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Chronological Study of *Quercus* Persica Growth Ring Response to Climatic Variables of Precipitation and Temperature in Zagros Forests (A Case Study of Dena Region)

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ABSTRACT

Plant species, including trees, react to environmental changes throughout their lives. One method of studying the response of trees to climatic variables is dendroclimatology. In this study, the effect of precipitation and temperature on annual growth of rings was investigated through extracting eighteen growth samples from 9 intact trees in Seesakht site of Dena region, located in Central Zagros Mountains (Iran). Counting and measuring annual rings were performed applying LINTAB5 measuring device that is equipped with the TSAP software. Time series of growth curves was standardized applying residual chronology and calibrated applying precipitation and temperature data of Hana weather station. Analyzing chronological relationships of site with precipitation and temperature pointed to the significant and positive impact of precipitation before growing season and its negative impact during the growing season in some months on annual growth rings. Also, temperatures in the months before and during the growing season had a significant and meaningful impact on the growth of rings. It can be concluded that *Quercus* Persica has the greatest sensitivity to the mean and the maximum mean of temperature at the onset of the growing season and colder months of the year. In other words, it is more accustomed to the warmer conditions before the start of the growing season and due to its higher sensitivity, EPS and SNR values, this species is suitable for dendroclimatology studies. Finally, a multiple regression model was fitted on the variables.

KEY WORDS: Cross dating, Pearson Correlation, *Quercus* Persica**,** Residual Chronology, Increment Borer

1. INTRODUCTION

Obtaining information regarding the plants' past conditions and realizing how they react in different climatic conditions enable scientists to forecast their present and future conditions and find a remedy for endangered plants. Consequently, based on past climate data, the nature of future climate can be realized [1]. Environmental changes and climatic variables are the most important factors in the distribution of plants [2] and the distribution of plant species in diverse regions is different.

A number of researchers have studied the effect of these changes on plant species and have found that studying some species can yield information with regard to climate track and environmental factors in tree growth rings. Studies have shown that various species of oak are suitable species for dendroclimatological studies [3]. Oak tree rings have woods with remarkable porous and holes which can be clearly seen in the bordering of fresh wood rings [4]. The nature of the formation of oak tree rings forms a clear boundary between the two areas of the rings and rarely creates false rings in the place of true rings, which makes this wood appropriate for Dendrochronology and Dendroclimatology studies [5].

Extensive studies have been carried out on growth rings' response to climatic variables. Some studies mainly focused on growth rings' response to temperature at different times of year and some focused on the effect of temperature and precipitation on rings simultaneously [6, 7, 8, 1, 9, 10, 11, 12]. Some studies investigated the relation between growth ring widths and droughts in local or regional scales [13, 14, 3, 15] and found a strong relation between droughts and a decrease in widths of growth rings. Researchers have conducted simultaneous studies on the response of different species to climatic variations [16, 17] and their findings show that each species can show different responses and sensitivity to climatic variables. Some species would have higher sensitivity to precipitation changes and some to fluctuations in temperature. Some attempts have also been made on the width of spring and summer wood rings [18] and they pointed to the higher contributions of maximum temperature in the width of spring and summer wood rings than precipitation.

Most studies conducted in Iran are concerned with North and West oak trees. Among such studies, one can point to [19], [20] and [21] who have investigated the effect of climatic variables on tree rings. Findings of these studies were different in different regions. In some sites, precipitation was found to have a higher effect on

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tree rings and in some sites temperature was found to have a higher effect. In addition, some studies have attended to the effect of climatic parameters of some years before the current growth year on tree rings. Dena region, despite having the region's biggest oak species habitat area, has been under-investigated and few dendroclimatological studies have been conducted in this area. Insufficient knowledge of the situation of region's site and the decrease in forests' area in recent decades, due to climatic and non-climatic reasons, call for extensive studies in this realm which is the goal of this study. This study aims to investigate the effect of precipitation and temperature on the growth of this species to solve the aforementioned problems.

2. METHODS AND INSTRUMENTATION

Dena region, which is 51.12° to 51.88° along the eastern longitude and 30.51° to 31.51° along the north latitude with an area of approximately 4,500 square kilometers, is in the central Zagros, parts of Isfahan, ChaharMahal and Bakhtiari, Fars province and Kohkiluyeh and Boyer-Ahmad province (Figure1).

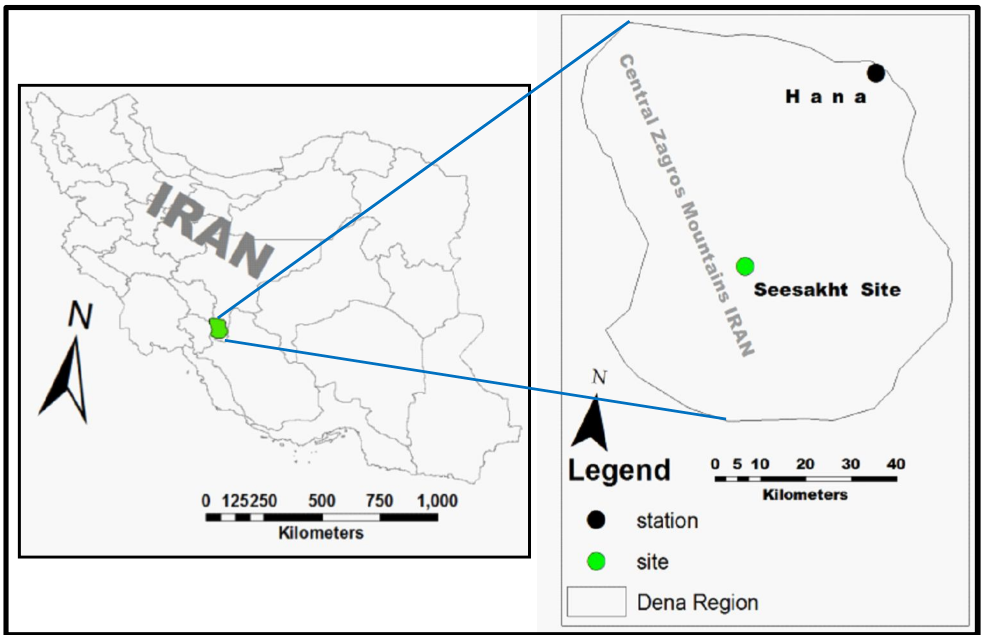


Figure 1: Location of studied site and climatic station in Dena Region, Central Zagros Mountains, Iran.

The mean, maximum and minimum temperature of the region were 14°, 22° and 5.3°C respectively and 30-year mean of total precipitation in the region was 643 mm.

In this study, precipitation and temperature data of 30 years (1982-2011) of Hana climatic station were used.

In order to study the response of tree rings to climatic variables of temperature and precipitation, Seesakht site of Dena region in the Zagros Mountains of central Iran was selected. For the purpose of sampling of this site, 9 intact trees and from each tree two samples (18 growth samples) in two Southwest and Northeast directions were extracted at the breast height of 1.3m. After scanning the samples, counting and measuring annual rings were performed applying LINTAB5 measuring device, which is equipped with the TSAP software with an accuracy of 0.01 mm from the skin to the core (Table 1). The cross dating of two samples from each tree and all trees of the site was performed applying the TSAP software. The GLK[1] sign test was used for evaluating the cross dating of tree growth samples through equation 1:

Equation 1:

$$GLK = \frac{1}{n}\sum_{i=1}^{n=1}\left| G_{ix} + G_{iy}\right|$$

where GLK is the percentage of variance matching, G_{ix} and G_{iy} are the difference between the growth rings width values in the year i before its previous year in the x and y graph.

Table 1 Type and Purpose of Sample collected at Seesakht Site of Dena Region in Central Zagros Mountains, Iran.

Site Name	Site Code	Number of Sample	Elevation	Purpose of Sample
Seesakht	SSQU	18 increment cores	2000-2020	Providing an appropriate chronology for the dendroclimatology study of the region

[1] Gleichlaeufigkeit

In addition to the climate, annual growth of tree rings is influenced by factors such as the age of the tree and other non-climatic factors. Thus, in order to eliminate these non-climatic tendencies, growth rings were standardized by ARSTAN program [22]. From the four chronology (RES, STD, RAW, ARS) made by the above-mentioned program, the residual chronology (RES) was used. This chronology maintains very weak signals well in the growth ring time series and is suitable for dendroclimatology studies [22]. Residual chronology (RES) is the residual mean of auto-regression model of standardized series. In addition, residual chronology lacks long-term trends resulted from internal consistency of the annual growth and accordingly in the evaluation of the relationship of growth - climate this chronology is used. For the chronology made, mean sensitivity (MS), signal to noise ratio (SNR) [23] and expressed population signal (EPS) [24] were calculated applying the following formula:
Mean sensitivity (MS) is calculated from equations (2 & 3):

Equation 2: $S_{i+1}=\frac{(x_{i+1}-xi)*2}{(x_{i+1}+xi)}$

Equation 3: $M.S=\frac{\sum_{i=1}^{n-1}|S_{i+1}|}{n-1}$

Where:
S_{i+1} is the annual ring sensitivity of the year i
M.S is the mean sensitivity for the year (in fact it is an evaluation of the relative difference in width between adjacent rings)
x_i is the width of growth ring in the year i
And the SNR value is calculated from Equation 4:

Equation 4: $SNR=t\,\frac{|r_{eff}|}{1-|r_{eff}|}$

where:
SNR is the signal to noise ratio
t is the number of trees
r_{eff} is the correlation coefficient mean between trees of the site
and the EPS value is calculated from Equation 4:

Equation 4: $EPS_{(t)}=\frac{tr_{eff}}{tr_{eff}+(1-r_{eff})}$

where EPS is expressed population signal, t is the number of trees and r_{eff} is the average correlation coefficients between the trees.
After providing the appropriate chronology for the site, in the calibration stage, the relationship between the residual chronology of Seesakht site with the climatic variables of precipitation and temperature in the time series of before and during the growing season, including a total of three months from October to December (OctDec), a total of three months from January to March (JanMar), monthly from January to December (Jan-Dec), a total of three months from April to June (AprJun), a total of three months from July to September (JulSep) and the growing season from May to September (GRS), are used in the region (Table 1).for monthly time series, growth season, current growth season and months before the growth season in the common statistical period (1982-2011) was gained applying the SPSS software and Pearson correlation (Table 2).

Table 2: Hana site features and time series of precipitation and temperature climatic variables for the purpose of dendroclimatology study of Dena region, Central Zagros Mountains, Iran.

station	Station code	Longitude	Latitude	Elevation	Time Spans Year	Time Series Precipitation and Temperature
HANA	H	51.720	31.198	2329	1982-2011	OctDec, JanMar, Jan-Dec, AprJun JulSep, GRS*

GROWING SEASON, i.e. May-September period.*

Then, applying a multiple-regression analysis, a model for estimating the width of growth rings through climatic variables of temperature and precipitation was provided.

3. RESULTS

After cross dating stage for two samples of each tree and calculating their means, the growth curve of all trees of the site was gained. In Figure 2, we can see the chronology index[2] of the site, which was drawn with TSAP software. Based on this index, it can be seen that all 18 extracted samples had appropriate cross-dating and correlation with each other.

[2] Chronology index of the site= the width of each growth sample *100

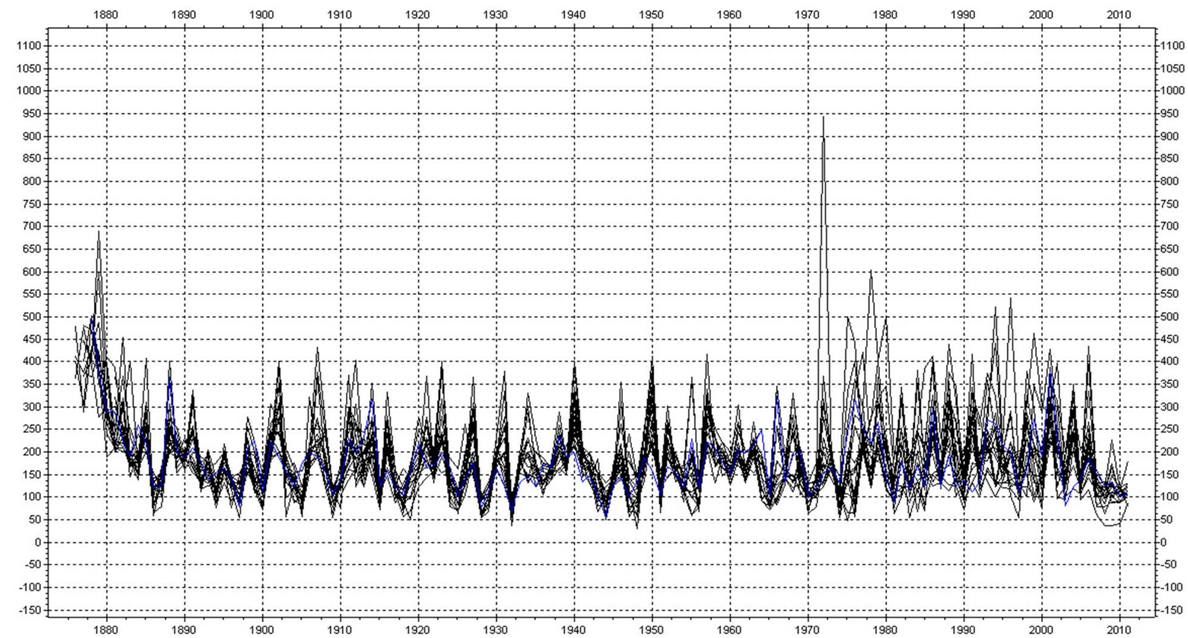


Figure 2: Chronology index of Seesakht site for all 18 extracted growth samples in 136-year (1876-2011) time series for Dena region through TSAP software

For instance, Figure 3 shows the growth curve of two samples from a tree after cross dating. It can be seen that growth curves have appropriate cross dating.

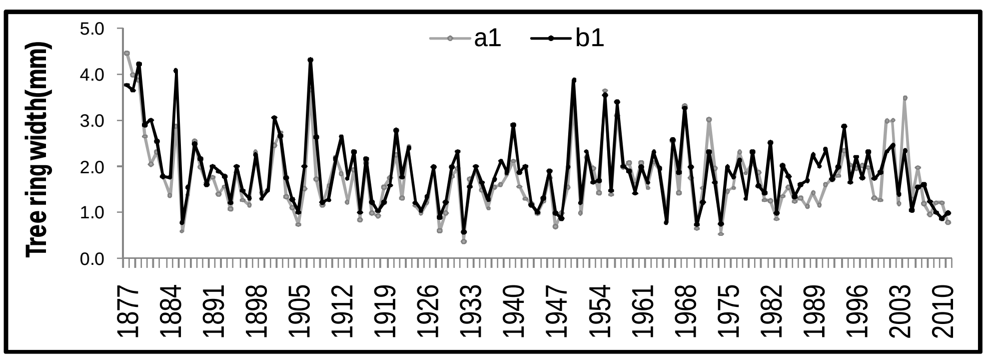


Figure 3: two samples of growth curves of a tree after cross dating in Seesakht site of Dena Region, Central Zagros Mountains, Iran

In addition, the Gleichlaeufigkeit between samples was calculated through GLK sign test. This test better specifies the adjustment degree and cross dating between the growth curves of site trees. Results of the test are provided in Table 3. According to the Table, it seems that the growth curves of two samples of each tree and all trees coordinate well with each other. This correlation was between the minimum of 79.2 and maximum of 92.6. The more this statistical amount, the more correlation observed between the samples.

Table 3: Correlation (GLK) between Mean chronology and Individual series

***** TSAP CORRELATION-TABLE *** DATE: 2013.09.20 TIME: 12.29. *****					
Time interval refers to absolute dates					
Correlation value:					
Glk = Gleichlaeufigkeit, % of equivalent slope intervals (0<=Glk<=100)					
Code	**GLK**	**Code**	**GLK**	**Code**	**GLK**
SNE*1	79.2	SNE4	89.1	SNE7	86.8
SSW1**	75.4	SSW4	78.9	SSW7	86.5
SNE2	84	SNE5	85.8	SNE8	83.5
SSW2	80.2	SSW5	80.6	SSW8	86.8
SNE3	78.3	SNE6	86.9	SNE9	92.6
SSW3	83.7	SSW6	90.3	SSW9	89.9

Statistically significant relationships are indicated by ($p<0.01$).
SNE* samples extracted from each tree from northeast direction
SSW** samples extracted from each tree from southwest direction

The effect of non-climatic factors was removed from growth rings time series through standardization of growth curves applying ARSTAN software. Figure 4 shows three chronologies a) main, b) residual, and c) ARSTAN with d) the number of applied samples in this site.

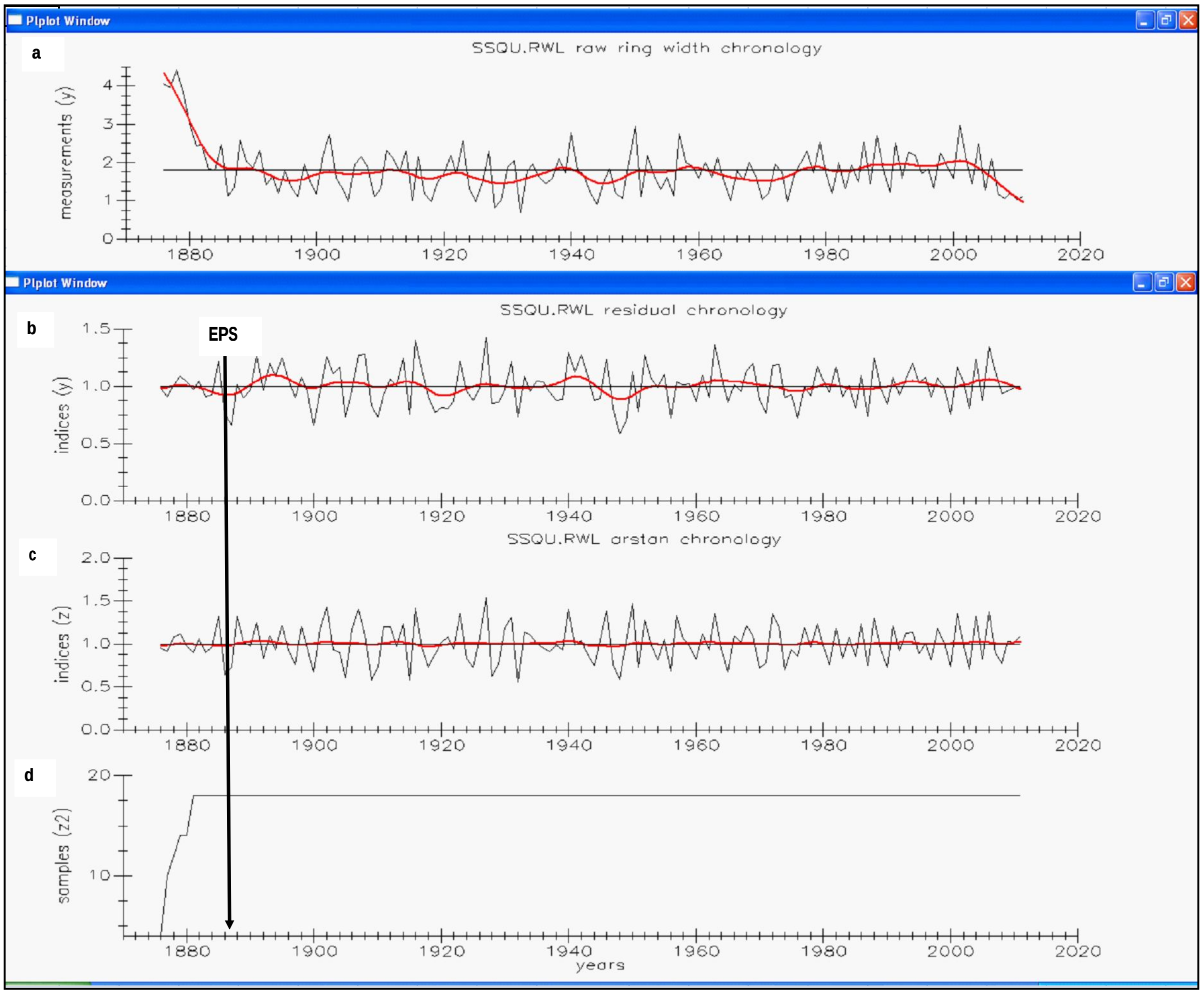


Figure 4: Representation of three chronologies: a) main, b) residual, and c) ARSTAN and d) the number of applied samples in dendroclimatology study of Dena Region in Central Zagros Mountains, Iran, applying ARSTAN software.

a chronology of Seesakht site for a duration of 136 years, from 1876 to 2011

b residual chronology of Seesakht site for a duration of 136 years, from 1876 to 2011, black arrow points to the EPS threshold in 1887.

c ARSTAN chronology of Seesakht site for a duration of 136 years, from 1876 to 2011, black arrow points to the EPS threshold in 1887.

d the number of extracted samples (18 growth samples), 17 of which are in residuals in residual chronology

The expressed population signal value depends on the number of trees and their correlation. As the correlation between the samples increases, the number of samples required for providing the species chronology decreases. The EPS signal was 84.4 percent for Seesakht site which shows that the 9 selected trees were sufficient for the provision of chronology and this number could well represent climate signals in the created chronology. As shown in Figure 5, the internal correlations between samples are high in most years (R-bar) and the EPS values of residual chronology are above the EPS threshold in all years, which indicate a strong correlation between samples.

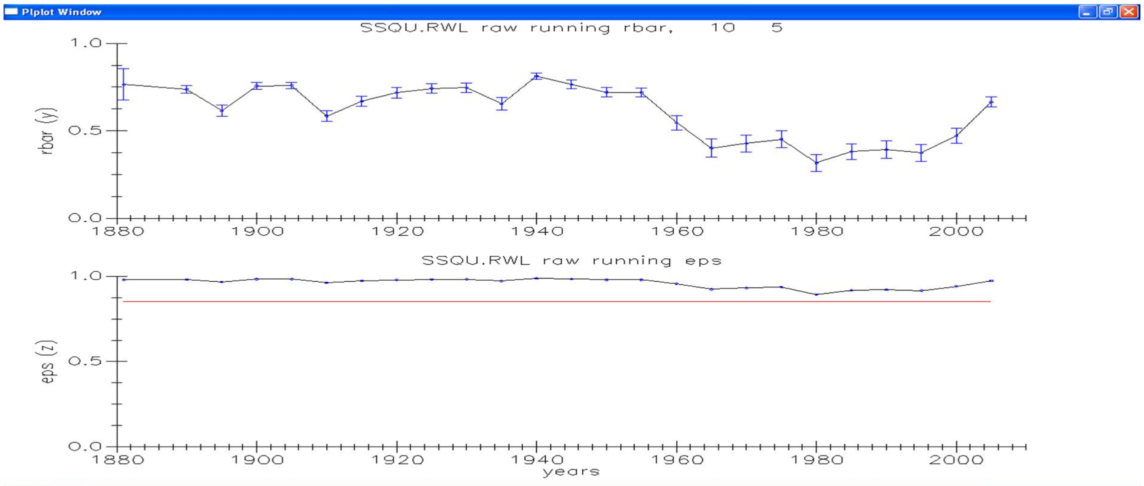


Figure 5: the E-bar and EPS values compared to the threshold EPS (EPS>85%) in the residual chronology of the growth samples of Seesakht site of Dena region in Central Zagros Mountains of Iran.

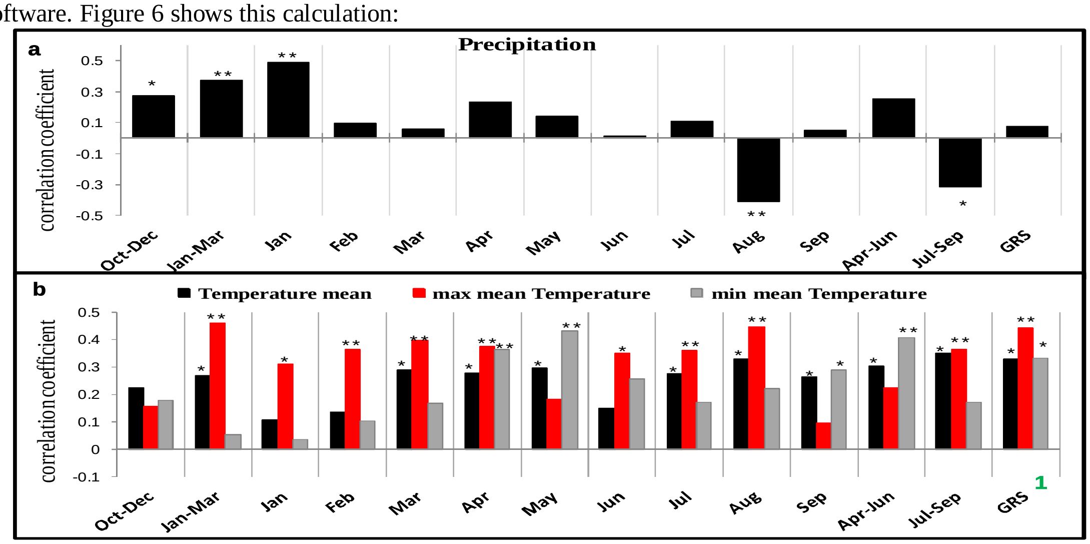
Features and statistical specifications of chronology for Seesakht site were calculated based on residual chronology (RES) and the results of these calculations are shown in Table 4. From 18 growth samples, 17 samples had the features for participating in the residual chronology from 1887 to 2011, for the duration of 125 years.

Table 4 Features and statistical specifications of residual chronology for *Quercus* Persica growth samples of Seesakht site in Dena region in the Central Zagros Mountains, Iran, applying ARSTAN software.

Site Code	N0. Trees / Series	Time Span	Mean Inter-series Correlation	Mean Sensitivity	Mean EPS(%)	Standard Deviation	Auto correlation	Signal-to-Noise Ratio
SSQU	9/17	1887-2011	0.529	0.296	84.4	0.111	-0.10	9/52

– **The correlation between site chronology and precipitation and temperature**

Considering the acceptable results of provided chronology for Seesakht site, we calculated the relation between provided chronology and climatic variables of precipitation and temperature of Dena region applying SPSS software. Figure 6 shows this calculation:



Shows the significance at the level of **0.05 and *0.1
1, GROWING SEASON, i.e. May-September period

Figure 6: the relation between Seesakht site chronology with the climatic variables of precipitation (Fig 6,a) and temperature (Fig 6,b) in the common time period (1982-2011) in Dena region in Central Zagros Mountains, Iran.

In Figure 6 a), the correlations between site chronology and total rainfall before the growing season (OctDec and JanMar) were 27 percent (P<0.1) and 37 percent (P<0.5) with a positive coefficient and for the current growing season with monthly precipitation were 41 percent (P<0.05) for Jan with positive coefficient and 41 percent for Aug with negative coefficient (P<0.05). In addition, this chronology had significant and reverse correlation with the total precipitation of JulSep (P<0.1).

The correlation of the chronology of Seesakht site with temperature mean (Figure 5,b) in JanMar period, before the growth season, is 27 percent and it is between 27 to 32 percent in the current growth year with Sep, Aug, Jul, May, Apr and Mar and it is 35, 30 and 33 percent with the AprJun and JulSep mean and growth season, respectively, all significant at the significance level of 90 percent (P<0.1) with positive coefficients. The correlation between the site chronology and maximum mean of temperature before the growth season (JanMar) is 46 percent and it is between 35 to 46 percent in the current growth year with JulSep, Aug, Jul, Jun, Apr, Mar and Feb and GRS in the current growth season, all significant at the significance level of 95 percent (P<0.05) with positive coefficient. This correlation was significant at the significance level of 90 percent (P<0.1) for Jan. The correlation of the chronology of the site with minimum mean of temperature in current growth season is between 36 and 43 with AprJan, May and Apr (P<0.05) and it is 26 to 33 percent with Jun and Sep and growth season (GRS) with positive coefficient. This correlation was not meaningful for other time periods.

Consequently, applying multiple regression analysis with stepwise method in SPSS, a model for estimating the ring width responses to major climatic variables of precipitation and temperature was obtained. The statistical features of this model are brought in Table 5. Based on the summary of the multiple regression model (Table 5, a and b), the R, R^2, Adj-R^2 and Durbin-Watson coefficient and the F value were 0.889, 0.791, 0.736, 2.072 and 14.498 respectively.

Table 5: Statistical specifications and final multiple regression model of estimating the width of growth rings through climatic variables of precipitation and temperature in the common time period (1982-2011) applying SPSS software in Dena region in Central Zagros Mountains, Iran.

Model Summary [g]					
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**
6	.889[f]	.791	.736	.07626	2.072
f. Predictors: (Constant), JanP, JanMarTma, MayTme, MayTma, AprTmi, GRSTma					
g. Dependent Variable: SSQU					

ANOVA[g]						
	Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
6	Regression	.506	6	.084	14.498	.000[f]
	Residual	.134	23	.006		
	Total	.640	29			
f. Predictors: (Constant), JanP, JanMarTma, MayTme, MayTma, AprTmi, GRSTma						
g. Dependent Variable: SSQU						

Coefficients[a]								
	Model	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	1.065	.017		63.440	.000		
	JanP	.054	.015	.362	3.500	.002	.849	1.178
	JanMarTma	.085	.017	.568	4.974	.000	.697	1.434
	MayTme	.087	.015	.822	5.977	.000	.481	2.081
	MayTma	-.110	.023	-.736	-4.703	.000	.371	2.693
	AprTmi	.048	.016	.321	3.030	.006	.811	1.233
	GRSTma	.042	.020	.285	2.079	.049	.483	2.070
a. Dependent Variable: SSQU								

The most important climatic variables of precipitation and temperature in various time series that remained in the final model, based on Table 5 (section c: Standardized Coefficients, Beta) include the temperature mean of May (MayTme), maximum mean of temperature of May (MayTma), maximum mean of temperature for January-March (JanMarTma), the January precipitation (JanP), the minimum temperature in April (AprTmi) and total maximum temperature of the growing season from May to September average (GRSTma), respectively based on the most impact.

Reviewing the performed calculation in this study, we can say that statistical parameters specially sign test or the percentage of variance matching (GLK), mean sensitivity (MS), the autocorrelation of samples and signal to noise ratio (SNR) confirmed the chronology obtained for Seesakht site. The high amount of GLK (79.2<=GLK<=92.6) shows the consistency and accuracy of measurement. The high degree of samples' autocorrelation (0.529) points to the suitability of the chronology made and the high degree of mean sensitivity (0.296) shows the sensitivity of *Quercus* Persica to climate and the signal to noise ratio high value (9.52) shows the importance of established chronology in assessing the relationship between growth – climate. In addition, the low autocorrelation between the samples (-0.10), reminds the relative autonomy of each loop compared to the subsequent loop. The expressed population signal with the mean of 84.4% and its high amount for all samples point to the adequacy of 18 extracted samples for dendroclimatology study.

Based on Pearson correlation results, precipitation in colder months of the year had positive and meaningful correlation with the chronology of the site at the level of 0.1 to 0.05. The correlation between total precipitation for the months of August and July - September has been reversed and for the other months was not significant. The inverse relationship for precipitation in the mentioned months and the insignificant correlation between rainfall and other months of warm season might be due the scarcity of rainfall in the region during this period and during this period, oak species uses more ground water aquifers because of their deep and vertical roots [25]. The correlation between the chronology of site and mean, maximum and minimum temperatures in most months, both during the growth period of the current year and before that, is direct and significant at the level of 0.1 to 0.05. [26] know the start of oak species growth with minimum temperatures of 10 degrees, which can also continue to grow at the maximum temperature of about 35 degrees. [27] and [28] have also mentioned a similar temperature interval. While, based on Figure 7, the maximum temperature in this region is below 35°C in all months of the year, and the optimum temperature for this oak species is maximum temperatures and thus this temperature set no limits for the growth. Also, based on Figure 7, because of the mountainous state of the region, only from May to the end of September, the minimum temperature of the region is above 10 degrees and since the onset of the growth of this species is in the temperatures above 10 degrees, the growing season is limited to this five-month period and during this period the minimum temperature has a significant positive relationship with the width of growth rings. In general, when the minimum temperature had an increase, there was also an increase in the growth of growth rings' width. Accordingly, any fluctuations in the temperature minimum of the region, particularly the occurrence of early frost or late frost can fluctuate the start or end of the growing season.It should also be noted that although plants do not grow in the cold season of the year, the increase in the temperature saves more food and leads to more growth in the growing season and thus the correlation between tree rings and the minimum temperature, before the growth season, is also positive.

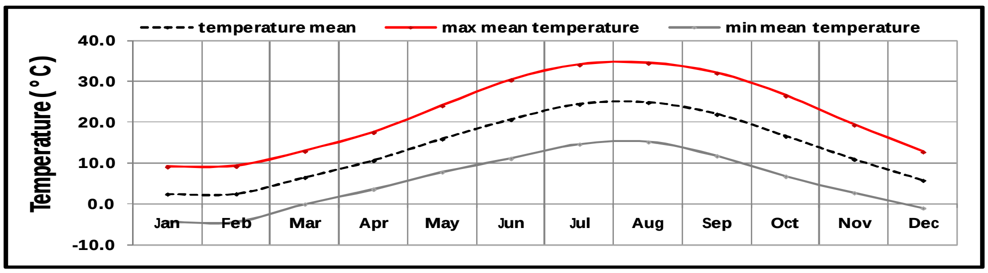


Figure 7: monthly mean, maximum mean, and minimum mean of Dena region in a 30-year (1982-2001) period (the minimum monthly temperature is above 10 degrees)

Based on the results of multiple regression analysis, the final model of the response of site chronology to climatic variables showed that from the climatic variables of temperature and precipitation, based on Table 5 (section c: Standardized Coefficients), May Tme, May Tma, JanMar Tma, JanP, AprTmi, GRSTma, had the highest contribution in predicting the width of growth rings, respectively. For example, the negativity of Mayma variable shows that if other variables which are entered into the model are provided and assuming the constancy of the other variables of the model, the increase in MayTma variable would meaningfully decrease the width of growth rings. It should be noted that in multiple regression analysis, the conditional relationship of variables with response variable is the determining factor in making the final model. In other words, though some variables might individually have high correlation with the response variable, it is possible that the correlation of a variable with the response variable, when all other variables are available, is low and that variable is missed in the final model. In other words, here the point is not the relation of each individual variable with the other one, but we should have all variables and the relationship between them for making the model.

4. CONCLUSION

In order to have a dendroclimatology study in Central Zagros Mountains (Iran), 18 growth samples from 9 intact *Quercus* Persica were selected from Seesakht site in Dena region and cross dating between samples was performed. Consequently, from four current chronologies, residual chronology was applied for standardization and comparison with climatic variables of precipitation and temperature. The statistical results of this chronology showed that the provided chronology is sufficiently accurate and worthy of being studied in dendroclimatology studies of the region. Consequently, applying precipitation and temperature data of Hana weather station, the correlation of site chronology with mentioned data for the common period of 1982-2011 was calculated. The results of this correlation showed that the rainfall before current growing season had significant impact on the growth of this species. Thus variations in the precipitation in colder months of the year cause significant fluctuations in the rise of the current growing season. The results of the correlation between the chronology of sites with temperature indicate that the maximum temperatures of region do not cause growth restriction. Perhaps the mountainous conditions and high altitude of the region has made the maximum temperatures the optimum temperature for this species in the region. The minimum temperatures of the region determine the duration of the growing season. The growth period of this species is about 5 months from May to September and only during this period the temperature minimums is higher than 10° and there is a good condition for its growth (the minimum temperature for the start of oak species growth is 10 degrees). The multiple regression model showed that the mean and the mean of maximum temperatures has more significant impact on the estimation of growth rings width in comparison to other variables in different time series. Of course, in addition to the above-mentioned factors, other factors such as light, nutrients in soil, accumulation of neighboring plants, human intervention and different types of pests may also be effective in the growth ring width which requires further investigation.

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