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Research Article

Al and Fe Changes in *Cedrus atlantica* Depending on Organ, Age Range, and Direction

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Abstract: Among the environmental pollution components that are among the most critical troubles of the present day, air contamination and, specifically, heavy metal (HM) contamination, whose release rises with industrial doings, are of great significance. One of the most effective methods for screening the differences in HM concentrations in the atmosphere over time is using annual rings of trees as biomonitors. This study tried to determine the changes in the concentrations of Fe and Al, the most common heavy metals, in the annual rings of the *Cedrus atlantica* tree, which was cut down at the end of 2019 in Kastamonu province, depending on the plant organ, age-range, and direction. According to the study results, the concentration of Fe element in the plant is not caused by traffic, while the concentration of Al increases due to traffic and enters the plant from the air. Study results show that both elements can be transferred in *Cedrus atlantica* wood.

Keywords: Heavy Metal; Biomonitor; *Cedrus atlantica*

Cedrus atlantica'da Organ, Yaş Aralığı ve Yöne Bağlı Al ve Fe Değişimleri

Öz: Günümüzün en kritik sorunlarından biri olan çevre kirliliği bileşenleri arasında hava kirliliği ve özellikle endüstriyel faaliyetlerle salınımı artan ağır metal (HM) kirliliği büyük önem taşımaktadır. Atmosferdeki HM konsantrasyonlarında zaman içinde meydana gelen farklılıkları taramanın en etkili yöntemlerinden biri, yıllık ağaç halkalarının biyomonitör olarak kullanılmasıdır. Bu çalışmada, Kastamonu ilinde 2019 yılı sonunda kesilen *Cedrus atlantica* ağacının yıllık halkalarında en yaygın ağır metaller olan Fe ve Al konsantrasyonlarındaki bitki organı, yaşına ve doğrultusuna bağlı olarak değişimler belirlenmeye çalışılmıştır. Çalışma sonuçlarına göre tesisteki Fe elementinin konsantrasyonu trafikten kaynaklanmazken, Al konsantrasyonu trafik nedeniyle artarak havadan tesise girmektedir. Çalışma sonuçları *Cedrus atlantica* ağacında her iki elementin de aktarılabildiğini göstermektedir.

Anahtar Kelimeler: Ağır Metal; Biyomonitör; *Cedrus atlantica*

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1. Introduction

Today, environmental pollution is one of the biggest crises around the world. The instantaneous increase in population with the industrial revolution, integrated with migration from rural to metropolitan areas, has induced a significant increase in population density in metropolitan areas (Kilicoglu et al., 2021; Şen et al., 2018). While approximately 9% of the world's population, which was around 700 million in the 1900s, lived in metropolitan areas, today, roughly 56% of the world's population lives in urban areas, and it is estimated that this rate may reach 90% by 2030 (Cetin et al., 2023). The urbanization trouble is shown as one of the irreversible crises that the world has to deal with today (Dogan et al., 2022).

Rapid population growth and urbanization bring with them many problems. One of the most critical negativities is undoubtedly environmental dirtiness (Canturk, 2023; Elsunousi et al., 2021; Key, Kulaç, et al., 2023). This process has resulted in pollution of air (Ateya, Bayraktar, & Koc, 2023; Ateya, Bayraktar, & Koç, 2023), water (Ucun Ozel et al., 2020; Xue et al., 2022), and soil (K. Isinkaralar et al., 2023; Istanbullu et al., 2023; Li et al., 2022) due to the release of various contaminants used as raw materials in the industry. In particular, air contamination has reached such severe levels that, according to the WHO (World Health Organization), about 90% of the population inhales contaminated air (Key, Kulaç, et al., 2023), and air contamination causes the death of roughly 7 million people every year (Ghoma et al., 2022). In fact, as a result of studies, air contamination is shown to be the foremost cause of global warming (Tekin et al., 2022). Global climate change (Key, Kulac, et al., 2023; Koç, 2022b) and urbanization, which are stated to occur as a result of the change in the composition of the atmosphere, are considered to be the most significant problems on a global scale (Dogan et al., 2022). These problems are related to environmental pollution, especially air contamination (Key, Kulaç, et al., 2023; Koc et al., 2024).

HMs are of specific importance among air contamination factors. HMs do not break down or disappear quickly in nature. HMs tend to bioaccumulate in living bodies, and some have lethal or carcinogenic outcomes even at lower concentrations (Kuzmina et al., 2022). Even HMs, which serve as micronutrients for living things, can have toxic effects on humans at higher concentrations (Çobanoğlu et al., 2022; Elajail et al., 2022; Koç et al., 2022). Therefore, watching HM concentrations in the atmosphere is of great significance.

The most effectively used method for screening HM pollution in the atmosphere is biomonitors. Live plants used as biomonitors can accumulate HMs in various organs, and defining the HM concentration in these organs provides essential evidence about the concentration of HMs in the atmosphere. HMs collected in the annual rings of trees over an extended span can provide us essential details about air contamination history. Reports on the usability of annual rings of plants as biomonitors have been conducted for a while (Cesur et al., 2022; Cobanoglu et al., 2023).

Within the scope of this study, the changes of iron (Fe) and aluminum (Al), which are the most common HMs, in the annual rings of a Cedar tree (*Cedrus atlantica*) growing in Kastamonu, Türkiye, were determined based on year, direction, and organ.

2. Experimental

This study was conducted on Atlas cedar (*Cedrus atlantica*) samples acquired from the Kastamonu urban center. Samples were obtained from the log taken from the main trunk in late autumn 2019 within the study scope. The site where the tree from which the samples subject to the study were taken occurs is located along the busiest street in terms of traffic density, which specifies entrance to the city midpoint. To the east of this park is the main street, where traffic density is relatively high, and to the north is the main road, with low-density traffic. The location of Kastamonu province is shown in Figure 1.

Figure 1. Location of study site, Kastamonu, Türkiye.

A log sample approximately 10 cm thick was taken from the cedar tree trunk about 50-cm from the soil level, with the north direction marked on the log. The upper surface of the taken log was sanded smooth in the laboratory to make the annual rings more clearly visible. The annual rings of the Cedar tree, determined to be 33 years old, are grouped from 1 to 11, from inside to outside, for three years, considering their width.

After the wood part was divided into clusters and age series were defined, examples were obtained from the outer bark, inner bark, and wood of each age category with the help of a steel-tipped drill and positioned in glass petri dishes. The wood examples taken were shredded and turned into sawdust. First, drying and then pre-burning processes were applied to the samples, and then Fe and Al concentrations were determined with the ICP-OES device. The method used in the study is one of the most frequently used techniques in HM analysis in the recent past (Aricak et al., 2019; Erdem et al., 2023; K. Isinkaralar, Koç, et al., 2022; K. Isinkaralar, Koc, et al., 2022; Key, Kulaç, et al., 2023). Variance analysis was applied using the SPSS 21.0 software program to the obtained data. As a result of the variance analysis, the results were evaluated by applying the Duncan analysis for the facets that were determined to have statistically significant differences at least a 95% confidence level (p<0.05).

3. Results

The change in the concentration of Fe, one of the elements evaluated in the study, depending on the direction and organ, is displayed in Table 1.

Table 1. Change of Fe element depending on direction and organ.

Organ	Directions				F value
	South	West	North	East	
Outer Bark	79722.5B	45220.3Cb	82776.5A	55844.3Db	1156.2***
Inner Bark	58145.4A	32981.3Bab	60372.8D	40729.9Cab	17793.0***
Wood	38439.0B	21803.4Aa	39911.5B	26925.9ABa	2.8*
F value	1.462 ns	8.635**	2.698 ns	6.144**	

* Different letters following each other signify the statistical alteration at p<0.05. Capital letters signify horizontal way while lowercase letters vertical direction. ns: not significant; *<0.05; **<0.01; ***<0.001. These descriptions are also valid for all Tables.

When the table values demonstrating the Fe element change are tested, the change in direction based on the variance analysis results differs statistically significantly. The peak Fe value of the outer bark part is obtained in the east direction (117634.1 ppm), the highest values of the inner bark and wood parts are found in the north (109790.2 ppm and 39911.5 ppm), while the lowest values are found in the outer bark part in the north. (24624.0 ppm), in the inner bark part in the south direction (31453.2 ppm) and the wood part in the west (21803.4 ppm). The change of Fe concentration in wood depending on the direction and age category is displayed in Table 2.

Table 2. Fe concentration changes in wood depending on age category and direction

Age category	Directions				F value
	South	West	North	East	
1987–1989	51822.8Df	13208.0Ab	28224.4Cd	24476.8Bf	8623.6***
1990–1992	176629.1Dg	16621.2Be	11462.2Aa	26685.3Ch	2819.3***
1993–1995	16601.9Bab	20487.3Dg	10757.8Aa	19901.0Cc	2368.4***
1996–1998	26404.4Cd	26540.0Ci	8740.8Aa	25989.6Bg	6590.7***
1999–2001	15126.0Ba	9687.2Aa	17094.6Eb	21340.5Ce	15.4**
2002–2004	16987.0Aab	18763.5Bf	20446.9Cbc	20559.7Cd	17.2**
2005–2007	17987.5Cbc	15123.6Bd	23770.6Dc	9255.3Aa	1432.0***
2008–2010	18364.2Abc	48784.4Bk	50687.6Be	16855.0Ab	570.6***
2011–2013	20531.0Ac	31386.4Bj	70358.6Cf	20854.1Ade	586.2***
2014–2016	24999.8Bd	14378.8Ac	75798.0Dg	40571.0Ci	3438.3***
2017–2019	37375.4Be	24857.2Ah	121685.4Dh	69696.5Cj	935.8***
F value	2734.6***	6269.0***	667.9***	5343.5***	

* Different letters following each other signify the statistical alteration at $p<0.05$. Capital letters signify horizontal way while lowercase letters vertical direction. ns: not significant; *<0.05; **<0.01; ***<0.001. These descriptions are also valid for all Tables.

When the change of the Fe element in wood is examined, the change based on age in all directions and directions in all age categories is statistically significant. Looking at the table values, out of 11 age categories, 4 of the lowest values were achieved in the west and 3 in the other directions. The difference in the Al element concentration evaluated in the study depending on the direction and organ is displayed in Table 3.

Table 3. Change of the element Al depending on direction and organ.

Organ	Directions				F value
	South	West	North	East	
Outer Bark	19522.0Bc	17385.4Ac	16133.4Dc	20367.3Cb	43899.0***
Inner Bark	14238.3Ab	12680.0Eb	11766.9Cb	14854.8Dab	9895.2***
Wood	9412.7a	8382.5a	7778.9a	9820.3a	1.9ns
F value	31.681***	13.653***	22.108***	5.536**	

* Different letters following each other signify the statistical alteration at $p<0.05$. Capital letters signify horizontal way while lowercase letters vertical direction. ns: not significant; *<0.05; **<0.01; ***<0.001. These descriptions are also valid for all Tables.

When the change of Al concentration on an organ basis is examined, it is listed as outer bark>inner bark>wood in all directions. While there was no statistically significant difference between the directions in the wood part, the highest values in the barks were obtained in the north and east directions. The change of Al concentration in wood depending on the direction and age category is displayed in Table 4.

Table 4. Change of Al element in wood depending on age category and direction.

Age category	Directions				F value
	South	West	North	East	
1987–1989	6704.3Bb	6663.0Bc	6118.3Ab	8135.4Ce	539.0***
1990–1992	14298.8Dj	5859.0Ab	6904.3Bb	8976.8Cf	1156.4***
1993–1995	8525.8Be	15775.2Di	4803.5Aa	13489.0Ci	5796.5***
1996–1998	10084.8Cg	10897.6Ch	4757.0Aa	7053.7Bd	40.5***
1999–2001	5732.7Ca	3244.0Aa	6143.2Db	3596.0Ba	284.2***
2002–2004	7531.6Cc	6682.2Bc	7886.1Dc	5752.2Ab	4359.8***
2005–2007	7985.8Bd	10052.6Df	8529.2Ccd	5863.2Abc	754.1***
2008–2010	9525.0Df	6476.7Bc	8758.6Cd	6032.8Ac	1019.4***
2011–2013	10123.3Bg	10578.2Cg	8962.8Ade	10171.2Bg	84.7***
2014–2016	11196.8Ch	7035.7Ad	9648.0Be	12902.1Dh	710.7***
2017–2019	11830.8Bi	8943.9Ae	13056.8Cf	26050.8Dj	7291.8***
F value	723.1***	2432.1***	80.4***	6548.0***	

* Different letters following each other signify the statistical alteration at $p<0.05$. Capital letters signify horizontal way while lowercase letters vertical direction. ns: not significant; *<0.05; **<0.01; ***<0.001. These descriptions are also valid for all Tables.

When the table values are examined, the age category in all directions and the change in direction in all age categories are statistically significant. Another striking result in the table is that although there is a difference of nearly three times between neighboring woods, there are no sharp differences between the values.

4. Discussion and Conclusions

As a consequence, it was found that Fe and Al elements changed significantly on an organ basis. The highest values in all aspects of the Al element were obtained in the outer bark and the lowest in the wood. At the same time, this was not the case for the Fe element. According to these results, the Fe accumulation in the barks of the species subject to the study is soil-borne, and the Al accumulation is air-borne. HMs enter the plant body directly from the soil through root cells and the air through foliages and stem (Key, Kulaç, et al., 2023). However, the concentrations obtained in the bark are much higher for many HMs. Studies have pointed out that HMs in the atmosphere stick to particulate matter (PM) and contaminate the PM with HMs. As this PM settles on plant organs, the HM concentrations in these organs increase (Cesur et al., 2022). The rough external structure of the outer bark makes it easier for PM to adhere there (Koç, 2021). Therefore, according to the study results, Al in the bark probably settles in the bark together with PM from the air, while Fe is taken from the soil.

As a consequence of the study, the topmost Al concentrations in the outer bark were obtained in the northern and eastern directions. However, there is no significant difference between the directions in Fe. There are hectic highways to the north and east of the point where the sample was taken. This result can be interpreted as AI being caused by traffic. Studies show that vehicles are one of the most significant sources of HMs (Aricak et al., 2019; Ghoma et al., 2023).

As a result of the study, it was determined that Fe and Al concentrations in wood were highly variable and that there was a several-fold difference between the concentrations obtained in neighboring wood samples. However, there is still a relatively moderate transition between values. However, in studies conducted to date, it has been determined that there are huge differences between neighboring wood samples in many HMs (Key, Kulaç, et al., 2023; Koc et al., 2024). Therefore, the study results can be interpreted as the transfer of both elements in the wood of the species subject to study, albeit limited.

The study results show that the species subject to the study can accumulate both HMs intensively. The potential of plants to absorb and accumulate HMs depends on many factors, such as organ structure, weather conditions, plant habitus, and the structure of the HM and its link with the plant (Savas et al., 2021). These factors are also linked to other factors. For example, plant physiology is shaped by genetic structure (Hrivnák et al., 2024; Sevik et al., 2012) and environmental conditions (Ertugrul et al., 2019; Koç & Nzokou, 2022b, 2022a; Sevik et al., 2019). Therefore, all features affecting tree physiology also distress the entry and accumulation of HMs into the tree, which affects plant physiology: genetic structure (Kurz et al., 2023; Sevik et al., 2016), edaphic (Yigit et al., 2023), climatic (O. Isinkaralar et al., 2024; Işınkaralar et al., 2023; Sevik et al., 2017) factors, stress factors (Cantürk et al., 2023; Halil Baris Ozel et al., 2021; Koç, 2022a; Koç & Nzokou, 2023). Thus, several of these features, directly and indirectly, distress plants' HM accumulation potential, and information about this complex mechanism is still restricted (K. Isinkaralar, Koc, et al., 2022; Sulhan et al., 2023; Varol et al., 2022).

In conclusion, the concentration of Fe element in the plant is not caused by traffic, while the concentration of Al increases due to traffic and enters the plant from the air. It is concluded that both elements can be transferred in *Cedrus atlantica* wood.

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