FALSE RING OCCURRENCES AND THEIR IDENTIFICATION IN TEAK (*TECTONA GRANDIS*) IN NORTH-EASTERN THAILAND

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PALAKIT K, SIRIPATTANADILOK S & DUANGSATHAPORN K. 2012. False ring occurrences and their identification in teak (*Tectona grandis*) in north-eastern Thailand. The objectives of this research were to identify and locate the position of false ring occurrences in natural teak (*Tectona grandis*) and to relate their formation to local climate variability. Vessel diameters were measured and standardised from pith towards the bark in order to identify false rings and define annual ring boundaries. Two types of false rings were classified as false ring type I and II in earlywood and latewood respectively. False ring type I had one or more rows of axial parenchyma associated with large vessels at the beginning of the annual ring. False ring type II was divided into two groups based on their characteristics. The first group had an aggregation of large vessels associated with paratracheal parenchyma while the second group did not have any paratracheal parenchyma. The occurrences of false rings could be explained by the fluctuations of rainfall and temperature during the growing season. False ring type I occurred during drought following heavy rainfall at the beginning of the monsoon period. After dense fibre occurrences in latewood, heavy rainfall and warm temperature at the end of the monsoon period re-stimulated large vessels and/or parenchymatous cells to form false ring type II.

Keywords: Annual ring, dendrochronology, earlywood, intra-annual density fluctuations (IADFs), latewood, quantitative wood anatomy, tree-ring

PALAKIT K, SIRIPATTANADILOK S & DUANGSATHAPORN K. 2012. Kejadian dan pengecaman gelang palsu dalam pokok jati (*Tectona grandis*) di timur laut Thailand. Objektif kajian ini adalah untuk mengenal pasti dan menentukan kedudukan gelang palsu dalam kayu jati (*Tectona grandis*) serta membuat kaitan antara pembentukan gelang tersebut dengan perubahan iklim. Diameter pembuluh diukur dan dipiawaikan dari arah empulur ke kulit kayu untuk mengenal pasti gelang palsu dan menentukan sempadan gelang tahunan. Dua jenis gelang palsu dikenal pasti iaitu jenis I dan jenis II yang masing-masing terbentuk dalam kayu awal dan kayu akhir. Gelang palsu jenis I mempunyai satu baris atau lebih parenkima aksial yang berhubung dengan pembuluh besar pada permulaan gelang tahunan. Gelang palsu jenis II terbahagi kepada dua kumpulan berdasarkan cirinya. Kumpulan pertama mempunyai pengagregatan pembuluh besar yang berhubung dengan parenkima paratrakea. Kumpulan kedua pula tidak mempunyai sebarang parenkima paratrakea. Kejadian gelang palsu dapat dijelaskan dengan turun naiknya jumlah hujan serta suhu semasa musim pertumbuhan. Gelang palsu jenis I terbentuk semasa kemarau setelah hujan lebat pada awal musim monsun. Setelah gentian tumpat terbentuk dalam kayu akhir, hujan lebat serta suhu yang panas pada akhir musim monsun merangsang semula pembuluh besar dan/atau sel parenkima untuk membentuk gelang palsu jenis II.

INTRODUCTION

Crossdating is one of the basic principles of dendrochronology; it matches patterns of wide and narrow tree rings within and among trees. Annual rings are generally assigned their exact growing years using the technique of crossdating. This technique is successful in dendrochronology because environmental conditions force similar growing patterns on all trees throughout a selected region (Fritts 1976). In the case of non-climatic injured tree rings, the anomalous tree ring usually occurs in an individual tree and crossdating is useful to examine any lack of coincidences and identify the exact years of absent or false ring occurrences. However, the occurrences of false rings or intra-annual density fluctuations (IADFs) induced by extreme climatic factors that usually occur in several trees in the same region is one of the most common sources of error in tree ring research. Increased numbers of dated annual rings cause errors in annual ring identification. However, occurrence of IADFs is the main obstacle in the determination of age, exact growing period and growth rate of each annual ring. Several studies have reported factors affecting false ring formation, especially in unusual climatic events (e.g. Campelo et al. 2006, Edmondson 2010, De Luis et al. 2011), but the method of false ring identification was not fully described.

Recently, the techniques of false ring identification in several species of long leafpines and broadleaf trees have been improved. Studies of vessel and tracheid diameter variations related to environmental signals have been reviewed by Fonti et al. (2010). In the Mediterranean ecosystem, false ring of *Pinus pinaster* was classified using variation of tracheid–lumen area and stable carbon isotope ($\delta^{13}C$) values from earlywood to latewood zones (De Micco et al. 2007). The potential of vessel size variations on IADFs identification was later confirmed by De Micco et al. (2011). In another study, false ring of *Arbutus unedo* was identified using the presence of collapsed or crushed xylem elements along the ring combined with vessel size variation and $\delta^{13}C$ values (Battipaglia et al. 2010). Wood density was another anatomical feature that could be used to identify false ring (Sutton & Tardif 2005).

In the tropics, teak (*Tectona grandis*) has been widely used as a high resolution proxy for dendrochronological research, especially in the dendroclimatic subfield (Bhattacharyya et al. 2007, Buckley et al. 2007, Shah et al. 2007, Ram et al. 2008, Borgaonkar et al. 2009). These studies suggested that the major climatic factor controlling teak growth was significantly associated with monsoon rainfall. However, one of the most common sources of error in teak tree-ring research is the occurrence of false rings. False ring formation in juvenile teak under controlled environmental conditions has been studied by Priya and Bhat (1998). They identified teak false rings using anatomical characteristics and classified them following relative positions of their occurrences in teak microsections. However, these microscopic investigations were complicated and difficult to study directly from increment cores which were commonly determined.

The objectives of this study were to (1) define annual ring boundaries and identify and locate the positions of false rings in natural *T. grandis* using the techniques of vessel size varied measurement and wood anatomical analysis, and (2) relate monthly climatic variability to the occurrences of these false rings.

This analysis will demonstrate the low-cost image analytical technique of false ring identification and increase the accuracy of dendrochronological studies. Additionally, causes of false ring occurrences due to climatic variability will be determined and the understanding of cell development associated with climatic data will be enhanced. Finally, this technique can be applied to study false ring occurrences and their correlation with climatic variability in other ring porous and semi-ring porous species.

MATERIALS AND METHODS

Study site

The study site is located at the Wang Nam Khiao Forestry Student Practicing Station (WNKFSPS) of the Faculty of Forestry, Kasetsart University in Nakhon Ratchasima province, lower north-eastern Thailand (14° 29' N, 101° 56' E) (Figure 1). This site was selected because of the discovery of anomalous tree growth forming false rings. The elevation of the study site is 339 m above mean sea level. The seasons are broadly classified as dry and cool (November till January), hot (February till April) and monsoon (May till October). Based on the 1969–2008 climatic data obtained from the meteorological station at the Sakaerat Environmental Research Station, which is the nearest station to the study site, the average monthly rainfall/temperature in the dry and cool, hot and monsoon seasons are 21.8/22.8, 54.4/28.0 and 142.1/27.2 mm/°C respectively. In the monsoon, rainfall rapidly increases at the beginning of the season (135.3 mm in May) followed by a short period of drought in the mid-season (95.5 mm in July). The highest rainfall occurs at the end of the season (230.2 mm in September). The highest and lowest mean temperatures are 29.25 °C in April and 21.85 °C in December respectively (Figure 2).

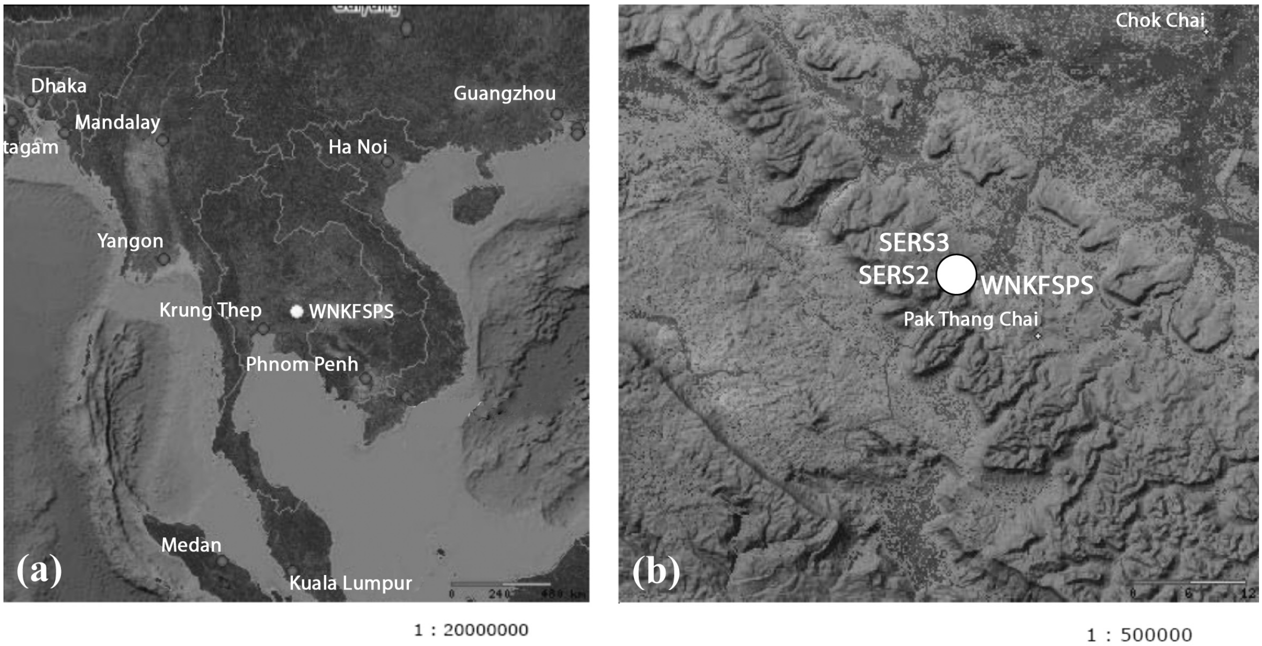

Figure 1 The anomalous teak growing site (white dots); the figure indicates the location and topography of the study site (Wang Nam Khiao Forestry Student Practicing Station, WNKFSPS) which is close to the Sakaerat Environmental Research Station (SERS) at Pak Thong Chai district, Nakhon Ratchasima province, north-eastern Thailand

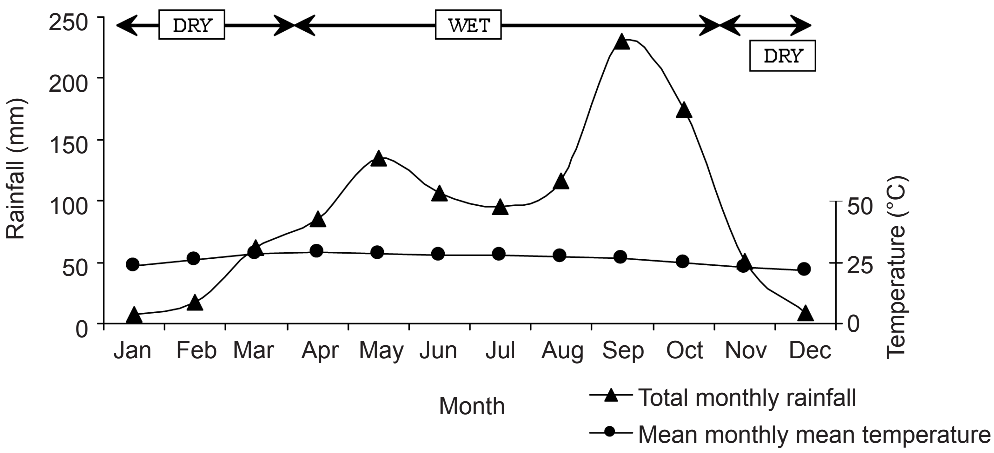

Figure 2 Averages of total monthly rainfall and mean monthly temperatures from 1969 till 2008 indicating dry and wet periods

Sample collection and preparation

Seven natural teak trees (coded TG01 to TG07), aged > 26 years old were selected for this study. Similar to criteria of dendroclimatic studies, each selected tree must be dominant, located on good drained area and have symmetrical crown and straight trunk. Wood increment cores were collected from the bark through the pith using an increment borer. Four cores were taken from each tree in cardinal (north, east, west and south) directions at breast height (1.3 m). Wood cores were kept in plastic straws to avoid damage. In the Laboratory of Tropical Dendrochronology at the Faculty of Forestry, Kasetsart University, wood cores were air dried at room temperature and fixed in wooden supports following the standard methods of dendrochronology (Stokes & Smiley 1996). The fixed core samples were polished with several grades of sandpaper until transverse surfaces were visible under a stereoscope. These increment cores were then coated with blackboard chalk so as to fill teak vessels with chalk powder. Filling teak vessels with chalk powder enhanced the visibility of vessel boundaries and made it easier to measure vessel diameters using image analysis.

Vessel size measurement using image analysis

To identify annual and false rings, image analysis was applied to study the variation of vessel diameters from pith to bark. The boundaries of annual rings were identified as the abrupt change of the vessel diameter sizes at the transition zone of adjacent annual ring combined with the appearance of paratracheal banded parenchyma. False rings only showed a small increase in vessel sizes and/or the occurrence of paratracheal parenchyma. Fixed teak cores, coated with blackboard chalk, were scanned along transverse surfaces at 2400 dots per inch (dpi) resolution using an ordinary scanner and converted to negative colour. The quadrilateral was overlaid in each 50 pixel widths (530 μm) of the scanned images (Figure 3). In each quadrilateral, all vessels were numbered and five vessels were selected using the technique of generated random number. Diameters of selected vessels were measured using the program ImageJ. Vessel sizes in each quadrilateral were averaged and plotted to examine the variation of vessel diameters from pith to bark. Trends of variation in vessel sizes due to the age effect were standardised using the ratio of average vessel diameters of current and prior quadrilaterals. Standardised vessel diameters were also plotted to examine the variation of vessel diameters from pith to bark and to indicate annual ring boundaries and false rings. The values of standardised vessel diameters were commonly close to 1 while peaked values higher than 2 indicated edges of annual rings.

Anatomy of teak cells forming false rings

Three each of annual and false rings from increment cores were chosen and separated from the wooden supports using chisel and razor blade in order to study anatomical features of teak cells. Ring samples were prepared for paraplast embedding and transverse sectioning. Microsections, each 15 μm thick, were cut using microtome. The wood sections were stained and mounted on microscopic glass slides using permount. Cell types forming annual and false rings were studied and their photographs were taken under compound photomicroscope.

Relationship between false ring occurrences and climatic variability

False rings detected during vessel size measurement were classified into two types according to their positions in earlywood (type I) and latewood (type II). The occurrences of false ring types I and II were separately counted and converted into percentages of false ring frequencies in each year.

Climatic data including mean monthly maximum (T_{max}), minimum (T_{min}) and mean (T_{mean}) temperatures and total monthly rainfall (Rainfall) obtained from the meteorological station were correlated with the percentages of false ring types I and II frequencies using simple correlation and stepwise regression analysis. Apart from monthly climatic data, average climatic data

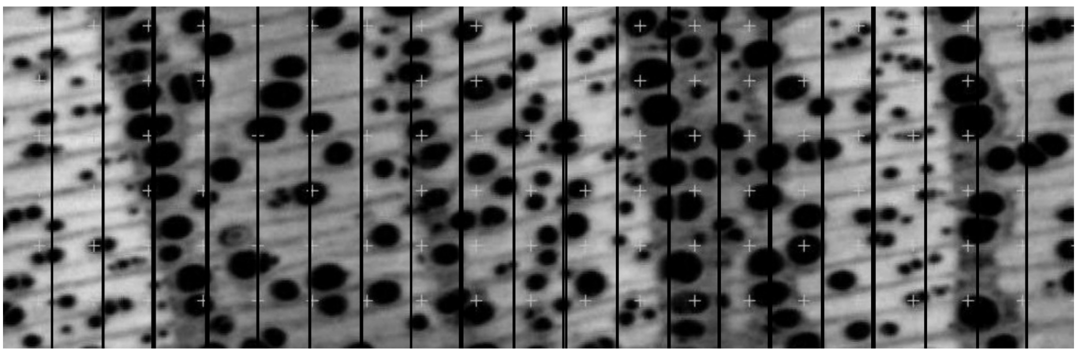

Figure 3 Scanned image of teak in transverse surface overlaid with the quadrilaterals of 50 pixels width along wood cores

during the drought period from January till April, the first half of wet season from May till August, and the second half of wet season from September till December were also correlated with the percentages of false ring frequencies in order to estimate the major climatic factors inducing false ring formation.

RESULTS AND DISCUSSION

Vessel size and tree-ring identification

Within normal annual rings, the largest vessels were found at the edge of the beginning of the annual ring and gradually decreased to the end of the ring. The abrupt change of the vessel sizes at the transition zone of the adjacent tree rings, where standardised vessel diameters were close to or greater than 2, was used as marker of annual ring boundaries (Figure 4). Similar approach and observations were made in studies of other broadleaf vessel and longleaf tracheid diameter variations (Eilmann et al. 2006, Park et al. 2006, De Micco et al. 2011).

Although the variation of vessel diameters within each annual ring decreased from the beginning to the end of the annual ring, trends of vessel diameter variations between annual rings gradually increased from pith towards the bark (Figure 5). Vessel lumen diameter of *Fraxinus excelsior* increased from immature to mature wood (Helinska-Raczkowska & Fabisiak 1999). It was reported that variation of vessel member length of *Ilex paraguariensis* showed similar pattern as vessel lumen size (Dunisch et al. 2004). To eliminate the effect of vessel diameter increment from pith to bark and increase differentiation of vessel sizes at transition zones of adjacent annual rings, values of standardised vessel diameters were calculated and commonly fluctuated close to 1, except for the abrupt change at the edge of annual ring boundaries where these values increased above 2 (Figure 6). The values of other standardised vessel diameters varied between 1 and 2 and were mostly defined as false rings.

Anatomical features of teak false rings

Vessel size variation helped to identify false rings. However, anatomical features of cell types forming tree rings were important to confirm the differentiation between false and normal annual rings. From the macroscopic and microscopic investigations of all teak sample cores and thin wood sections, we found that normal annual rings composed of paratracheal banded parenchyma associated with the largest vessels at the beginning of the annual ring. Vessel diameters gradually narrowed from earlywood to latewood (Figure 7a). False rings exhibited different features in both earlywood and latewood zones. Similar to the study by Priya and Bhat (1998), we also defined the occurrences of false rings nearby large vessels and thick banded parenchyma at the beginning of the annual ring as false ring type I. It was the zone resembling earlywood where one or

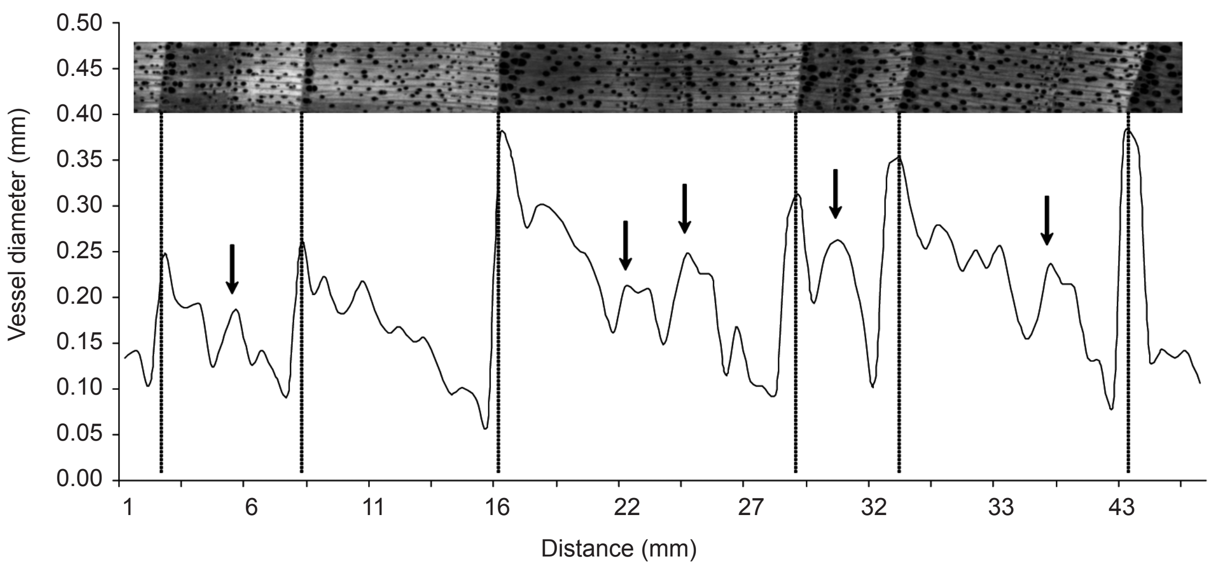

Figure 4 Variation of vessel diameters indicating annual ring boundaries; dotted lines and arrows indicate abrupt changes at the border of each annual ring and intra-annual fluctuation respectively

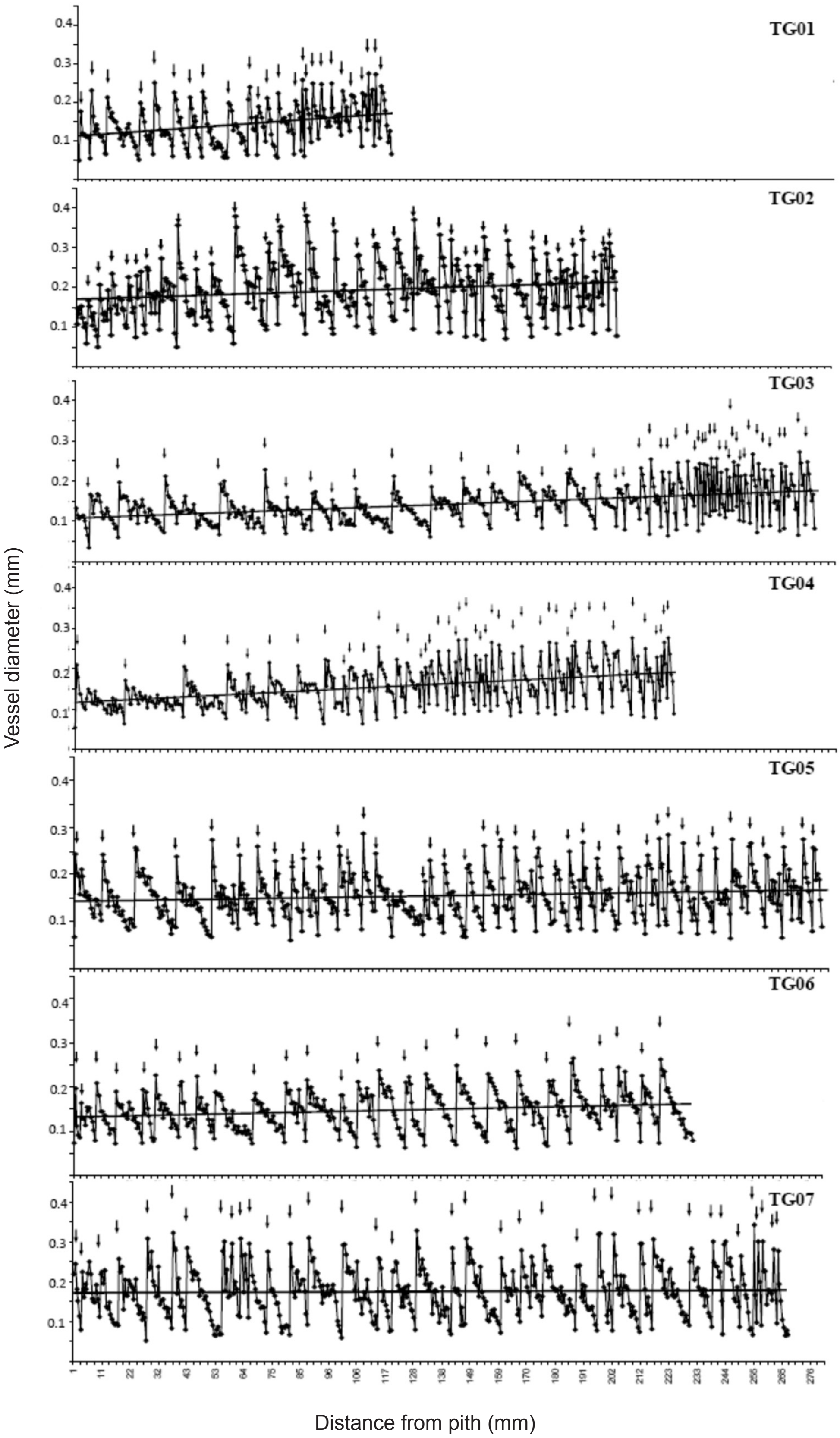

Figure 5 Vessel diameter variations from pith to bark for the seven sample trees (TG01 to TG07); straight lines show increasing trend of vessel diameters and arrows indicate ring width boundaries

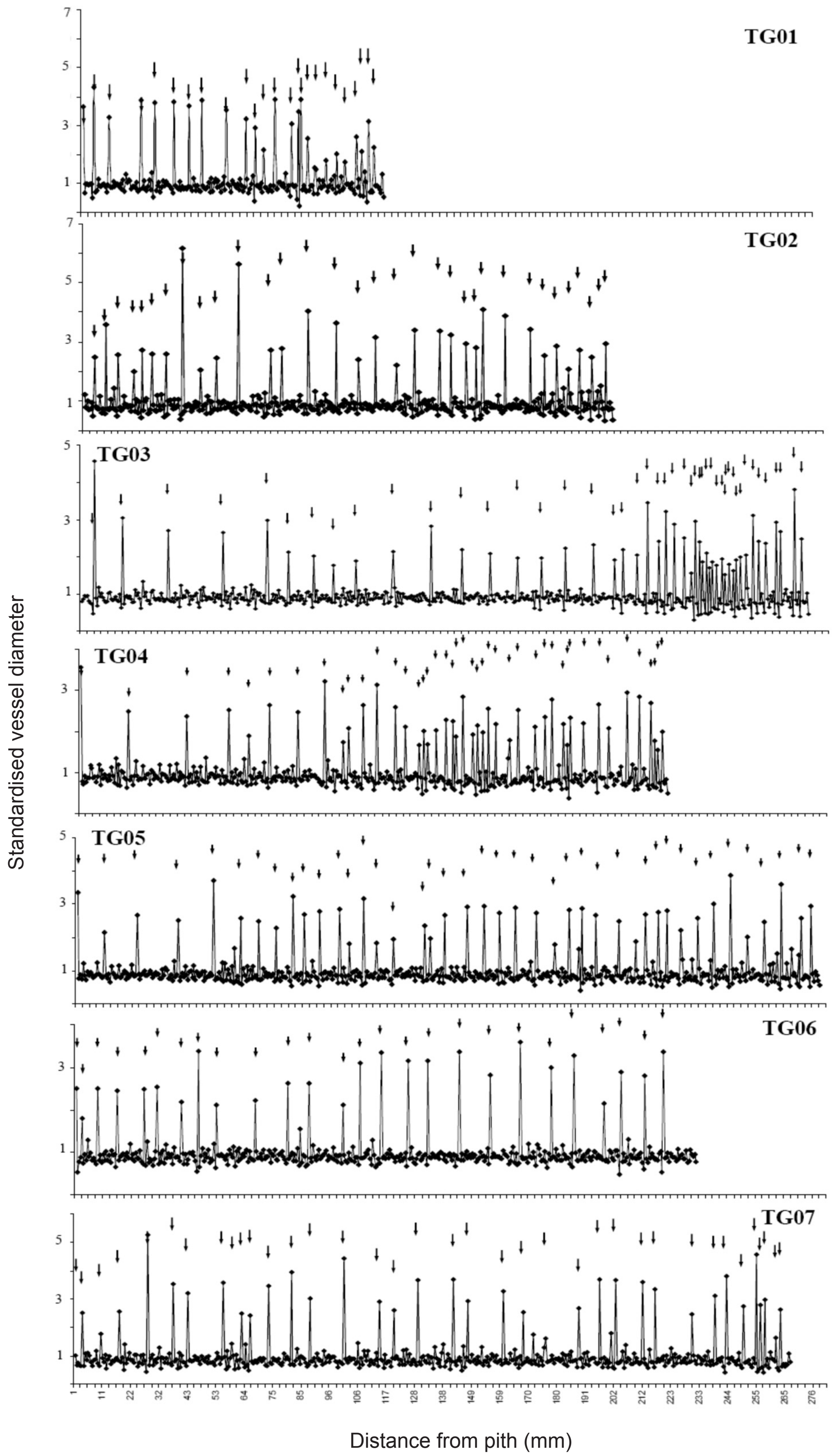

Figure 6 Standardised vessel diameters from the pith to the bark for the seven sample trees (TG01 to TG07); arrows indicate annual ring boundaries

more rows of paratracheal parenchyma and large vessels generated (Figures 7b and 8a). Two other features of false rings occurring in the latewood zone were defined as false ring type II. One was the aggregation of large vessels associated with one or more rows of paratracheal parenchyma after dense fibre formation (Figures 7c and 8b), and the other was small vessels scattered nearby dense fibre without paratracheal parenchyma (Figures 7d and 8c).

Relationship between climatic variability and false ring formation

False ring type I occurrence was approximately 85.7% in 1998 and less than 40% in the remaining growing years, i.e. from 1976 till 2008 (Figure 9). In 1979, 1981 and 1990 false ring type II was found in all wood cores. High amounts of false ring type II (80–100%) were also observed in 1977, 1982, 1984, 1988, 1993, 1996, 1997, 2002, 2005 and 2006. In the rest of the growing years, false ring type II varied within the range 0–80% (Figure 9).

There were several climatic data which were used to explore the significant correlation with false ring occurrences derived from teak wood cores growing from 1976 till 2008. The occurrence of false ring type I was significantly correlated with mean monthly maximum and mean temperatures in May ($p < 0.01$), with coefficients of determination (r^2) of 0.26 and 0.28 respectively. The average mean monthly maximum and mean temperatures from May till August and average monthly rainfall from January till April were significantly correlated with the occurrence of false ring type I at $p < 0.01$ and $r^2 = 0.29$, 0.24 and 0.18 respectively (Figure 10). However, using stepwise regression, the occurrence of false ring type I was not significantly related to the monthly rainfall, mean monthly minimum and grouped minimum temperatures.

The correlations between false ring type II and climatic data are shown in Figure 11. The frequency of false ring type II was significantly correlated with mean monthly maximum and mean temperatures in August and rainfall in July at $p < 0.01$ ($r^2 = 0.45$, 0.38 and 0.29 respectively). False ring type II was also significantly correlated with the average climatic data from May till August including mean monthly maximum and mean temperatures, and total monthly rainfall at $p < 0.001$ ($r^2 = 0.18$, 0.20 and 0.32 respectively).

False ring studies in juvenile teak showed that drought during active growing season stimulated false ring formation (Priya & Bhat 1998). This result was similar to findings in the current study although the procedures used to study false ring

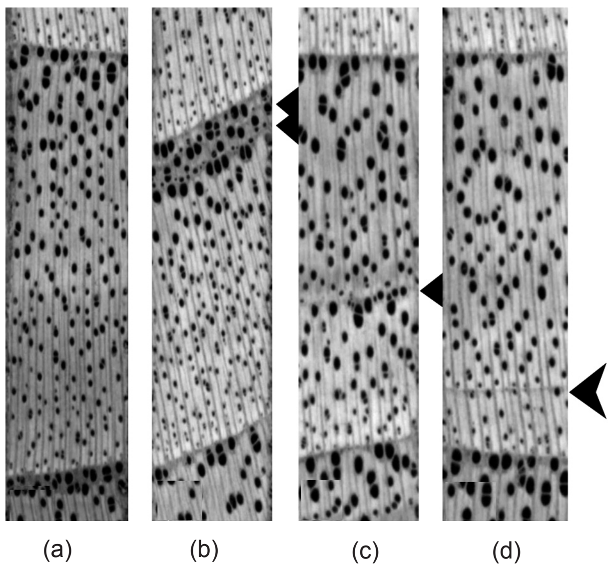

Figure 7 Macroscopic structures of false rings and their relative positions within annual tree rings of teak: normal annual ring (a), false ring type I in earlywood (b), false ring type II showing the aggregation of vessels multiplied with paratracheal parenchyma in latewood (c), false ring type II showing dense fibres with small vessels scattered nearby (d); arrowheads indicate false ring position

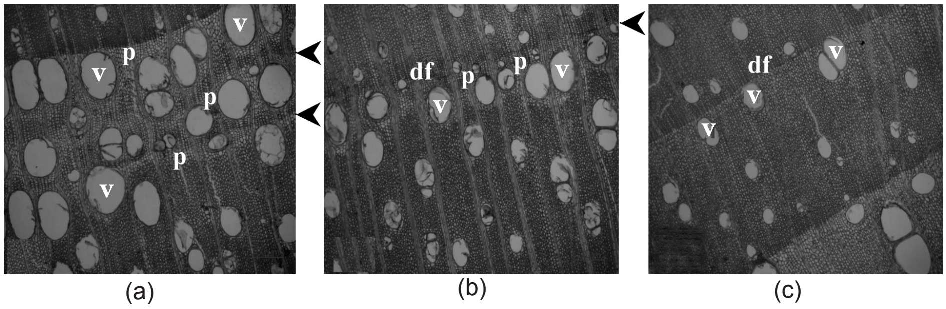

Figure 8 Microscopic structures of false ring in teak (10×): false ring type I (a), false ring type II: vessels (v) associated with paratracheal parenchyma (p) and dense fibre (df) in latewood (b), false ring type II showing dense fibres with small vessels scattered nearby (c); arrowheads indicate false ring position

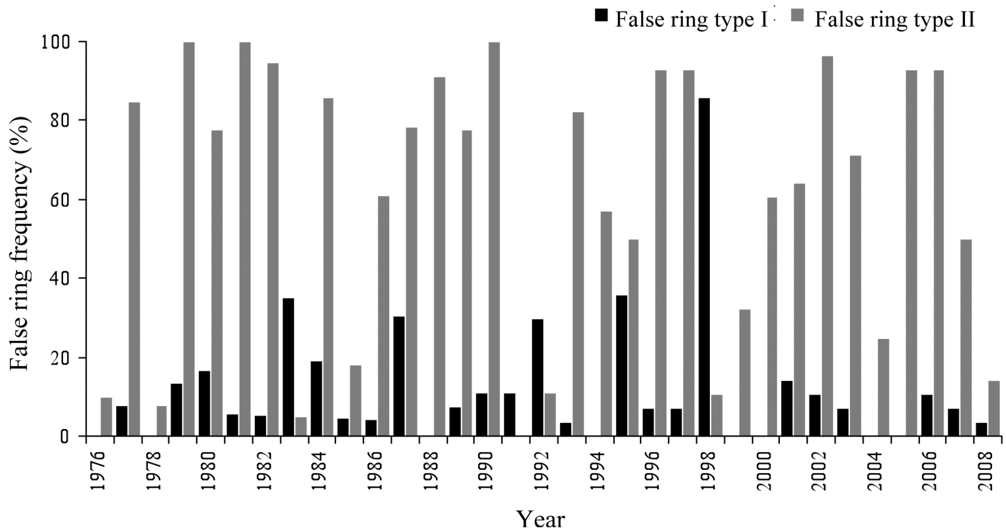

Figure 9 Frequency of false ring for each growing year

formation were different. Priya and Bhat (1998) simulated drought to induce false ring formation while we identified major climatic factors that induced false ring formation in natural stands.

It was suggested that drought at the beginning of the growing season following declination of the accumulated January till April rainfall and increment of the May till August temperature (especially in May) were the main factors affecting false ring formation in earlywood (false ring type I). This was similar to results reported by Priya and Bhat (1998) who stated that artificial drought during growing season was the cause for earlywood false ring formation. The decreased rainfall and increased temperature from May till August were also the main causes for false ring formation in latewood (false ring type II).

Although, heavy rainfall at the end of the growing period (September till October) did not show significant correlation with the occurrences of false ring type II, the availability of water and/or rainfall after drought induced the appearance of false ring in the latewood zone and this was also observed by Priya and Bhat (1998), Masiokas and Villalba (2004) and Campelo et al. (2006). To explain the occurrences of false rings based on water transport and water storage functions of earlywood and latewood, earlywood had lower water storage and higher water uptake capacities than latewood (Domec & Gartner 2002). Earlywood cells, generally differentiating in wet condition, are suitable for water uptake and transport at the beginning of the rainy season. On the other hand, latewood cells store water and are commonly found during dry period at the end of the growing season. The short period of drought in this study induced differentiation of latewood cells in order to store water for use during the rest of the growing period. However, heavy rainfall after the short drought induced

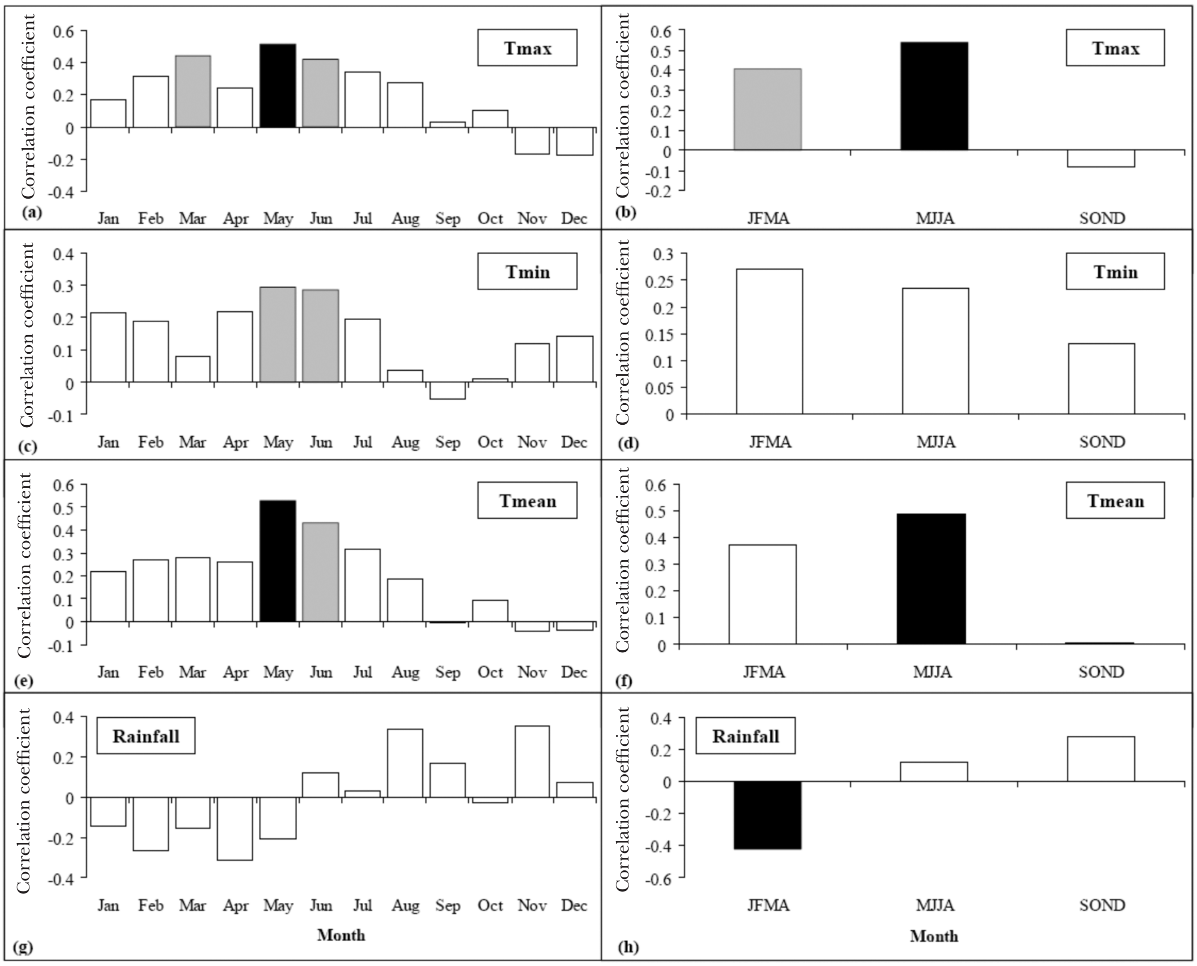

Figure 10 Climatic data and false ring type I relationship; correlation of false ring type I and mean monthly maximum (T_{max}) and grouped maximum temperatures (a–b), mean monthly minimum (T_{min}) and grouped minimum temperatures (c–d), mean monthly (T_{mean}) and grouped mean temperatures (e–f), and total monthly (Rainfall) and grouped rainfalls (g–h); black box indicates significant correlation ($p < 0.01$) using stepwise regression analysis, while grey box indicates only the correlation coefficient of simple correlation analysis

earlywood cell-like structures suitable for water uptake and transport in water-excess situation. The occurrences of actual earlywood cells at the beginning of the growing season followed by earlywood cell-like structures in earlywood and/or latewood when wet period was re-stimulated were the cause of false ring formation in each annual ring. Therefore, we could suggest that variability in natural climate—i.e. drought followed by wet period during the growing season—was the main factor that induced false ring appearances.

CONCLUSIONS

Two types of false rings were classified using their relative positions in earlywood (false ring type I) and latewood (false ring type II). The measurement of vessel diameters, combined with the use of wood anatomical features, were suitable to define annual ring and identify false ring occurrences in natural teak trees. The occurrences of both types of false rings could be explained by fluctuations of rainfall and temperature during the growing season, whereby drought followed by wet weather during the growing season caused the formation of false rings in natural teak trees.

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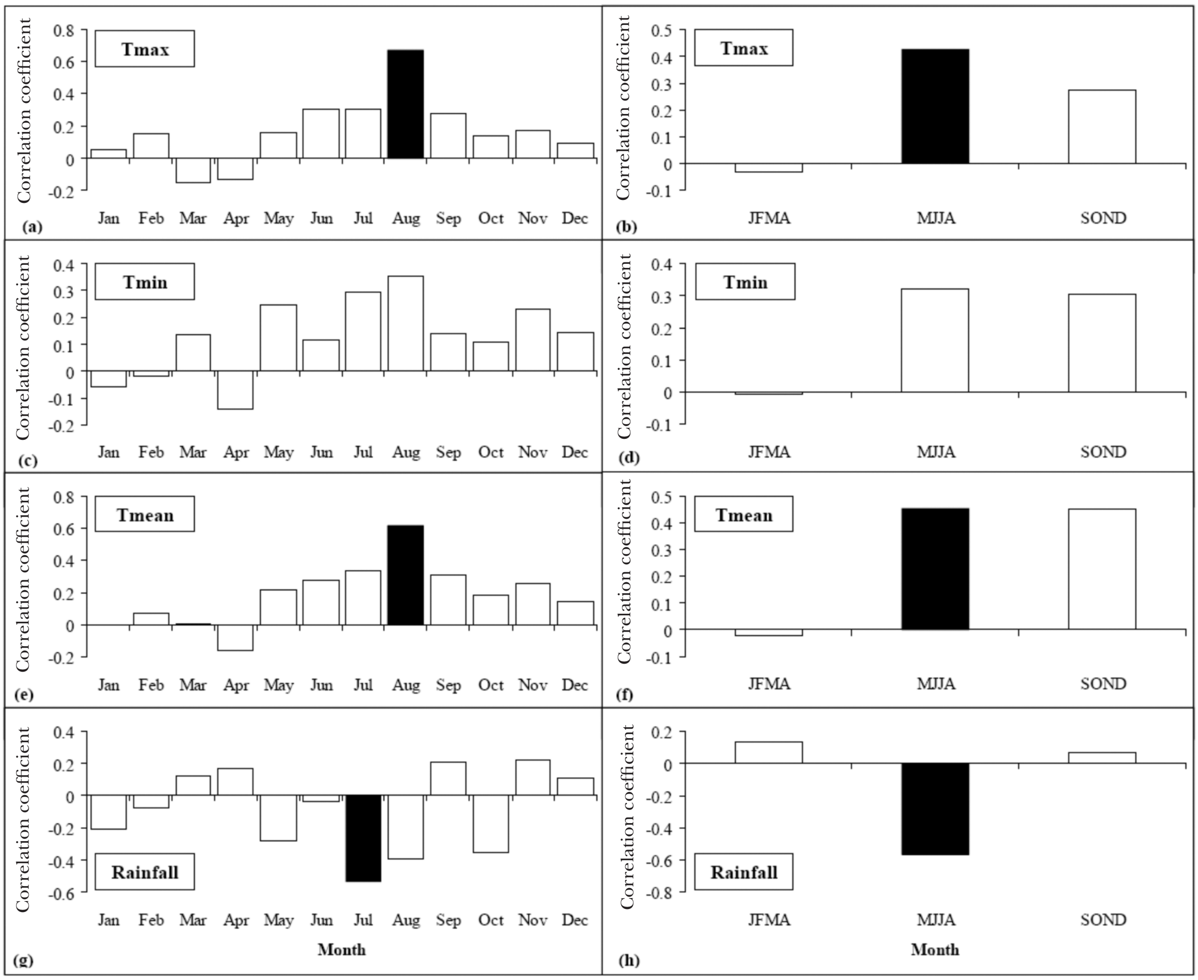

Figure 11 Climatic data and false ring type II relationship; correlation of false ring type II and mean monthly maximum (T_{max}) and grouped maximum temperatures (a–b), mean monthly minimum (T_{min}) and grouped minimum temperatures (c–d), mean monthly (T_{mean}) and grouped mean temperature (e–f), and total monthly (Rainfall) and grouped rainfall (g–h); black box indicates significant correlation ($p < 0.01$) by using both simple correlation and stepwise regression analysis

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