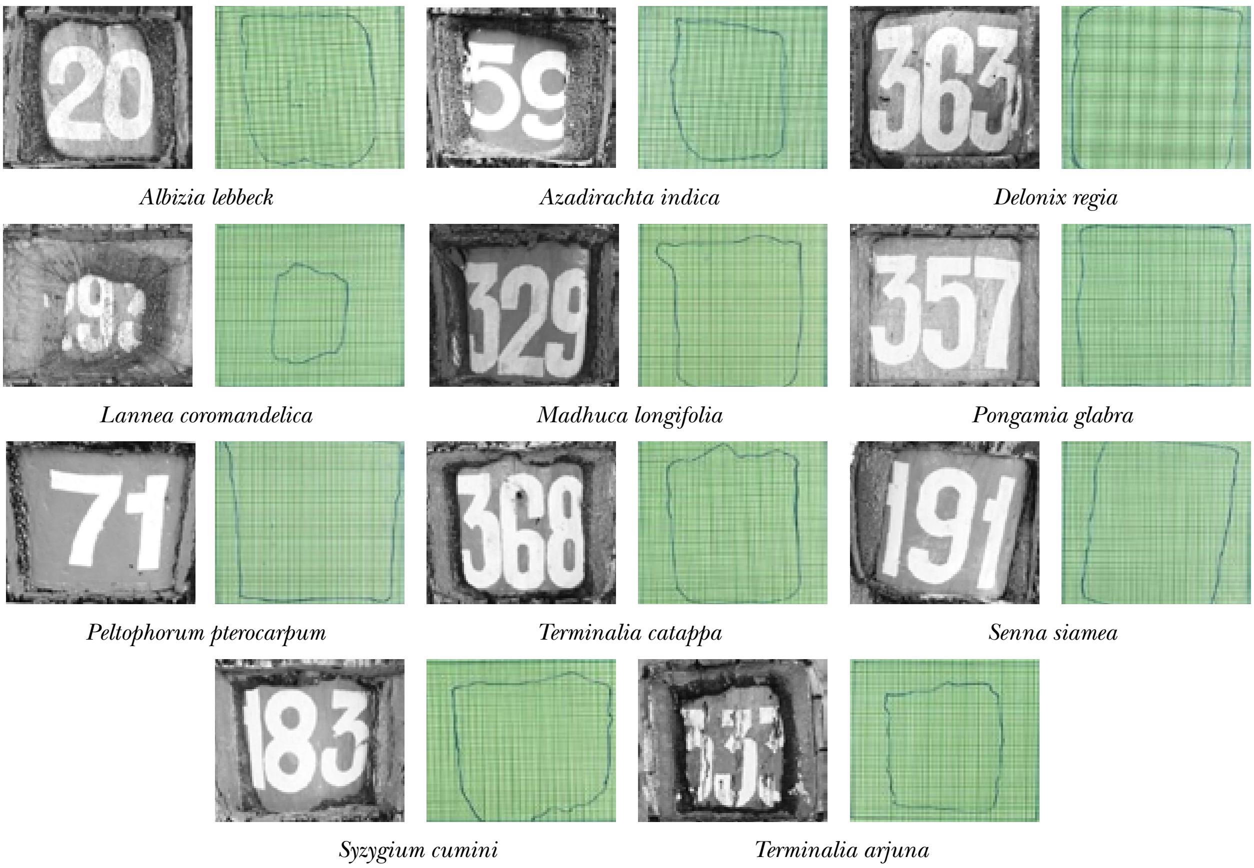

Figure 2 Cambium growth of different tree species was represented by the graph paper drawing method

CONCLUSIONS

The study revealed that among the 11 species of trees, three species such as *S. cumini, T. arjuna* and *L. coromandelica* showed injury recovery of more than 50% with *L. coromandelica* having a cambium recovery growth of 73%. In contrast, *D. regia*, which is an ornamental species, showed very slow cambial growth with a meager 0.04% recovery. Furthermore, cambial activity was faster in horizontal growth than vertical growth. This paper gave preliminary finding on the cambium recovery of injured wood and required further investigation for a better understanding of the reproductive tissue rates and cambium growth dynamic of different tree species.

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