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The Effect of Climate on Fiber Properties of Maple Wood (*Acer velutinum* Boiss)

Reza Bakhshi, Majid Kiaei and Samane Veylaki

Department of Wood and Paper Science and Technology,
Islamic Azad University (IAU), Chalous Branch (IRI)

Abstract: The influence of climate on the fiber length, fiber diameter and cell wall thickness of maple wood (*Acer velutinum Boiss*) was studied. A total of 5 normal maple trees were sampled in Khanican forests (north part of Iran). Disks were taken at breast of stem height. Fibers of the early wood from each ring (1978 o 2005) were separated by Jeffrey's solution method and the dimensions of fibers were measured by Leica Image Analyzer. To determine the response to the climate, correlation coefficients (Pearson correlation) between fiber properties and climatic data were calculated during biological years from October of the previous year to September of the current year. Results of Pearson correlation showed that the climate condition had no effect on fiber length and fiber cell wall thickness and had significant effect on the fiber diameter. The fiber diameter correlated with the monthly total precipitation of November, June and August and monthly maximum temperature of August and November. In addition, the relationship between fiber diameter and monthly minimum temperature of January and monthly mean temperature of August were negative and positive, respectively. The significant variables obtained from Pearson correlation results were analyzed by forward stepwise. Results of forward stepwise indicated that the fiber diameter values was related to precipitation of November (52.9%), precipitation of August (19.6%), minimum temperature of January (5.6%) and maximum temperature of November (4.4%).

Key words: *Acer velutinum* · Climate · Fiber length · Fiber diameter · Cell wall thickness

INTRODUCTION

The Northern forest of Iran stretches from Astara in the northwest of Giulan province to Golidagh in the east of Golestan province. The length of these forests is 800 km and the width is 20 to 70 km. The Caspian forests (Hyrcanian) comprise a little more than 2.1 million hectares of almost 100 percent hardwoods, primarily beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*). Other marketable species include maple (*Acer velutinum*), oak (*Quercus castanefolia*), alder (*Alnus subcordata*), elm (*Ulmus glabra*), ash (*Fraxinus excelsior*) and iron wood (*Parrotia persica*). The small percentage of softwoods include cypress (*Cupresuss sempervirens*), juniper (*Juniperus polycarpos*) and yew (*Taxus bacata*) [1].

The width of tree rings is the anatomical trait that is traditionally used in dendrochronology for studying forest dynamics, dating geodynamic processes, or reconstructing past climate variations [2,3]. The variations in the environmental conditions can also be inferred by other wood characteristics such as the composition of stable isotopes [4,5] density [6,7] or by micro-anatomy [8]. One of the important advances in dendrochronological studies has been the inclusion of anatomical variables, which, in addition to tree-ring width, expand dendrochronologic methods for solving numerous environmental problems [9].

Climate variations induce changes in the growth of trees, which are reflected in the particular anatomy of the tree rings [10]. Characteristics of the conduction fiber properties and vessel elements, such as their diameter and length, their density, the thickness of their cellular wall and their organization within the ring (e.g., their grouping and changes in size to prevent collapse during adverse conditions) may indicate responses of tree-ring anatomy to variable environmental conditions [11]. The precise chronological assessment of these variables in the wood of trees provides the basis for improving our knowledge about seasonal changes in the anatomical properties of wood and consequently the derivation of climatic information from these characteristics.

Corresponding Author: Majid Kiaei Department of Wood and Paper Science and Technology, Islamic Azad University (IAU), Chalous Branch (IRI).

Some studies suggested that there is great potential for using these anatomical characteristics of wood to characterize past environmental conditions [12], including precipitation [8, 13-15] and temperature [15, 16]. In this direction, Silkin *et al.* (2003) explained that the mass of earlywood tracheids of larch trees correlates positively with June temperature and latewood cell mass with June and July temperatures [17]. Also, Giantomasi *et al*. (2009) reported that the width of the rings, the number of vessels and the total area of vessels were positively influenced by regional precipitation corresponding to the seasonalized November to December period, which reflects the importance of the water availability in the initial stage of the formation of the wood. The width of the rings and the total area of vessels of *Prosopis flexuos*a were negatively influenced by temperature during the same period, while the number of vessels was not significantly correlated with temperature [18].

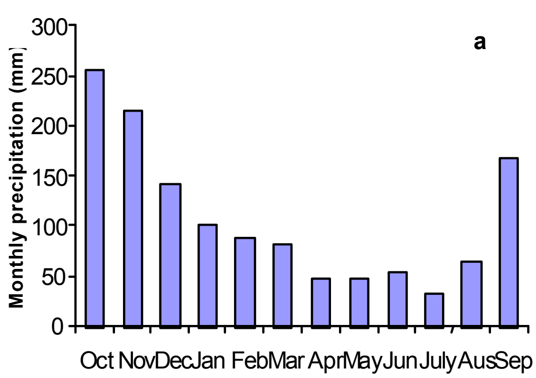
There has been a lack of dendrochronological studies based on the length and diameter of fibers and fiber cell walls thickness. Thus, we describe the development of chronologies based on dimensions of fibers per tree ring of *Acer velutinum Boiss* from the north region of Iran and we assessed the influence of climate on these variables.

MATERIALS AND METHODS

A total of 5 maple trees (*Acer velutinum* Boiss) were sampled in Khanican forests (Noshahr province in north of Iran). All the trees were randomly selected, taking into account stem straightness and the absence of obvious decay. The sample disks were taken at breast height. The age and diameter of all trees was 55 to 60 years and 30 to 35 cm, respectively. Study area was located at 51º 27' 45"-51º 23' 45" E longitude and 36º 37' 45"–36º 33' 15" N latitude. The altitude of sea level for this site was 100 m. The soil texture of this region was clay to clay-loam with a clay percentage of 30 to 35%. The annual rainfall and annual average temperature (1978-2005) was 1302 mm and 16 °C, respectively. October (256 mm) and November (216 mm) are high-rain months and July (32.6 mm) is a low-rain month. The mean monthly temperature reaches its maximum level in August (25.4 °C) and July (25.2 °C). The mean of monthly maximum temperature and monthly minimum temperature was 19.5 and 12.7 °C for Noshahr site. The monthly mean temperature, monthly minimum temperature, monthly maximum temperature and monthly total precipitation are shown in Fig. 1. The climate data were obtained from the Iranian meteorological organization.

A disk, 5 cm in thickness, was removed from each tree at breast height level for evaluation of fiber dimension properties. The fiber dimensions of the early wood of every ring from the radial direction (from 1978-2005) were measured for each of the tree samples disks. After macerating them with Jeffrey's solution (10% nitric acid: 10% chromic acid: water, 1: 1: 18), the dimensions of 20 fibers (fiber length, fiber diameter and fiber cell wall thickness) of every ring were measured using the Leica Image Analysis System.

Pearson's correlation analyses were used to explore the climate (monthly mean temperature, monthly total precipitation, monthly maximum temperature and monthly minimum temperature) and fiber dimensional relationships. To determine statistical difference, correlations were used at the 0.01 and 0.05 levels. The relationship between the significant variables obtained from Pearson correlation results and fiber diameter (there are no relationship between climate condition and fiber length and cell walls thickness in results of Pearson correlation) were measured by a forward stepwise procedure, which has the ability to categorize the significant variables. In this calculation, biological year, which is from October of the previous year to September of the current year [2], was used.



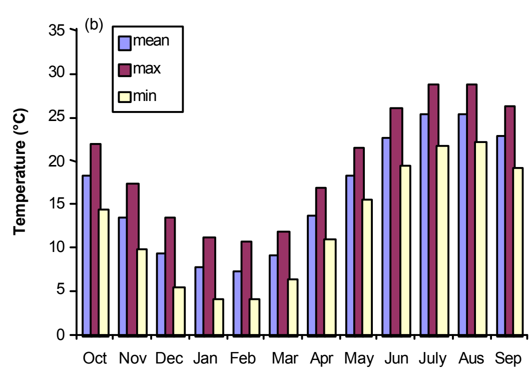


Fig. 1: Variations of monthly mean temperature and precipitation from 1978-2005

RESULTS AND DISCUSSION

Fiber Properties: Table 1 shows the results of the descriptive statistics for the fiber length, fiber diameter and single cell wall thickness of maple wood. Results of ANOVA indicated that there were significant differences between radial position (age cambium) versus fiber length, fiber diameter and fiber cell wall thickness at the 0.01 level. The fiber length, fiber diameter and single cell wall thickness values increased with increasing age of the cambial tissue (Fig. 2), as reported previously by Hossini and Naghdi 2004; Panshin and de Zeeuw (1980); Zobel and van Buijtenen (1989); and Quilhó *et al*. (2006) [19-22]. As is already known, fiber properties are important indicators for pulp and papermaking production. The cell size and relative cell dimensions have a major influence on the quality of pulp and paper products as well as solid wood products [23]. Fiber length and width, single wall thickness and lumen size have an effect on the bulk, burst, tear, fold and tensile strengths of paper [24]. For pulp and paper production, species with higher lengths are preferred, since a better overall fiber length is achieved, resulting in a higher resistance of the paper [20, 21, 24, 25]. These traits were seen in ring samples near to the bark of trees, where there tended to be higher fiber length compared to the ring samples the near of tree pith.

Table 1: Descriptive Statistics of Fiber Properties of Maple Wood

Fiber properties	Fiber length(μm)	Fiber diameter (μm)	Single cell wall thickness (μm)
Mean	1016.17	22.570	3.940
Max	1717.52	48.440	12.850
Min	117.23	9.980	1.590
Standard deviation	253.19	4.780	1.050
Standard error	10.69	0.202	0.044

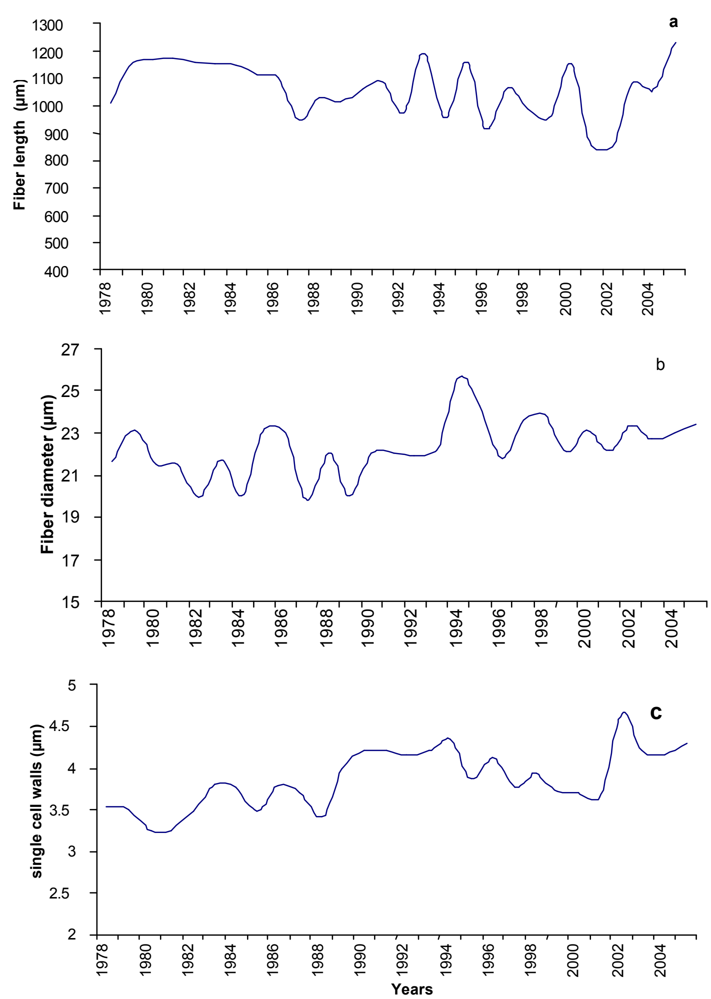


Fig. 2: Variations of fiber length (a), fiber diameter (b) and cell wall (c) in radial axis

Table 2: Correlation Coefficients between the Climate and Fiber Length of Maple Wood

Months	Precipitation	Mean temperature	Minimum temperature	Maximumtemperature
October	-0.144	0.103	0.049	0.147
November	-0.044	0.151	0.155	0.147
December	0.111	-0.101	-0.184	-0.013
January	-0.038	0.023	-0.134	0.136
February	0.149	-0.327	-0.257	-0.35
March	-0.012	-0.342	-0.358	-0.279
April	-0.26	0.134	0.002	0.192
May	-0.164	0.122	-0.041	0.14
June	-0.007	-0.078	-0.077	-0.073
July	-0.115	0.257	0.347	0.135
August	-0.079	-0.166	-0.233	-0.112
September	-0.08	0.017	0.038	-0.007

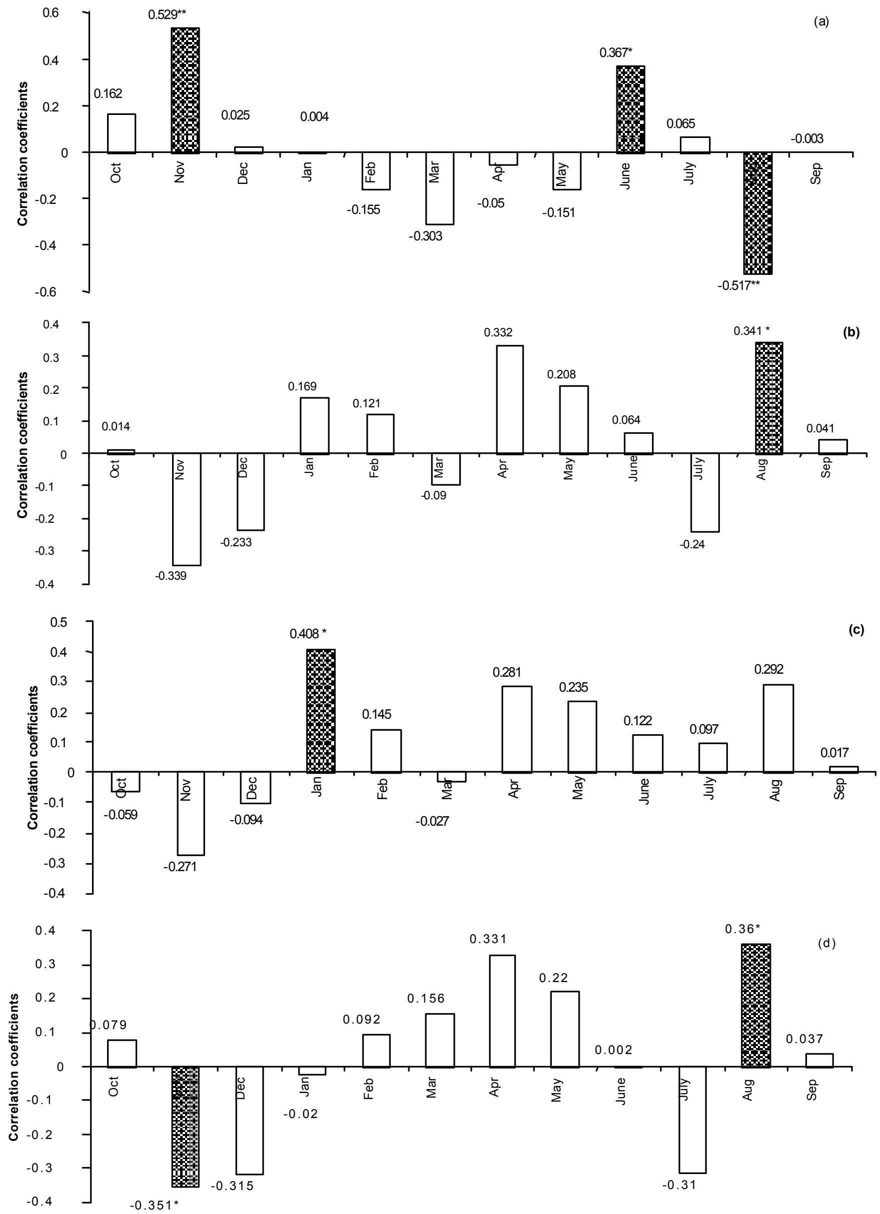


Fig. 3: Pearson correlation between fiber diameter and precipitation (a), mean temperature (b), minimum temperature (c), maximum temperature (d), **: at level 0.01, *: at level 0.05

The mean of fiber length was 1016.17 ± 253.19µm; the fiber diameter was 22.57 ± 4.78 µm and the single cell thickness 3.94±1.05 µm. The mean fiber length of maple wood in Noshahr site (this study) was larger than the fiber length at the Noor site (870.26 µm) [26] and less than those of the Gorgan site (1036 µm) [19]. Also, the mean fiber length of maple wood was smaller than the fiber length of beech (1214 µm) [27] and hornbeam wood (1714 µm) [28]. The Iranian industrial factories use from hornbeam, beech and maple for papermaking productions.

Relationship between the Climate and Fiber Length: The relationships between the climate and fiber length of maple wood are shown in Table 2. Results of Pearson correlation show that there weren't any significant relationships between the climate (temperature and precipitation) and fiber length. In all of relationships between climate and fiber length, the highest and lowest of correlation coefficients were found between fiber length and monthly minimum temperature of March (R = -0.358) and fiber length-monthly minimum temperature of April (R = 0.002), respectively.

Relationship between the Climate and Fiber Diameter: The relationships between the monthly precipitation and fiber diameter of maple wood are shown in Fig. 3a. Results of Pearson correlation showed that there were positive correlations between fiber diameter and monthly precipitation of November (R = 0.529) and June (R = 0.367) and a negative correlation between fiber diameter and monthly precipitation of August (R = -0.517). The highest and lowest of correlations between monthly precipitation-fiber diameter were found in November and September months (R = -0.003), respectively.

The relationship between the monthly mean temperature and fiber diameter of maple wood are shown in Fig. 3b. Results of Pearson correlation showed that there were positive correlations between fiber diameter and monthly mean temperature of August (R = 0.341). The highest and lowest of correlations between monthly mean temperature-fiber diameter were found in August and October months (R = 0.014), respectively.

The relationships between the monthly minimum temperature and fiber diameter of maple wood are shown in Fig. 3c. Results of Pearson correlation show that there are positive correlations between fiber diameter and monthly minimum temperature of January (R = 0.408). The effect of this variable from April to September on fiber diameter was positive, but very low and not significant. The highest and lowest of correlations between monthly minimum temperature-fiber diameter were found in January and September (R = 0.017), respectively.

The relationships between the monthly maximum temperature and fiber diameter of maple wood are shown in Fig. 3d. There were positive correlation between monthly maximum temperature of August and fiber diameter (R = 0.36) and negative correlation between fiber diameter and monthly maximum temperature in November (R = -0.351). The effects of maximum temperature from February to June on fiber diameter were positive. But these correlations are very low and not significant. The highest and lowest of correlations between monthly maximum temperature-fiber diameter were found in August and June months (R = 0.002), respectively.

According to the results of Pearson correlation, the effects of seven variables (precipitation during November, June and August, monthly mean temperature of August, monthly minimum January, monthly maximum temperature of November and monthly maximum temperature of August) on fiber diameter were significant. The effects of these seven variables on the fiber diameter were analyzed by a forward stepwise procedure. Multiple correlation analysis (Table 3) showed that the fiber diameter value was related to precipitation of November (52.9 %), precipitation during August (19.6 %), minimum temperature of January (5.6 %) and maximum temperature of November (4.4 %). Based on these results, we can conclude that the rainfall has an important role on the

Table 3: Multiple Correlation Analysis for the Relationship between Fiber Diameter and Climate Condition of Maple Wood in Iran

	Correlation parameters			
Properties	1st	2nd	3rd	4th
Fiber diameter** R = 0.908a	Precipitation of November** 0.529 b	Precipitation of August **0.196	Minimum temperature of January **0.056	Maximumtemperature ofNovember **0.044

** Statistically significant at 99% confidence; * statistically significant at 95% confidence; a Multiple correlation coefficient; b Contribution of the parameter to the coefficient of determination (r^2)

Table 4: Correlation Coefficients between the Climate and Cell Wall Thickness of Maple Wood

Months	Precipitation	Mean temperature	Minimum temperature	Maximumtemperature
October	0.024	0.178	0.079	0.265
November	0.254	0.017	-0.174	0.104
December	0.1	-0.204	-0.113	-0.256
January	-0.115	-0.077	-0.005	-0.12
February	0.096	-0.032	-0.049	-0.018
March	0.023	0.25	0.262	0.214
April	0.279	-0.088	-0.126	-0.05
May	-0.298	-0.061	0.028	-0.016
June	0.198	-0.07	-0.009	-0.12
July	-0.031	-0.098	-0.104	-0.091
August	-0.332	0.127	0.205	0.062
September	0.091	-0.045	0.02	-0.095

Relationship between all of mentioned items is not significant

fibre diameter, as also reported by Carlquist [8]. Who reported that the lack of water in the soil texture and rainfall reduced fibre diameter and vessels. In this direction, February[29] found that vessel diameters in *protea caffra* and *P. roupelliae* were positively correlated with rainfall, suggesting that such measurements from archaeological charcoals may be successfully used to reconstruct past rainfall patterns. For *Eucalyptus globulus Labill*, it was shown that low rainfall was associated with smaller rings, a higher proportion of earlywood vessels, a reduced latewood proportion, smaller vessel diameters and shorter fibers [30]. Villar-Salvador *et al.* [31] demonstrated that water shortage appears to be the most important factor influencing xylem anatomy variations, while low winter temperatures have less relevance in the wood of *Quercus coccifera L.* and *Q. ilex L.*

Relationship Between Fiber Cell Wall Thickness and Climate Condition: The relationship between the climate and cell wall thickness of maple wood are shown in Table 4. Results of Pearson correlation show that there weren't any significant relationships between the climate (temperature and precipitation) on the cell wall thickness. In all of climate-fiber cell walls thickness relationships, the highest and lowest of correlation coefficients were found between cell wall thickness and monthly precipitation of August (R = -0.332) and cell wall thickness-monthly minimum temperature of January (R = -0.005), respectively.

CONCLUSIONS

In this study, the effect of climate on fiber properties of maple wood (*Acer velutinum Boiss)* in north of Iran were determined. The following conclusions were obtained:

- The effects of climate on the fiber length and fiber cell wall thickness weren't significant, but climatic factors did affect the fiber diameter of maple wood.
- The relationship between climate and fiber diameter by Pearson's correlation were that there are positive between monthly precipitation of November and June, monthly mean temperature of August, monthly minimum temperature of January and monthly maximum temperature of August month. Negative relationships were found between monthly precipitation of August and maximum temperature of November and fiber diameter. In Pearson's correlation results, the effects of seven variables on the fiber diameter were significant.
- The effects of seven variables on fiber diameter were analyzed by a forward stepwise procedure. Results showed that the precipitation of November and precipitation (step 1) of August (step 2) had an important effect on the fiber diameter of maple wood. Then, minimum temperature of January and maximum temperature of November were categorized in the next steps.

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