MINERAL CONTENT IN RELATION TO RADIAL POSITION, ALTITUDE, CHEMICAL PROPERTIES AND DENSITY OF PERSIAN IRONWOOD

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ABSTRACT

Persian ironwood (*Parrotia persica*) is native species from Iran and covers 10,54% of the commercial volume. Its wood structure and its chemical composition are affected by growth conditions. The aim of the study was to assess the variation of mineral content (Ni, Fe, Cu, Zn, Pb, Cd), wood density and chemical properties (cellulose, lignin, ash and extractive) of ironwood in relation to altitude above sea level (100, 500 and 700 meter) and pith distance within stem (near to pith and bark and middle point). In addition was investigate the relationship between mineral content with oven-dried density and chemical properties. Results showed that Cd, Cu, Fe, Ni and Zn content (except Pb concentration) increased by increasing of altitude and decreased along radial position within stem from the pith to the bark. Lignin, ash and extractive content increased by increasing altitudes from 100 to 700 meter while cellulose decreased. Radial position had not significant impact on the chemical properties. There are significant relationships between mineral content–chemical properties and between mineral content-wood density (except Cu - density). Forward stepwise regression showed that ash and lignin content had important role on the variation of all of mineral content except on Cd.

Keywords: Ash content, cellulose, chemical properties, density, lignin, *Parrotia persica*, wood variation.

INTRODUCTION

Persian ironwood (*Parrotia persica*) is one of the deciduous trees of Hyrcanian forests (Northern coast of the Caspian Sea in Iran) are from the Hamamelidaceae family (Parsakhoo and Jalilvand 2009). *Parrotia persica* is usually a low-branched and multi stemmed small specimen tree. Persian Parrotia provides significant autumn and winter interest (Parsakhoo and Jalilvand 2009).

This species, as many others, is affected by genotype and ecological conditions of the trees habitat which have impact on the growth and development of the trees (Yilmaz *et al.* 2008). Ecologic conditions of site directly or indirectly affect the availability, development and fertility, body form and height of tree types, herbal type variety, stand closure and availability rates of plants (Creber and Chaloner 1984, Tessier *et al.* 1994, Roo-Zielinska and Solon 1997, Yilmaz *et al.* 2008, Wodzicki 2001), and they resemble different wood properties.

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The factors that cause the changes in the wood structure are the age and genetic properties of the tree and the environmental conditions (Doğu 2002). These factors affect the growth rate of tree, composition, structure and wood different properties (Wilson and White 1986). Wood density (important wood properties) is a complex physical property, related to the anatomical structure, including cell wall thickness, vessel number and characteristics, and the wood chemical composition, including extractives contents, that responds to genetic, environmental and physiological influences (Wimmer *et al.* 2002, Wimmer *et al.* 2008, Trugilho *et al.* 1996, Zhang and Morgenstern 1995, Hylen 1997, Zhang 1998). Site and environmental conditions affect density of wood and therefore its properties (Moya and Perez 2008, Silva *et al.* 2009, Moya and Calvo-Alvarado 2012, Zobel and Van Buijtenen 1989).

Important wood properties, as ash content from hardwood species produces higher levels of macronutrients in their ash than conifers, and the silica content is frequently lower (Pitman 2006). Ash derived from branch and root wood is richer in many elements than stemwood, while that derived from bark and foliage has concentrations between five and 10 times greater than from stemwood (Werkelin *et al.* 2005). Bark thus produces more ash than stemwood (Pitman 2006).

Mineral nutrients are limiting resources to plants and the allocation and translocation of mineral nutrients among different organs are important mechanisms enhancing nutrient use efficiency in plants (Aerts and Chapin 2000, Eckstein 1999, Nambiar and Fife 1991, Meerts 2002). In trees, wood usually has the lowest mineral nutrient concentration of all organs (Woodwell *et al.* 1975). However, wood itself is not necessarily homogeneous with respect to mineral element concentrations (Hillis 1987, Myre *et al.* 1994). There is a higher of P, N and K concentration in sapwood compared to heartwood for oakwood (Attiwill 1980, Augusto *et al.* 2000, Penninckx *et al.* 2001).

Although, there is much information about the mineral content in relation to pith distance and other important aspect to relation with growing condition, information about variation of the mineral content in *Parrotia persica* is less known. Therefore, the objectives of this research were: a) to examine the effect of altitude and radial position on different wood properties such as chemical properties, wood density and mineral content on *Parrotia persica*in Noshahr region located in Iranian forest, and b) to investigate the relationship between chemical properties and wood density with mineral content by Pearson correlation and forward stepwise regression.

METHODS

Experimental material

In the present study, 9 normal Persian ironwood (*Parrotia persica* (DC) CA Meyer) trees were felled from three different altitudes, i. e., 100 (low elevation), 500 (intermediate elevation), and 700 (high elevation) meters above sea level from northern natural forests (Noshahr region) in Iran. At all three sites, the trees were 35-40 years-old. All nine trees were randomly selected, taking into account stem straightness and the absence of evident decay. Traits of environmental and climate conditions of these sites and characteristics of trees are listed in Table 1. A cross-section with 15 cm in thickness was extracted from each tree at breast height. This cross-section was utilized for evaluation of wood properties. Afterwards, three samples were prepared along radial position from pith to the bark (near to pith, middle between pith and bark, near to the bark). Wood density (according to ISO-3131) and chemical properties (according to TAPPI standard) were determined in each position.

Table 1. The characteristics of the sites, and climate of Persian Ironwood (*Parrotia persica*) plantation studied in Iran.

Sites	Altitudes (m)	Soil type	Annual temperature (°C)	Annual rainfall (mm)	Height (m)	Diameter (cm)
	100	Alfisols	13,5	1,345	23,4	32
Noshahrregion	500	Alfisols	11,5	1,300	23,3	31,6
	700	Alfisols	8,5	1,300	22,5	30,4

Chemical properties and mineral content

All of radial samples were milled to wood flour to examine chemical properties and mineral content. Lignin, ash and extractives soluble in alcohol-acetone were determined according to TAPPI test methods. The cellulose content of iron wood was determined according to the nitric acid method (Rowell *et al.* 1997). Then the mineral content such as Nickel (Ni), iron (Fe), copper (Cu), Zinc (Zn), plumb (Pb), and Cadmium (Cd) dissolved and separated from ash of wood flour by 63% nitric acid for an hour, mineral content of iron wood identifications by atomic adsorption system (Varian AA240, Australia). All of measurements (mineral content and chemical properties) were repeated three times.

Wood density measurement:

First, the specimens (3 Tree x 4 geographical directions (north, south, east, west) x 3 position x 3 altitude classes =108 samples) were soaked in distilled water for 72 h in order to ensure that the moisture content could reach the fiber saturation point. Then the dimensions in all three radial positions were measured with a digital caliper ($\pm$ 0,001 mm). Specimens were also weighed to the nearest 0,001 g. Finally, the samples were oven dried at 103 $\pm$ 2 °C to 0% moisture content. After cooling in desiccators, the oven-dry weights of the specimens were measured. The oven-dry density of the specimens was calculated by the following equations:

$$D_0(density) = \frac{p_0(oven-dried\ weight)}{v_0(oven-dried\ volume)}$$

Statistical analysis

First, the assumptions of normal distribution, variance homogeneity and absence of extreme data of different mineral content (Ni, Pb, Cd, Cu, Zn and Fe) were verified. ProcUnivariate procedure was applied of SAS 8.1 for Windows (SAS Institute Inc., Cary, N.C.). Second, the values of each mineral relation to radial position and altitude were compared by ANOVA procedure from SAS (SAS Institute, 1997). The following statistical model was used:

$$Y_{ijk} = \mu + p_i + a_j + p*a_{ij} + e_{ijk}$$

where Y_{ijk} is the single observation of each mineral of the ij[th]-tree, μ is the overall mean, p is the ith-radial position fixed effect, a is j[th]-altitude fixed effect, $p*a_{ij}$ is the random interaction between the ith radial position and the jth altitude and e_{ijk} is the residual random effect.

The average differences were analyzed by Duncan test with 0,01 in significance in order to find which treatments varied. And third, a Pearson correlation matrix was used for determining the relationships of different mineral content with some wood properties (density oven-dried, and chemical composition, specifically ash, cellulose and lignin content and extractives in alcohol-acetone. Four, forward stepwise analysis was carried out for defining the priority wood properties affecting the mineral content the most. Finally, three-dimensional graphs (XYZ) were performed as graphical support to relation between mineral content and two main variables with most effects indicated forward stepwise analysis.

RESULTS

Effects of radial position and altitude on chemical properties

The average and standard deviation of chemical properties in relation to radial position for iron wood growing in three different elevations were shown in table 2. Analysis of variance results (ANOVA) indicated that the effect of altitude on the chemical properties was significant, while radial position and their interaction hadn't significant differences on the chemical properties of ironwood (Table 3). The mean of lignin, extractive and ash were increased by increasing of altitude in ironwood. The cellulose content is higher at low altitude (44,70%) and lower at high altitude (43,53% in altitude 500 m and 43,68% in altitude 700 m) in this region (Table 2). Regular pattern of chemical properties variations (except ash content) weren't observed along radial position from the pith to the bark at three studied altitudes. There is an insignificantly decreasing trend of ash variation along radial position from pith to bark in each of fixed elevation (Table 3). The standard deviation of chemical variation except lignin content in high altitude is higher than other altitudes (Table 2).

Table 2. Chemical properties in relation to radial position for Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran.

Altitude (m)	Radial position	Cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)
100	Pith	44,79 (0,50)	23,65 (0,25)	2,60 (0,16)	1,15 (0,15)
	Middle	44,80 (0,37)	23,82 (0,17)	2,62 (0,20)	0,93 (0,13)
	Bark	44,50 (0,33)	23,71 (0,36)	2,59 (0,31)	0,74 (0,25)
	Average	44,70 (0,38)	23,73 (0 25)	2,60 (0,20)	0,94 (0,24)
500	Pith	43,49 (0,63)	25,11 (0,63)	4,08 (0,25)	1,78 (0,13)
	Middle	43,60 (0,62)	25,01 (0,52)	3,62 (0,43)	1,69 (0,14)
	Bark	43,51 (0,32)	24,62 (0,45)	3,92 (0,27)	1,66 (0,23)
	Average	43,53 (0,47)	24,91 (0,52)	3,87 (0,35)	1,71 (0,16)
700	Pith	42,15 (0,66)	26,11 (0,23)	4,77 (0,32)	2,20 (0,36)
	Middle	43,81 (0,88)	25,50 (0,56)	4,62 (0,31)	2,05 (0,28)
	Bark	43,77 (0,65)	25,86 (0,32)	4,04 (0,39)	1,95 (0,24)
	Average	43,68 (0,94)	25,83 (0,43)	4,48 (0,44)	2,07 (0,28)
Total	Pith	43,48 (1,26)	24,96 (1,13)	3,82 (0,98)	1,71 (0,50)
	Middle	43,81 (0,88)	24,78 (0,84)	3,62 (0,91)	1,56 (0,52)
	bark	43,77 (0,65)	24,73 (0,99)	3,52 (0,75)	1,45 (0,58)
	Average	43,68 (0,94)	24,82 (0,96)	3,65 (0,86)	1,57 (0,53)

Legend: Standards errors are presented in brackets.

Table 3. Results from ANOVA: F-value (in analysis of variance) of the results of chemical properties in Persian ironwood (*Parrotia persica*) trees growing in Iran.

Chemical properties	Cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)
Altitude (A)	31,10**	56,10**	85,67**	56,98**
Radial position (B)	1,16[ns]	0,720[ns]	2,185[ns]	2,96 [ns]
A × B	1,727[ns]	1,058[ns]	2,073 [ns]	0,31 [ns]

Ns: not significant; ** significant at 0,01 level.

Effects of radial position and altitude on wood density

The average and standard deviation of wood density in relation to radial position for iron wood growing in three different elevations were shown in table 4. Analysis of variance results (ANOVA) indicated that the effect of altitude (F=8,738; p =0,002), radial position (F=14,493; p=0) and their interaction (F=2,983; p=0,047) on the wood density were significant. The highest and lowest of wood density were found at intermediate (0,796 g cm^{-3}) and low altitudes (0,733 g cm^{-3}), respectively. The variation of wood density along radial position from pith to the bark was decreased in each of fixed altitude (Table 4). The mean of wood density was 0,769 g cm^{-3} for three studied altitudes in north of Iran.

Table 4. Wood density (g/cm^3) in relation to radial position for Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran

Altitude/position	Pith	Middle	bark	Average
100	0,810 (0,072)	0,706 (0,020)	0,683 (0,057)	0,733 (0,069)
500	0,806 (0,020)	0,796 (0,025)	0,786 (0,025)	0,796 (0,022)
700	0,823 (0,037)	0,790 (0,026)	0,720 (0,017)	0,777 (0,051)
Average	0,813 (0,042)	0,764 (0,048)	0,730 (0,047)	0,769 (0,056)

Legend: Standards errors are presented in brackets.

Effects of radial position and altitude on mineral content

Analysis of variance results (ANOVA) indicated that the radial position, altitude and their interaction (except for Cd and Pb) had significant differences on mineral concentration in iron wood for this region (Table 5). Radial variations of mineral content of ironwood for three different altitudes and for interaction radial position x altitude were shown in figures 1 to 3, respectively. The average of Ni (0,07-2,21 ppm), Cd (0,05-0,29 ppm), Cu (0,17-1,18 ppm), Zn (1-2,43 ppm) and Fe (0,62-1,02 ppm) were increased by increasing of altitude (Figure 1a, 1c-f). In each of fixed altitude, the mentioned properties were decreased along radial position from the pith to the bark (Figure 2). Pb concentration (0,13 -0,91 ppm) is higher at low altitude and lower at high altitude (Figure 1b). Pattern variation of Pb concentration was increased along radial direction from pith to the bark in ironwood (Figure 2b).

Table 5. *F*-value (in analysis of variance) of the results of mineral content in Persian ironwood (*Parrotia persica*) trees growing in Iran.

Mineral content	Ni	Pb	Cd	Cu	Zn	Fe
Altitude (A)	1762,2**	682**	721,2**	320,5**	1255**	534,1**
Radial position (B)	304,96**	76,95**	46,76**	48,92**	72,51**	72,91**
(A × B)	1,03 **	1,09[ns]	1,15[ns]	5,08**	7,42**	3,71 *

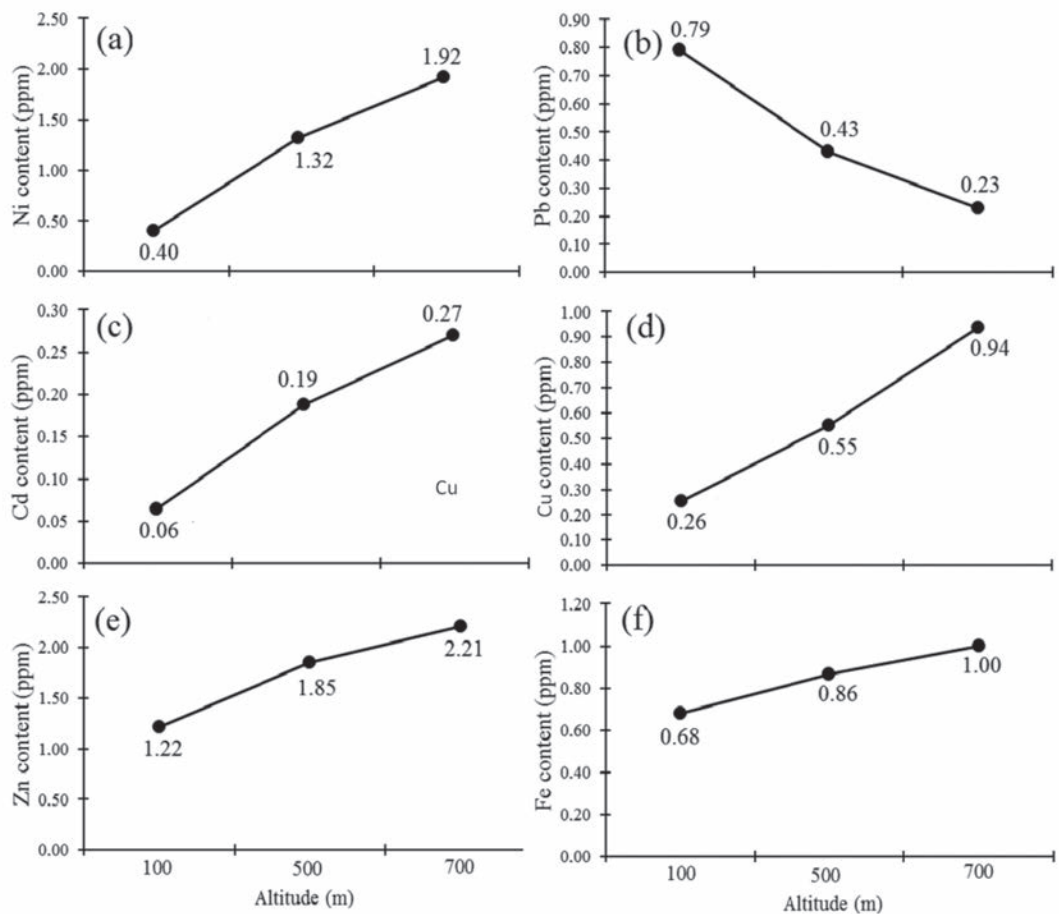** and * were significant at 0,01 and 0,05; ns: is not significant

Figure 1. Nickel (a), plumb (b), cadmium (c), copper (d), zinc (e) and iron (f) content variation of Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran.
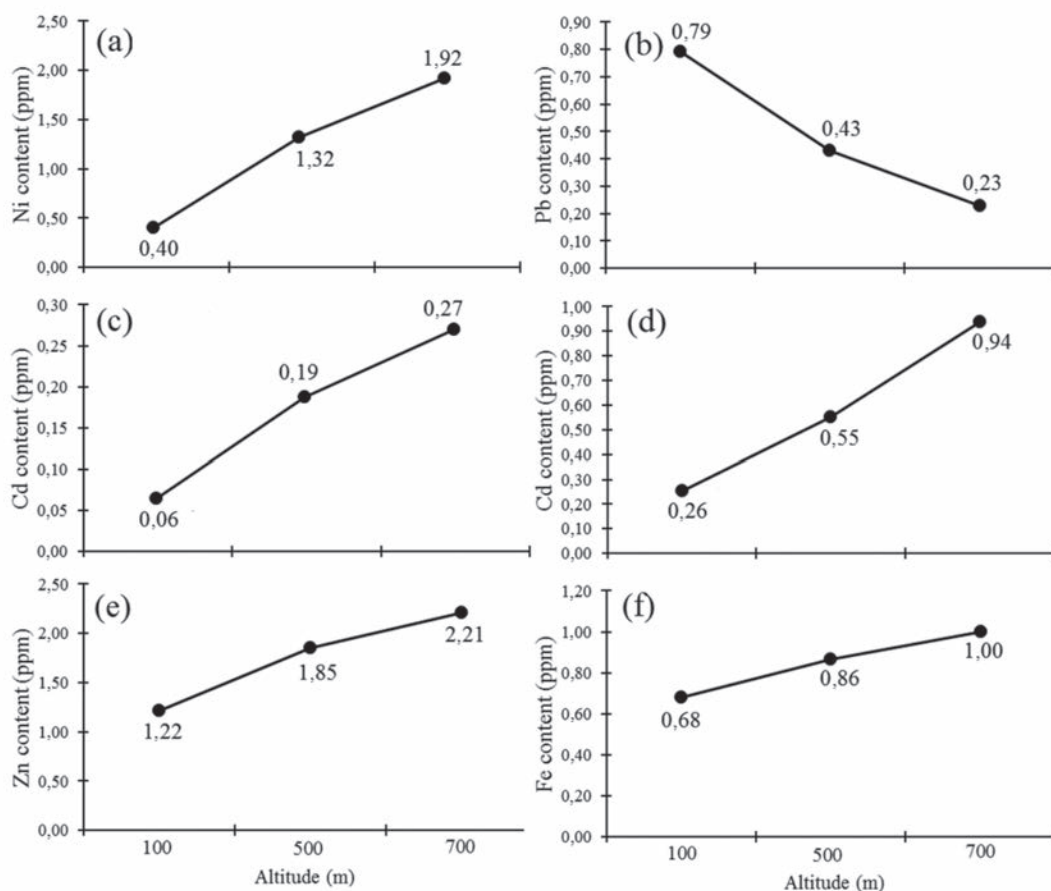
Figure 2. Nickel (a), plumb (b), cadmium (c), copper (d), zinc (e) and iron (f) content variation in relation to radial position for Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran.

Another important observation was that almost of values of mineral were statically different between them in trees growing in altitude of 100 and 700 m (Table 5), but trees growing in altitude of 500, some radial position were not statistically different. For example, Cu content in wood middle distance between pith-bark was not difference with wood near to bark in altitude 500 m (Figure 3D). Zn and Fe content were statistically equal in wood near pith and in middle distance (Figure 3E and 3F). Besides other radial position were similar in trees growing in different altitude, For example, Cd content in wood near pith in trees growing at altitude of 500 was not difference with wood near to bark in trees growing at 700 m in altitude (Figure 3C).
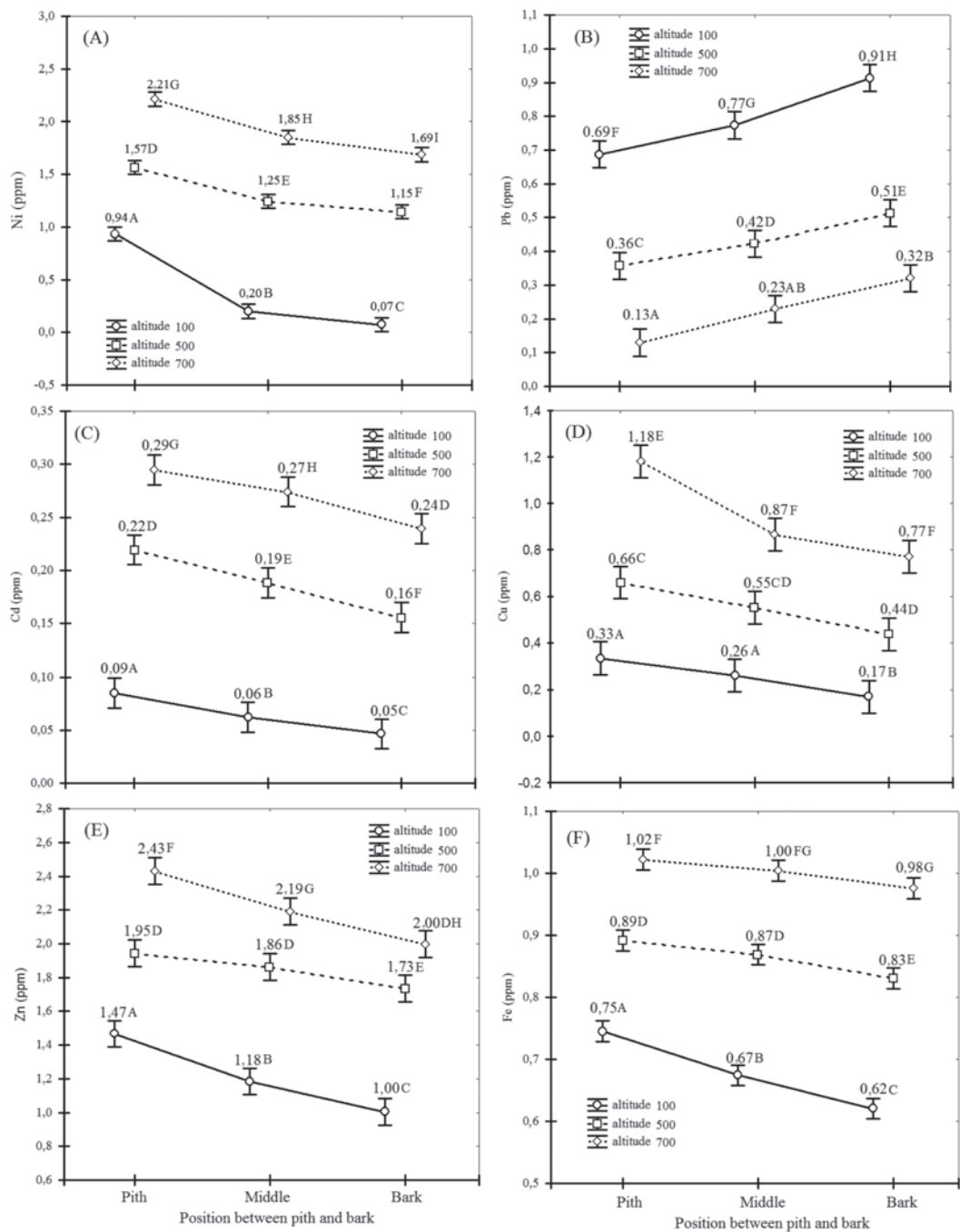
Figure 3. Nickel (a), plumb (b), cadmium (c), copper (d), zinc (e) and iron (f) content in ash variation in relation to radial position for Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran.

Relation between mineral content with chemical properties and wood density

Relationship between mineral content with chemical properties and wood density are shown in Table 6. Ni, Cd, Zn, Cu and Fe content were had positive relationships with wood density, lignin, extractives, and ash content. All of mentioned relationships were significant, except for relationship between Cu and wood density (r = 0,46). Pb content presented negative significantly relationship with wood density (r = -0,57); lignin (r = -0,88); extractives (r = -0,91); and ash content (r = -0,92). The all of mineral content, except for Pb content (r = 0,82); presented negative correlations with cellulose content. Correlation coefficients between mineral content and oven-dried density are below 60%, while these relationships between mineral content and chemical properties were above 80%. Therefore, it can show that mineral content had stronger relationship with chemical properties than wood density. The highest of correction coefficients was found in Zn-ash relationship (r = 0,94) for Persian ironwood (*Parrotia persica*) in Iranian forest (Table 6).

Table 6. Values of coefficient of correlation (r) between mineral component in ash and wood properties of Persian ironwood (*Parrotia persica*) trees growing in Iran.

Mineral content in ash	Density oven-dried	Chemical compositions			
		Cellulose	*Lignin*	*Extractives*	*Ash*
Ni	0,59*	-0,81**	0,86**	0,89**	0,91**
Pb	-0,57*	0,82**	-0,88**	-0,91**	-0,92**
Cd	0,50*	-0,84**	0,89**	0,92**	0,92**
Cu	0,46^{NS}	-0,85**	0,88**	0,88**	0,85**
Zn	0,60*	-0,84**	0,86**	0,90**	0,94**
Fe	0,50*	-0,81**	0,90**	0,90**	0,91**

*statistically significant at 95% and **statistically significant at 99%.

Mineral content were influences by three chemical properties, except for iron content (Fe), which was correlated with two variables (Table 7). Multiple stepwise correlation analysis (Table 7) showed mineral content can be explained by model $Y= a + b*\beta_1 + c*\beta_2 + d*\beta_3$ (where a, b, c and d are model coefficient and β_i are wood properties) and this model presented high correlation coefficient (R>0,93; Table 7). However, Fe content was explained only for two properties (ash and lignin content) and it was modeled by $Y= a + b*\beta_1 + c*\beta_2$. The ash content in the wood explained up to 82% of the Ni, complemented by the lignin content representing 7% of total variation, while variations in Cd were explained by extractive content (84%) and lignin content (7%). Pb content was correlated with ash content (84%), lignin (8%) and wood density (3%). This trend was found in Cu and Zn which were related with ash (78 vs 88%), lignin (6 vs 5%) and wood density (3%) of total variation. Ash, lignin and wood density had important effects in the mineral content variation for Persian ironwood.

Table 7. Results from multiple stepwise regression analysis for the relationship between mineral content and wood properties for Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran

Mineral content	Correlation parameters	β_1	β_2	β_3	Equation
Ni R=0,96	Variable	Ash**	Lignin**	Density**	$Y= -11,13 + 0,48*\beta_1 + 0,37*\beta_2 + 3,04*\beta_3$
	R^2 ap.	0,82	0,07	0,04	
	R^2mul.	0,82	0,89	0,93	
Pb R=0,97	Variable	Ash**	Lignin**	Density**	$Y= 4,90 - 0,14*\beta_1 - 0,19*\beta_2 - 0,92*\beta_3$
	R^2 ap.	0,84	0,08	0,03	
	R^2mul.	0,84	0,92	0,95	
Cd R=0,97	Variable	Extractives**	Ash**	Lignin**	$Y= -0,79 + 0,03*\beta_1 + 0,08*\beta_2 + 0,03*\beta_3$
	R^2 ap.	0,84	0,07	0,03	
	R^2mul.	0,84	0,91	0,94	
Cu R=0,93	Variable	Ash**	Lignin**	Density**	$Y= -5,17 + 0,20*\beta_1 + 0,19*\beta_2 + 0,67*\beta_3$
	R^2 ap.	0,78	0,06	0,03	
	R^2mul.	0,78	0,84	0,87	
Zn R=0,98	Variable	Ash**	Lignin**	Density**	$Y= -5,24 + 0,41*\beta_1 + 0,20*\beta_2 + 1,68*\beta_3$
	R^2 ap.	0,88	0,05	0,03	
	R^2mul.	0,88	0,93	0,96	
Fe R=0,96	Variable	Ash**	Lignin**	-	$Y= -1,08 + 0,07*\beta_1 + 0,14*\beta_2$
	R^2 ap.	0,84	0,09	-	
	R^2mul.	0,84	0,93	-	

** Statistically significant at 99% confidence; R^2ap: Contribution of the parameter to the coefficient of determination; R^2mul: Multiple coefficient of determination.

In order to visualize the behavior of the two main variables on the mineral content is presented the figure 4. The Ni content increases with increment of ash and lignin content and the highest Ni, Pb and Fe content is obtained when ash content is higher than 2,4% and lignin content is higher than 26,0% (Figure 4A,4B and 4F).The Cd content increases with increment of ash and extractives content and the highest Cd content is obtained when ash content is higher than 2% and extractives content is higher than 4,5% (Figure 4C).The Cu content increases with decreasing of ash and the increment of extractives content and the highest Cu content is obtained when ash content is lower than 1% and extractives content is higher than 4,5% (Figure 4D).The Zn content increases with increment of ash and lignin content and the highest Zn content is obtained when ash content is higher than 1,6% and lignin content is higher than 26% (Figure 4E).
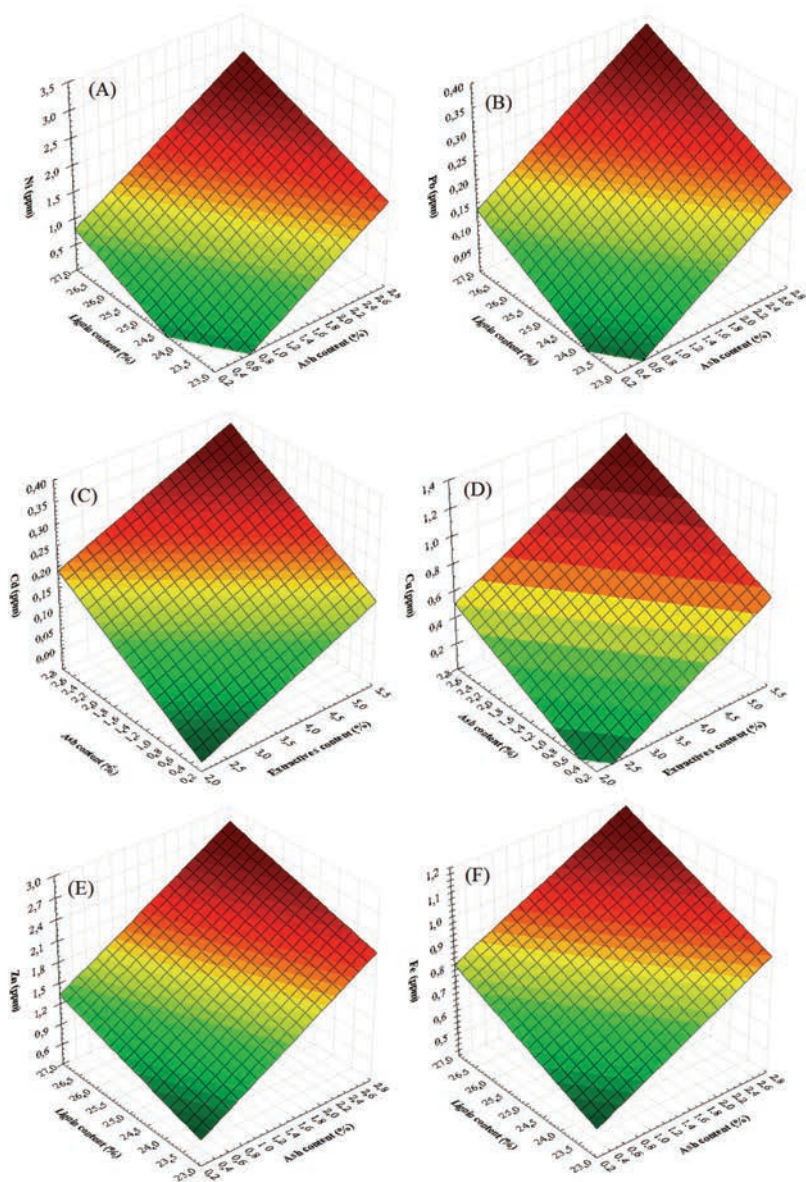
Figure 4. Response surfaces for the most significant variable correlations between mineral content and wood characteristics of Persian ironwood (*Parrotia persica*) growing in three different altitude of Iran. Nickel (A), plumb (B), cadmium (C), copper (D), zinc (E) and iron (F) content.

DISCUSSION

In general, in small amounts as micronutrients, some minerals such as zinc, nickel and copper are essential for the growth of trees and are absorbed from the soil by the roots (Marry *et al.* 1986). Meanwhile, some of these minerals such as Pb do not have any specific role in the physiological reactions of the plants and due to their chemical similarity with essential elements of their absorption by plants is possible (Kord *et al.* 2010). By increasing the altitude from the sea level, the cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), and zinc (Zn) amount in ironwood ash increased. Also, this mineral content decreased along radial axes from the pith to the bark (Figure 1 and 2). These performances of the mineral within tree (Table 2) and with sea level (Table 4) could be attributed to highest share of wood ash content in the core at a height of 700 meters above sea level. Similar trend was found in Cd and Zn concentration along radial position from the pith to the bark before and after growing season for beech wood in the two sites (Schwaney and Glindfeld sites) in Germany (Hagemeyer and Schäfer 1995).

The reverse performance in plumb content (Pb) changes in ironwood compared with other minerals has been observed (Figure 1 and 2). As a result, the Pb content in ironwood decreased by increasing the altitude and increased along radial axes from the pith to the bark. Pb high content in the lower altitude (100 meters above sea level) can be ascribed to the proximity of the selected samples to the urban areas and also the pollution and environmental conditions of the region and also the higher concentration of Pb in the soil (Kord *et al.* 2010). The minimum and maximum of Pb content of Ironwood in three altitudes and three samples of radial position varied 0,23 to 0,79 Ppm (Table 2 and 4), which is lower than the pb content in beech wood (0,32- 3,67 Ppm at Schwaney site and 0,30-1,51 Ppm at Glindfeld site) for different growth season (April, June, September and October) in Germany (Hagemeyer and Schäfer 1995), and lower than the pb of aspen wood (1,4 Ppm) in USA (Ragland *et al.* 1991). Other mineral content of aspen wood is higher than the studied species (Ragland *et al.* 1991).

Taneda *et al.* (1986), categorized nutrient concentration profiles as follows: i) a gradual decrease from pith to cambium, ii) a minimum at the heartwood/sapwood boundary region, iii) a maximum at the boundary region. Ni, Cd, Cu, Zn, and Fe in ironwood are representative of the first pattern. No element could be ascribed to the second and third category. Pb content wasn't in any of the above classification. Our results was agreed with beech wood and disagreed with oakwood species (Penninckx *et al.* 2001). They reported that the Ca, Mn and K in beech wood was in first pattern, while the Ca, Mg, K and Mn concentration was in second category for oakwood in Belgian forest.

With the increase of elevation from sea level, the lignin, ash and extractives increased but cellulose amount slightly decreased (Table 2), the reason of which can be attributed to the site conditions such as altitude, soil, climate condition, and the humidity of the region. Some researchers reported that the site variation had significantly differences on the wood different properties (Doğu, 2002, Kiaei *et al.* 2012). The increase of cellulose at low altitude (100 meter) (Table 4) can be associated to the more cellular wall thickness (Vaziri *et al.* 2009). The increase of lignin percentage on intermediate altitude (500 meters) and high elevation (700 meters) can be ascribed to the excessive cell growth and cell proliferation which increase lignin macromolecules with shorter chains naturally increasing the lignin weight amount (Vaziri *et al.* 2009). The same phenomenon is true in the case of extractives increment. Regarding the high percentage of extractives in Ironwood trees at a height of 700 meters above sea level (Table 4), it is very significant to produce side products such as paper pulp, tall oil and turpentine.

Many researchers believe that there is an increase in cellulose content (due to the maturity of the cambium cells) and a decrease in the amount of extractives (due to formation of heartwood and more storage of extractives content in pith area) and lignin reduction in trees radial axis from the pith to the bark (due to the juvenile wood in the pith part) (Panshin and De Zeeuw 1980, Gominho and Figueira 1999, Scholz *et al.* 2007) which is similar to the chemical properties and changes achieved in this research. But no significant difference is existed among the radial position in terms of chemical properties (cellulose, lignin, extractives and ash) in the ironwood samples.

Some researchers have reported that wood density decreases with age or distance from the pith (Pinto *et al.* 2004). This is supported by the fact that heartwood is usually known to be of a lower density than sapwood. Our results showed that there is a decreasing trend of wood density variations along the radial axis from the pith to the bark and an increasing pattern at intermediate altitude. The increase of wood density around the pith part of tress and intermediate altitude was due to the existence of more ratio of heartwood-sapwood and saving of more extractives composition in these parts.

Ash content had most important role on the variation of Ni (82 %), Pb (84 %), Cu (78 %), Zn (88 %) and Fe (84 %) compared to other wood chemical properties (Table 7 and Figure 4). Mineral content are distributed along and radial direction in the trees (Sander and and Ericsson 1998) and they are located in the ash after combustion process (Vassilev *et al.* 2013). Then they are widely correlated with ash content as it was showed in ironwood from Iran (Table 7). However Cd content was related firstly with extractive (84%) and afterwards with ash content (7%). Another important observation showed that the lignin content was the second chemical variables related with mineral content (Table 7): in Ni with 7% of variation, in Pb with 8%, in Cu with 6%, in Zn with 5% and in Fe with 9% (Table 7 and Figure 4).

CONCLUSIONS

In this research, the effects of altitude and radial direction on the mineral content, wood density and chemical properties and the relationship between mineral content and wood density of ironwood were studied in Noshahr region in Iranian forest. The following conclusions were obtained from this research:

Analysis of variance (ANOVA) indicated that the effect of altitude on the chemical properties, wood density and mineral content were significant. With increasing of altitude from 100 to 700 m, the values of lignin, extractives, ash, and mineral content (except Pb content) increased, while Pb and cellulose content decreased (slightly). Maximum and minimum of wood density were found at intermediate and low altitudes.

ANOVA indicated that there are significant differences between radial axes with wood density and mineral content, while had not on the chemical characteristics. The wood density and mineral content (except Pb content) decreased along radial position with increasing distance from the pith.

Interaction effects between altitude and radial position on the wood density and mineral content were significant. This factor had not significant differences on the chemical properties. In each of fixed altitude, the mineral content except Pb content and wood density was decrease along radial position from the pith to the bark.

Results of Pearson correlation showed that there are significant differences between mineral content with wood density and chemical properties except the relationship between Cu and wood density. Positive relationships were found between mineral content (except Pb) content with chemical properties (except cellulose content) and wood density.

The ash content of ironwood had important significant roles on the wood mineral content except the Cd content. This property explained up of 82% of the Ni, 84% of the Pb, 78% of the Cu, 88% of the Zn and 84% of the Fe. The second and third of variables are lignin content and density, which had important effects on mineral content.

Variations in Cd content were explained by extractives content (84%) and by ash content (7%) and by lignin content (3%) in ironwood.

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