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Original Research Article

Natural weathering of eight important timber trade Mexican species

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Wood exposed to conditions such as sunlight and rain undergoes a phenomenon known as weathering. Colour change and cracks formation in the wood can be evaluated in order to determine the effect of environmental conditions. This study determined the natural weathering of the important trade timber species in Mexico *Cordia elaeagnoides*, *Dalbergia granadillo*, *Enterolobium cyclocarpum*, *Hura polyandra*, *Swietenia humillis*, *Tabebuia donell-smithii*, *Tabebuia rosea* and *Fagus sylvatica* as control. The procedure was performed according to EN 927-3. The action of environmental factors was monitored during five months with changes in appearance and colour and cracking formation also determined. The results indicated that *Cordia elaeagnoides* (ΔE19.7) and *Dalbergia granadillo* (ΔE 15.9) showed the lowest values in colour change.

Key words: Wood, tropical species, changes in appearance, Mexico, environmental conditions

INTRODUCTION

Wood production in Mexico reached 5.9 million m^3r (roll cubic meters) in the year 2012. Of this, more than 4% corresponded to tropical common and precious wood species (Semarnat, 2013); national production re-stock on 30% of the country's consumption, the rest is covered by imports; tropical woods represent 0.6% of imports (Financiera Rural, 2009).

Chapela (2012) notes that only a minority of tropical species has been widely used and many species have been partially used thus providing a great research area in order to determine the appropriate use of other tropical species for industrial purposes. The imports of furniture and wood components of Mexico amounted to US$ 263 million in 2011 (ITTO, 2012). Tropical hardwoods have many applications, all of them in the segments of higher value. The main uses are in fine furniture, mouldings, doors, windows, frames as well as the construction of musical instruments of high quality, interior decoration (parquet, plank,covers), wall coverings, columns and other surfaces. Wood veneer has multiple applications such as structures, economic wood or metal furniture coating.

Woods have great physical, mechanical and decorative qualities. However, wood exposed to biotic and abiotic factors lose its original qualities because of its organic nature (Sell and Feist, 1986; Zabell and Morell, 1992). The changes in colour (from its original condition to gray) are mainly due to solar radiation (ultraviolet, visible and infrared light) (George et al., 2005). The main chemical components of wood surface shows a transformation with the affected lignin producing carbonyl and carboxyl chromophoric compounds which results in the surface' colour transformation (Deka et al., 2008; Ghost et al., 2009). During weathering, extractives are moved toward the surface by water where they are partially oxidized (Lavoie and Stevanovic 2006). The fine surface of wood is also transformed by the formation of cracks and wobbling caused by the absorption and loss of moisture resulting in swelling and shrinkage (Sell and Feist, 1986; Williams and

Feist, 1993). Natural weathering of wood is gradual and significant variation exists between species due to differences in their chemical and density properties (William et al., 1990). The change in colour of wood exposed to sun and rains is influenced by the kind of extractives present in the cell wall (Pandey, 2005).

Schulte et al. (2004) while analyzing the effects of weathering on modified wood of *Pinus sylvestris* using untreated wood as control concluded that modified and unmodified wood are different. Hirche (2009) after 18 months of exposition of wood to natural weathering in *Pinus silvestris* L. established a pattern of the colour change in wood according to the position in which the wood was exposed. Schnabel et al. (2009) studied the variation in the colour of *Abies alba* and *Larix decidua* wood in two different localities and concluded that changes in colour are different between sites and regression analysis is a suitable method for modeling the effects. In another way Valverde and Moya (2010) evaluated the natural weathering of two coats in wood of *Cedrela odorata* and *Carapa guianensis*. The results showed that ΔE changes in both species were similar.

Mexico has numerous species of tropical woods with high potential to trade on the international market. However, there is a lack of information about its technological aspects including weathering. In order to increase information on natural weathering, this research elucidates the weathering process of important Mexican timber yielding species *Cordia elaeagnoides* DC*, Dalbergia granadillo* Pittier*, Enterolobium cyclocarpum* (Jacq.) Griseb, *Hura polyandra baill , Swietenia humillis Zucc, Tabebuia donell-smithii Rose, Tabebuia rosea* (Bertol) DC while using *Fagus sylvatica* as control.

MATERIALS AND METHODS

Origin of the study material

Heatwood free of damage and defects of the species *C. elaeagnoides* DC, *D. granadillo* Pittier, *E. cyclocarpum* (Jacq.) Griseb, *H. polyandra* Baill, *S. humillis Zucc*, *T. donell-smithii* Rose, *T. rosea* (Bertol) DC., and *F. sylvatica* were used to study the weathering process. The wood was provided by the Faculty of Wood Technology of the University of San Nicolas of Hidalgo in Michoacán, Mexico.

Study site

The field test was carried out at the Faculty of Forest Sciences of the Autonomous University of Nuevo León Campus Linares, Nuevo León México located on 24° 47´ N and 99 ° 32´ with an altitude of 384 m. The weather according to the Köppen, modified by García (2004) is classified as semi-arid and subhumid (A) C (Wo) with two rain periods (summer and fall). The National Water Commission reported an average rainfall of 2.1 mm/annum with a minimum average temperature of 16.3°C and maximum of 20.0°C for this region.

Weathering

The resistance to weathering was evaluated according to EN 927-3. Ten wood samples of 375 mm x 78 mm x 20 mm were prepared for each species and used in this study. The samples were conditioned in a climatic chamber at 20°C and 65% relative humidity. The samples were placed in 1m high racks inclined at 45° in a south direction to ensure that samples received sunlight for longer periods. Weathering was evaluated monthly from May to October 2013. The evaluation (study) period has the greatest amount of rainfall and solar luminosity values in the region.

Change in appearance

The change in appearance of the samples' surface was determined according to the standard ENpr 927-6. The samples were classified from 0 to 5 according to the weather effect. The value 0 corresponds to samples without any change in colour and 5 corresponds to the greatest change.

Change in colour

Changes in colour of the samples were determined according to the coordinates established by the International Commission on illumination (CIE Lab). "L" represents the brightness and its scale is from 0 (black) to 100 (white). The coordinate "a" corresponds to red colour with values from -a (red) to a (green), coordinate -b (yellow) to b (blue) (Brock et al., 2000). The samples were scanned six times; the first scan corresponded to upgraded samples without exposure to sunlight or precipitation. The other five scans were performed in 30, 60, 90, 120 and 150 days of exposition. The equipment was a scanner brand Brother Industries, Ltd ® model MFC 8890DW. The images were analyzed to obtain three data "L", "a" and "b" using the Adobe Photoshop ® CS software. Four values from each samples of each parameters L, a and b of each test were obtained from a systematic distribution on the x-coordinates (4.4, 4.12 4.20 and 4.28 cm) as shown in Figure 1. The change in colour (ΔE) of each samples were determined according to five successive scans after exposure to weather and the values were calculated with the following equation:

$$\Delta E=[(\Delta L^{*})^2 + (\Delta a^{*})^2 + (\Delta b^{*})^2]^{1/2}$$

Where:
ΔE= colour change
ΔL= difference between the values of initial brightness and after exposure.
Δa= difference between the values of "a" initial and after each exposure.
Δb= difference between the values of "b" initial and after each exposure.

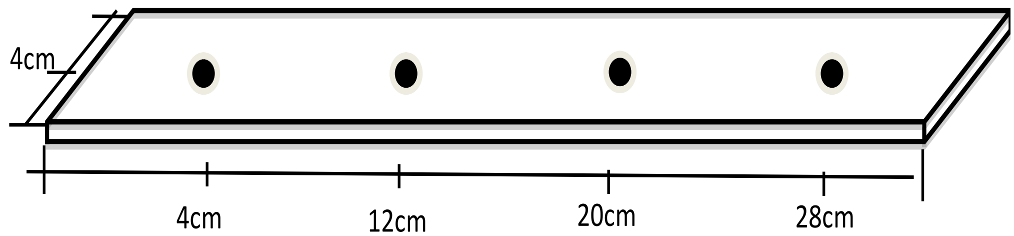

Figure 1: Dots corresponds the area where the L, a, and b values were obtained on each sample

Table 1. Craks classification

Class	Classification	Length of the cracks
0	No cracks	0
1	Fine and small cracks	<1/3 of L[1]
2	Long and wide cracks	1/3 to 2/3 of L
3	Continuous cracks	>2/3 of L

[1] Exposed area.

Cracks formation

The longest crack formed on each sample and on each scanned image was selected and measured on each scanned Figure 1. Measurements were taken with the Axion Vision Rel 4.8 software and the cracks were classified according to Schulte et al. (2004). Table 1 shows the classification of cracks.

Statistical analyses

The results of the colour change (ΔE) as well as the values of the length of the cracks were subjected to univariate variance analysis with factors species (8), number of scan (6), and position in the sample (4). The comparison of averages between the factors was carried out with the Tukey test (p ≤0. 05). All analyses were carried out using the statistical package SPSS version 20.

RESULTS

Change in appearance

Changes in appearance and colour of the species studied are shown in Figures 2 to 9. The change in appearance is shown in Figure 10. The species with greater appearance change after five months of exposition to natural weathering were *F. sylvatica* and *T. rosea* classified as class 5 (severe). *E. cyclocarpum* and *H. polyandra* exhibited a change in appearance class 4 (considered), *C. elaeagnoides* and *T. donell-smithii* showed a change in appearance class 3 (moderate) and *D. granadillo* and *S. humillis* showed a change in appearance class 2 (slight). The species *F. sylvatica* and *T. rosea* developed fungi on the surface, changing the colour of samples to dark (Figures 2 and 9). The same was reported by Kuhne et al. (1970), Sell and Leukens (1971) and Roux et al. (1988).

In addition to the weathering effect, some changes in appearance may result from microorganisms such as bacteria, mold and basidiomycetes. The pigments of these microorganisms appear in wood surface as humidity and luminosity (conditions) favor their growth (Hon and Minemura, 2001). *C. elaeagnoides, D. granadillo and S. humillis* (Figures 3, 4 and 7) showed a change in appearance after the first month of exposition and is in tandem with reports of Feist and Hon (1984).

Colour change

Values in colour change (ΔE) caused by natural weathering of wood are shown in Figure 11. The colour of the wood surface changed to grayish or dark in the first month itself (Figures 2 to 9). The results agrees with Feist (1983) and Sell and Leukens (1971). Changes in colour on wood surface may occur because of breaking of links of chemical compound derived from foto-oxidation reactions (Hon, 2001). Colour change was statistically different (p>0.0001) among species, months of exposition and interaction of species and month of exposition (Table 2). Mean comparison using Tukey's test shows seven statistical groups. Results of the analysis of variance on the change in colour (ΔE) values are also shown in Table 2.

Species with bigger ΔE on the last month were *T. rosea* (65.7) and the *F. sylvatica* (45.3). Species with a medium level of ΔE were *T. donell-smithii* (39.3), *S. humillis* (37.3), *E. cyclocarpum* (28.9) and *H. polyandra* (31.8) while those with low ΔE were *D. granadillo* (15.9) and *C. elaeagnoides* (19.7). Comparison between ΔE values obtained by "L", "a" and "b" for the first month were higher than the ΔE of the third month because of the minimum value of changes in

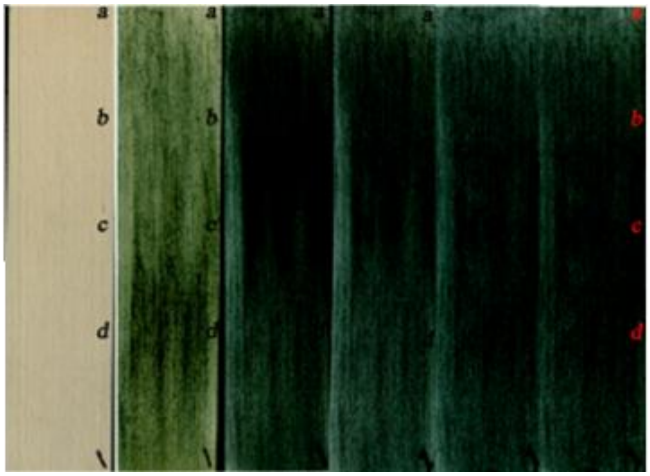

Figure 2: *Fagus sylvatica*

Figure 3: *Cordia elaeagnoides*

Figure 4: *Dalbergia granadillo*

Figure 5: *Enterolobium cyclocarpum*

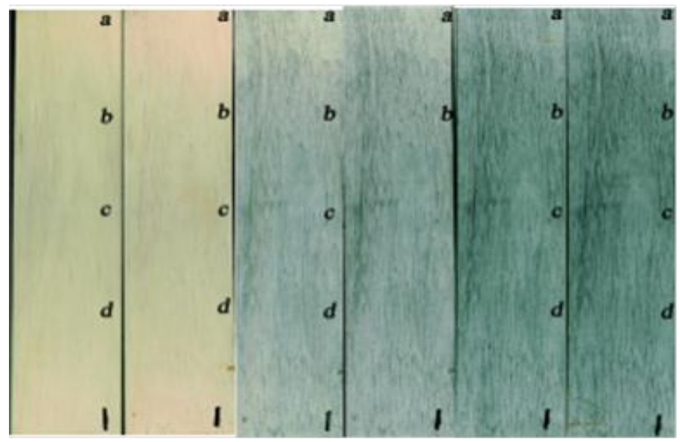

Figure 6: *Hura polyandra*

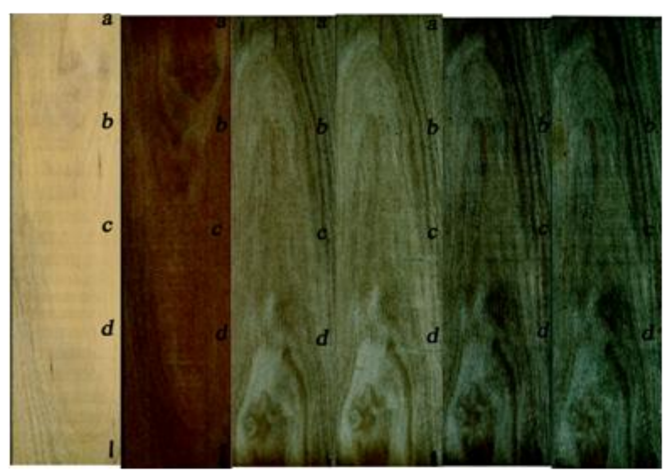

Figure 7: *Swietenia humillis*

the colouration of certain wood (Hon and Minemura 2001). In a study of artificial weathering, Baar and Gryc (2012) reported ΔE for the following South American tropical species: *Hymenaea courbaril* L. (11.34), *Manilkara bidentata* A. Chev (8.64), *Astronium graveolens* Jacsq *Vatairea*, spp. (18.68), *Hymenolobium* spp. (5.63) and *Dinizia excelsa*

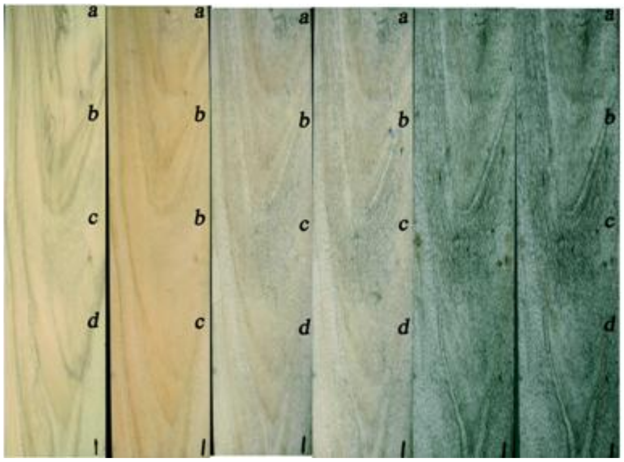

Figure 8: *Tabebuia donnel-smithii*

Figure 9: *Tabebuia rosea*

Ducke (12.72) after 144 h of exposure. On the other hand, Oliveira et al. (2007) obtained values of change in colour from tropical timbers *Tabebuia impeginosa* (2.95), *Mezilaurus itauba* (13.13). *Manilkara huberi* (6.04), *Bagassa guianensis* (15.47) and *Couratari* spp (3.69) after 2,000 h of radiation and 400 h of leaching. Values of ΔE 35 were reported for *Cedrela odorata* and *Carapa guianensis* after exposure to natural weathering for 200 days (Valverde and Moya, 2010).

Results from this study are consistent with Sandermann and Schlumbom (1962), Pandey (2005) and Hon (2001) and the order of change in colour of wood is dependent on wood species. On the other hand, Schnabel et al. (2009) found significant differences in the colour change of wood of the same species exposed to different atmospheric conditions.

Changes in values L*, a*, y and b*

Changes in luminosity of the wood were presented after the first month of exposition (Figure 12). The change in luminosity was statistically different ($p<0.0001$) between species, month of exposition and interaction species and month of exposition, as shown in Table 3. Means comparison using Tukey's test shows seven statistical groups. Change in luminosity after the fifth month of exposition was thus: *T. rosea* (- 84.5%), *F. sylvatica* (- 57.5%), *S. humillis* (- 35.4%), *H. polyandra* (-30.8%), *E. cyclocarpum* (-26.9%), *T. donell-smithii* (- 26.0%), *C. elaeagnoides* (- 8.6%) and *D. granadillo* (6.9%). Change in luminosity reported by Carrillo (2007) on the artificial weathering *F. sylvatica* was - 3% which is in contrast to values found in the present study (- 57.5%) because of the proliferation of microorganisms that causes wood staining thus, its consequent loss of brightness. In this study, the clear colour of woods (*F. sylvatica, H. polyandra, T. donell-smithii, T. rosea*) changed to a dark colour, while dark woods (*C. elaeagnoides, D. granadillo, S. humillis*) changed to a mixture of dark and opaque. This is consistent with that described by Hon and Minemura (2001).

Cordia elaeagnoides, D. granadillo and *S. humillis* (Figures 3, 4 and 7) showed a reduction in luminosity (wood darkening) after the first month of exposition while in months two and three the luminosity rises again and finally declined. Similar behaviour was reported by Feist and Hon (1984) who established that weathering of wood occurs at an early stage where the colour becomes more obscure because extracts migrate to the surface, followed by photo-decomposition of those chemical components and leaching. These changes occur at depths ranging from 0.05 to 2.5 mm.

The values of "a" for all species except *F. sylvatica* and *T rosea* increased on the first month of natural weathering (Figure 13). Values from the second month showed a reduction as a result of spots on their surfaces caused by fungi growth and the values in the subsequent months showed a steady decline to near-zero values. Values of "b" were different between species in the first month. *D. granadillo*, *T. donell-smith* and *T. rosea* showed increased "b" values, while *E. cyclocarpum* and *S. humillis* had reduced values. Finally *F. sylvatica, C. elaeagnoides* and *H. polyandra* presented similar values where during the following months "b" values were reduced (Figure 14). Natural weathering performed by Valverde and Moya (2010) and Schnabel et al. (2009) in two tropical timber species showed similar behavior as shown in this study. The values of the variables colour "a" and "b" reduced and after a period of exposition changes in colour tend to remain constant.

Cracks formation

After the first month of exposition, all the specimens started to show cracks with the exception of *H. polyandra*. Figure 15 shows the classification of cracks formation after five months of exposure. The species *H. polyandra* presented a value type 0 (no cracks) while other species showed type 1 (L1 <1/3) and was classified as small

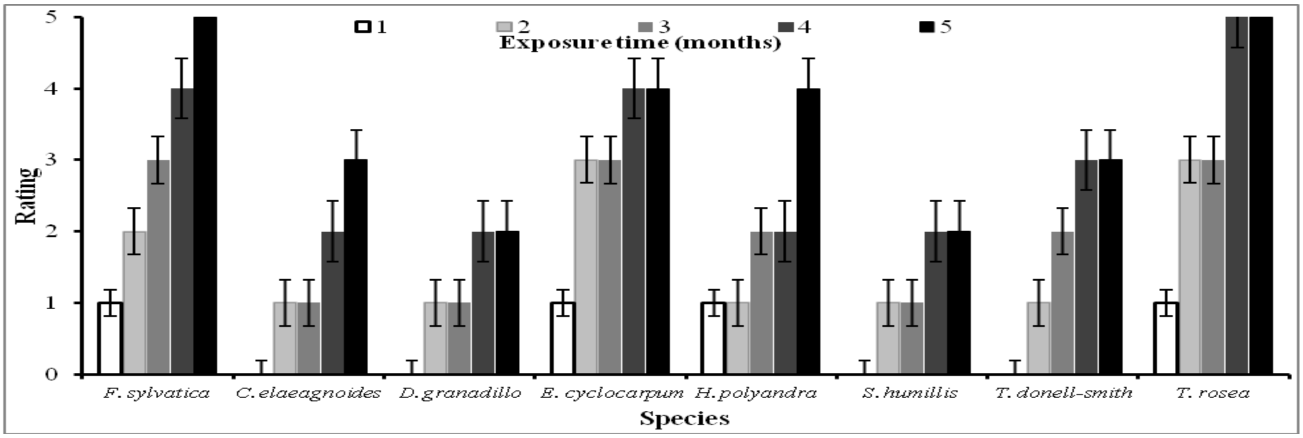

Figure 10: Rating of appearance of eight important trade timber species of Mexico after five months on natural weathering

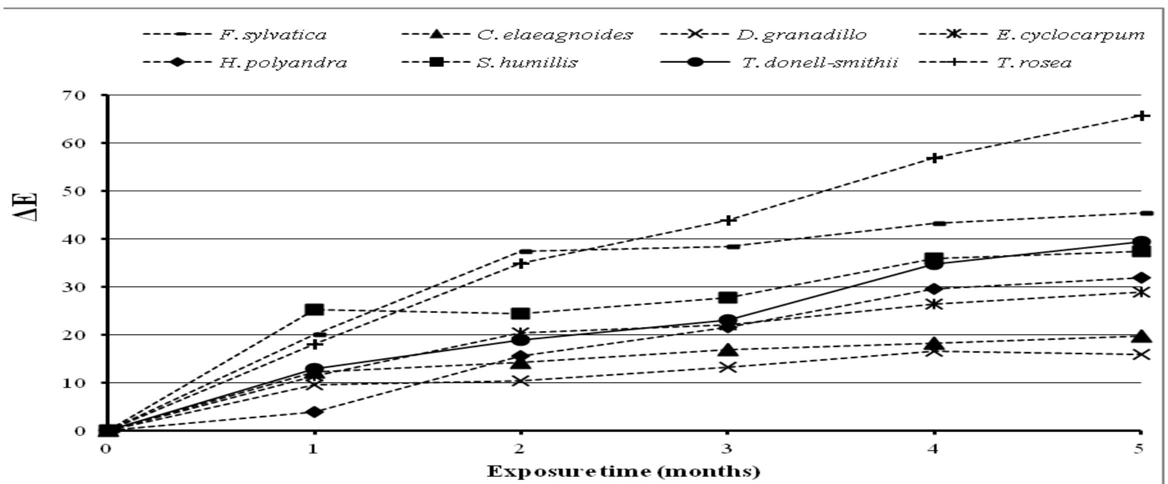

Figure 11: Color change of eight important trade timber species of Mexico after five months on natural weathering

Table 2. Summary of the analysis of variance of color change of eight timber species of Mexico

Variation source	Sum of squares	D.F.	Quadratic mean	F	Sig.
Model	280571.547[a]	39	7194.142	147.780	.000
Intersection	1081042.985	1	1081042.985	22206.546	.000
Specie	152511.984	7	21787.426	447.552	.000
Month	93304.556	4	23326.139	479.160	.000
Specie * Month	34725.824	28	1240.208	25.476	.000
Error	75942.791	1560	48.681		
Total	1437069.390	1600			
Total corrected	356514.337	1599			

a. R^2 = .787 (R^2 Corrected = .782)

(Figure 15). The cracks formation occurred in greater proportion after the third month but was lower after the fourth month. Cracks formation was statistically different ($p<0.0001$) between species, month of exposure and interaction between species and duration of exposition. The results of the analysis of variance on crack formation value are presented in Table 4.

Hura polyandra, *E. cyclocarpum* and *S. humillis* presented the lowest percentage of cracks increase (0%, 1.3% and 3%, respectively) whereas *C. elaeagnoides* and *T. donell-smithii* recorded the highest percentages of 14 and 20%, respectively (Figure 16). Formation of micro-cracks may be

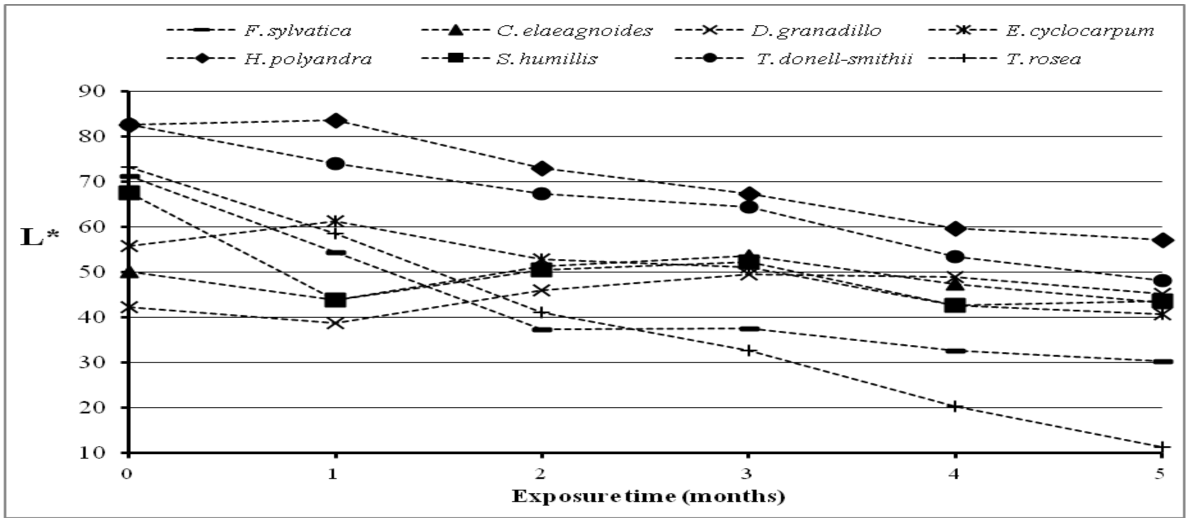

Figure 12: Reduction of luminosity of eight important trade timber species of Mexico

Table 3. Summary of the analysis of variance of results of luminosity of eight timber species of Mexico

Variation source	Sum of squares	D.F.	Quadratic mean	F	Sig.
Model	446480.412a	47	9499.583	175.732	.000
Intersection	5127503.563	1	5127503.563	94853.346	.000
Specie	192780.908	7	27540.130	509.463	.000
Month	139272.546	5	27854.509	515.279	.000
Specie * Month	114426.958	35	3269.342	60.479	.000
Error	101195.025	1872	54.057		
Total	5675179.000	1920			
Total corrected	547675.437	1919			

a. R^2 = .815 (R^2 Corrected= .811)

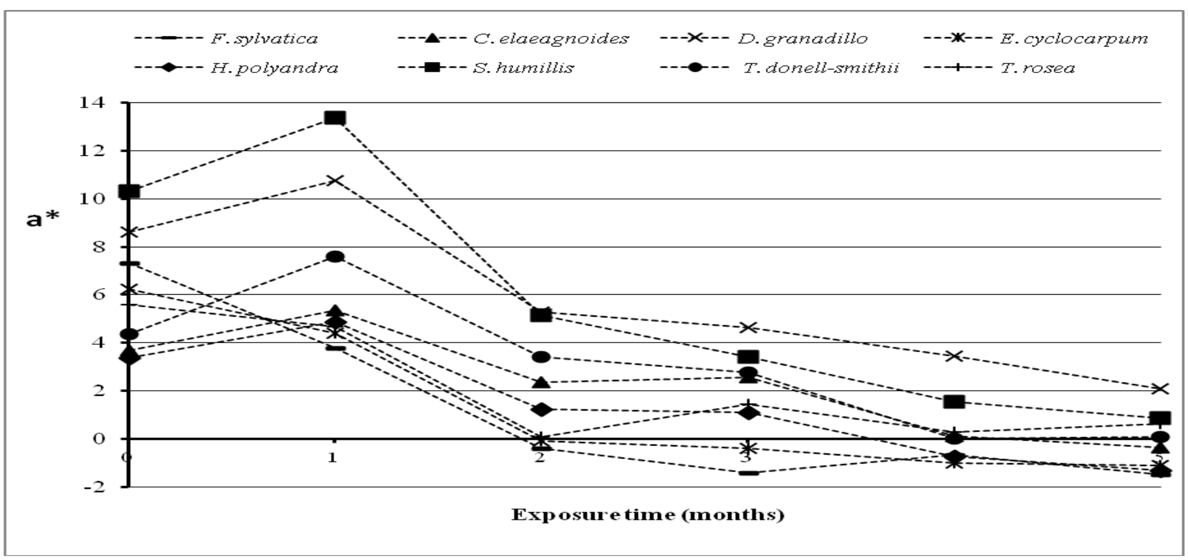

Figure 13: Color change of variable "**a***" on eight important trade timber species of Mexico

the result of combined effect of water absorption and degradation of lignin which causes a change in tension among fibers (Sandberg and Soderstrom, 2006). In a similar test, Kueera and Sell (1987) described a formation of

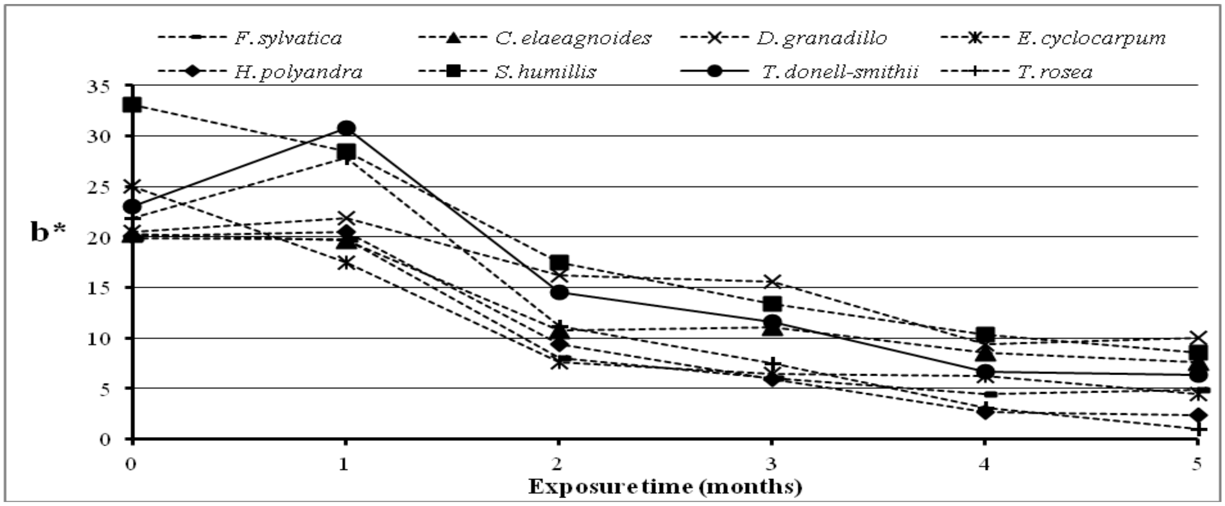

Figure 14: Change of "b*" on eight important trade species of Mexico

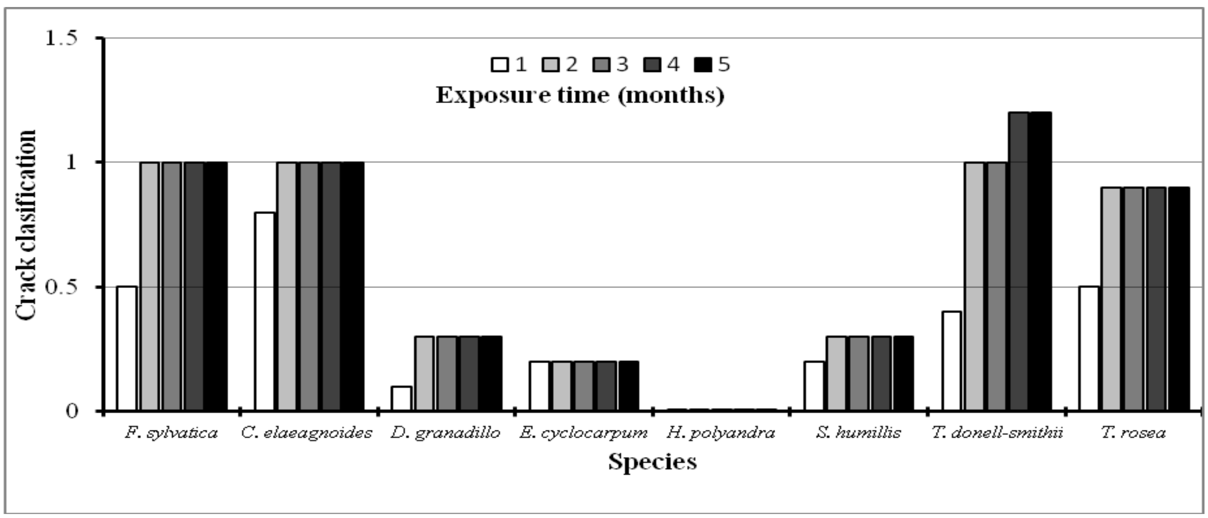

Figure 15: Cracks classification on eight important trade species of Mexico
The species *H. polyandra* presented a value type 0 (no cracks) while other species correspond to type 1 (L1 <1/3) classified as small.

Table 4. Summary of the analysis of variance of craks formation of natural weathering of eight timber species of Mexico

Variation source	Sum of squares	D.F.	Quadratic mean	F	Sig.
Model	405.894a	7	57.985	9.937	.000
Intersección	650.541	1	650.541	111.486	.000
Specie	405.894	7	57.985	9.937	.000
Error	420.133	72	5.835		
Total	1476.569	80			
Total corrected	826.027	79			

a. R^2 = .491 (R^2 corrected = .442)

rupture areas because of fragility of rays on tangential section and the natural movement of the wood (swelling and shrinkage).

DISCUSSION AND CONCLUSIONS

Natural weathering modified the appearance of wood in the

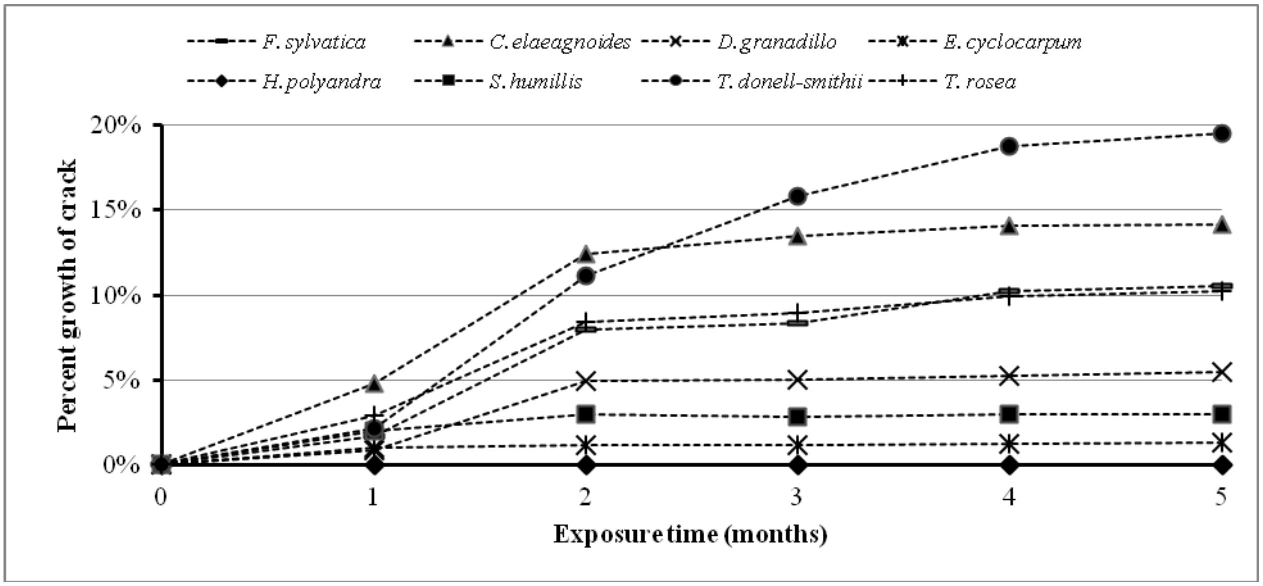

Figure 16: Cracks formation after natural weathering of eight important trade species of México

sampled species at different magnitudes. The species *F. sylvatica* and *T. rosea* had an effect class 5 (severe), *E. cyclocarpum* and *H. polyandra* exhibited an effect class 4 (considered), while in *E. elaeagnoides* and *T. donell-smithii* the effect was classified as class 3 (moderate). Finally *D. granadillo* and *S. humillis* had effect class 2 (slight). Wood exposed to natural weathering was transformed to gray or dark colour. The change was detected after the first month of exposition. The species that exhibited greater difference in colour change were *T. rosea* (ΔE 65.7) and *F. sylvatica* (ΔE 45.3). In the lower affected class *T. donell-smithii* (ΔE 39.3), *S. humillis* (ΔE 37.3), *E. cyclocarpum* (ΔE 28.9) and *H. polyandra* (ΔE 31.8) were grouped while *D. granadillo* (ΔE 15.9) and *C. elaeagnoides* (ΔE 19.7) presented the lowest values. Loss of brightness was recorded in *T. rosea* (-84.5%), *F. sylvatica* (- 57.5%), , *S. humillis* (-35.4%), *H. polyandra* (- 30.8%), *E. cyclocarpum* (-26.9%), *T. donell-smithii* (-26.0%), *C. elaeagnoides* (-8.6%) and *D. granadillo* (6.9%). Natural weathering effect was enhanced by fungi infection on the surface of *F. sylvatica* and *T. rosea*. The species with dark colour wood such as *C. elaeagnoides*, *D. granadillo* and *S. humillis* changed from dark to opaque. The cracks formation, type1 (<1/3 L1) was observed in all species with the exception of *H. polyandra* and qualified as type 0. The data obtained will provide a baseline data for further research on quantitative and qualitative descriptions in changes in appearance and colour of tropical species.

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