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Physiological responses of different Oak species to dust in Northern Zagros Forests, Iran

Physiologische Reaktion von verschiedenen Eichenarten auf Staub im nördlichen Zagroswald, Iran

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Keywords: dust, *Quercus libani*, *Quercus infectoria*, *Quercus brantii*, Photosynthesis, Chlorophyll, Proline, Zagros Forest, Reforestation

Schlüsselbegriffe: Staub, *Quercus libani*, *Quercus infectoria*, *Quercus brantii*, Photosynthese, Chlorophyll, Prolin, Zagros Wald

Abstract

This study was conducted to examine the impacts of dust on leaf mineral elements and selected physiological responses of three different Oak species in Western Zagros, Iran. Three-year-old seedlings of the Oak species *Quercus brantii*, *Q. libani* and *Q. infectoria* were exposed to dust under natural conditions. Photosynthesis, chlorophyll, proline and selected leaf mineral elements were examined in a two-factorial experiment including species (*Q. brantii*, *Q. libani* and *Q. infectoria*) and dust exposure (dust-exposed and without dust as control). The results showed that dust had a significant effect on photosynthesis rate of all species. Dust decreased photosynthesis rate to about 38%, 13% and 32% for *Q. brantii*, *Q. libani* and *Q. infectoria*, respectively. Dust also had a significant effect on

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proline and chlorophyll content of Oak leaves. *Q. infectoria* had the lowest total chlorophyll content with 42%. Among the studied species, *Q. libani* appears to be most suitable for growing under dust exposure, as this species had the lowest reduction in chlorophyll and photosynthesis. Planting *Q. libani* on northern slopes in Zagros forests, where Oak forests receive higher precipitation, presumably enhances the success of forest restoration under the combined effects of climate change and dust exposure.

Zusammenfassung

Diese Studie hat das Ziel die Auswirkungen von Staub auf Blattmineralelemente und ausgewählte physiologische Reaktionen von drei verschiedenen Eichenarten im westlichen Zagros, Iran, zu untersuchen. Drei Jahre alte Sämlinge von *Quercus brantii*, *Q. libani* und *Q. infectoria* wurden unter natürlichen Bedingungen Staub ausgesetzt. Photosynthese, Chlorophyll, Prolin und ausgewählte Blattmineralelemente wurden in einem zweifaktoriellen Experiment untersucht, hinsichtlich Baumart (*Q. brantii*, *Q. libani* und *Q. infectoria*) und Staubexposition (staubexponiert und ohne Staub als Kontrolle). Die Ergebnisse zeigten, dass Staub einen signifikanten Einfluss auf die Photosyntheserate aller Arten hatte. Staub verringerte die Photosyntheserate für *Q. brantii*, *Q. libani* und *Q. infectoria* auf etwa 38 %, 13 % bzw. 32 % im Vergleich zu Kontrollvariante. Staub hatte auch einen signifikanten Einfluss auf den Prolin- und Chlorophyllgehalt der Eichenblätter. *Q. infectoria* hatte mit 42 % den niedrigsten Gesamtchlorophyllgehalt. Unter den untersuchten Arten scheint *Q. libani* am besten für das Wachstum unter Staubeinwirkung geeignet zu sein, da diese Art die geringste Reduzierung von Chlorophyll und Photosynthese aufwies. Die Anpflanzung von *Q. libani* an Nordhängen in Zagros-Wäldern, wo Eichenwälder höhere Niederschläge erhalten, steigert vermutlich den Erfolg von Aufforstungen unter den kombinierten Auswirkungen von Klimawandel und Staubexposition.

1 Introduction

Dust particles is an important source of air pollution including a mixture of particles suspended in the atmosphere. Overall, particulate matter (PM) includes different types of materials ranging from fine solid materials like soil dust, various types of micro-organisms, ashes, plant pollens, soot and many others (Pandey and Singh, 2012). Anthropogenic activities such as mining and land use changes are one of the most important sources of PM (Schelle-Kreis *et al.*, 2007; Ghaffari and Mostafazadeh, 2015). In general, two types of pollutants have been detected in aerosols: the first type includes SO_2, NO_2, CO compounds and heavy metals, especially lead and cadmium, and the second type including physical, chemical and biological components in dust (Zarasvandi *et al.*, 2011). Since 1990 with the development of precise measuring equipment, particles with an aerodynamic diameter smaller than 10 micrometers (PM10) could have been detected and are now called suspended particles (Particulate Matter) by United States Environmental Protection Agency (Irene *et al.*, 2009).

Dust and sand storms sweep the western parts of Iran every year from March to June, endangering human health, fauna and flora. An important source of these fine particles are neighboring countries, where misuse of water resources and severe drought contributed to soils erosion even at low-speed winds (Boloorani *et al.*, 2020; Jahanbakhsh *et al.*, 2022). Over the last few decades, due to different reasons including war, agricultural activities and natural drought, dust flux into Iran has intensified in terms of both frequency, duration and severity (Javanmard *et al.*, 2019, Moradi *et al.,* 2017). Dust threatens ecology, economic activity and even the social life of inhabitants in the frontier cities where people are directly exposed to continuous flows of particles (Moradi *et al.*, 2017). Because of their immobility, trees and plants are heavily exposed to dust deposition (Javanmard *et al.*, 2020). Depending on the deposition rate, chemical composition of the particles, particle size and tree age, the reaction of trees to the dust will vary (Darley, 1996; Chaturvedy *et al.*, 2013). Some tree and plant species appear to have a higher potential for dust accumulation on their surfaces. For example, *Celtis caucasica* compared to *Melia azedarach* and *Fraxinus rotundifolia* accumulated more dust, but was also more vulnerable to the effects of dust. *Morus alba* was recognized as desirable tree for dust reduction and has been suggested to be the most suitable species for urban forests of semiarid zones, where dust pollution is high (Javanmard *et al.*, 2020).

The dust-retention capability of trees is determined by tree age and structure of the leaves, presence or absence of trichomes and wax on the leaf surface, height of plant, surface geometry, phyllotaxy, epidermal and cuticular features, orientation of the leaf and length of petiole (Chaturvedi *et al.*, 2013; Javanmard *et al.*, 2020). Studies show that dust affects trees and plants through depositing on their leaves and also by making chemical changes to soil characteristics in the habitats where they grow. When particles cover tree leaves, leaves receive less light and this leads to lower photosynthesis and in consequence less biomass produced (Wijayratne *et al.*, 2009). Moreover, lower photosynthesis in fruit trees is associated with lower productivity in terms of grains and fruit. Studies show that different species react differently to dust flux. For example, in *Q. infectoria*, dust has the greatest impact on photosynthesis, stomatal conductance, leaf internal CO_2, transpiration and mesophyll conductance (Siqueira-Silva *et al.*, 2016), while for *Q. brantii*, dust has a greater effect on photosynthesis and mesophyll conductance.

Considering that Iran and its Western neighbors are in the dry and semi-arid belt of the world, more than two-thirds of Iran's area is in the dry and semi-arid climate. Moreover, recording annual rainfall less than 250mm, Iran is at risk of dust phenomenon. Studies show that dust storm events have dramatically changed in terms of the amount and size of suspended particles, duration, extent and time over the past two decades. And compared to the previous events, the number of dusty days in the west of the country increased from less than 16 days until 2005 to more than 130 days in 2010. Measuring chlorophyll is an important tool for evaluating the effects of air pollutants on plants, because it plays an important role in plant metabolism. With the deposition of fine dust particles on the surface of the leaf, a shadow is created on the outer surface of the leaf, and it probably causes a decrease in light absorption and subsequently decreases the concentration of chlorophyll. The amount of proline increases in different plants under different stresses. In comparison with other common osmolytes, especially common and alcoholic sugars, proline has a higher efficiency for protection against stress and with a direct effect in stabilizing macromolecules and their water absorbing layers and also because Its antioxidant properties indirectly show a protective effect (Delauney and Verma, 1993). Air pollution weakens trees and reduces their resistance to natural stresses. The increase in pollution, which includes dust, disrupts the process of photosynthesis and the amount of production of organic compounds in trees and causes the trees to weaken.

Zagros forests or western oak forests are in the west of Iran covering 6 million ha (Sadeghi *et al.*, 2017). Along with grasslands in Kurdistan, oak forests in Kurdistan are important natural environments which provide habitats for wild animals and endemic plant species and for recreational opportunities for people in the region (Karami et al. 2021). In addition, numerous springs contribute to water resources that are used for agricultural, recreational and household purposes (Karami *et al.*, 2019; Jahanbakhsh *et al.*, 2022). The forests are composed of different communities of plants and trees and act like a natural filter on which dust is deposited every year. These oak woodlands have been continuously experiencing flows of dust over the last few decades. It has been reported that being exposed to dust flux may in the long run facilitate a loss of these valuable woodlands (Moradi *et al.*, 2017). Studies on the effects of dust on oak trees showed that dust flux disrupted physiological activities of oak species, decreased leaf gas exchanges and increased leaf internal CO_2 concentration (Moradi *et al.*, 2017). Although previous studies reported some of the effects of dust on specific plant species, aspects relating to the leaf mineral elements and physiological properties of the western oak forests have not yet been investigated.

The objectives of this study are

(1) quantifying dust deposition on three *Quercus* sp., which are the dominant species of Zagros forests,
(2) exploring the effect of dust deposition on leaf nutrient, proline and chlorophyll content and
(3) investigating the impact of dust on photosynthesis.

2 Materials and methods

2.1 Study area

This investigation was carried out in 2020 in a wooded area approximately 35 km from Mariwan (46°17'28.96'' to 46°20'32.04'' E and 35°36'12.97'' to 35°39'57.86'' N latitude) at an altitude of 1700 m (Fig. 1). An area of 1705 hectares directly exposed to dust was selected for study. Mean annual precipitation is 800 mm (Iran Meteorology Organization, 2021; Sadeghi *et al.*, 2021; Balist *et al.*, 2022). In most years the maximum monthly precipitation occurs in February and the minimum in June. The mean annual temperature is 16 °C and the study area is described as "Csa" (Mediterranean Climate) in the Köppen Climate Classification. Soils have a sandy loam texture, with a pH of 6.5-7. The common tree species in the area include *Quercus brantii*, *Q. libani* and *Q. infectoria*, the species selected for this study, and *Pistacia atlantica*, *Pyrus* Sp., *Crataegus* sp., *Acer monspesulanum*, *Amygdalus* sp., and *Cerasus* sp.

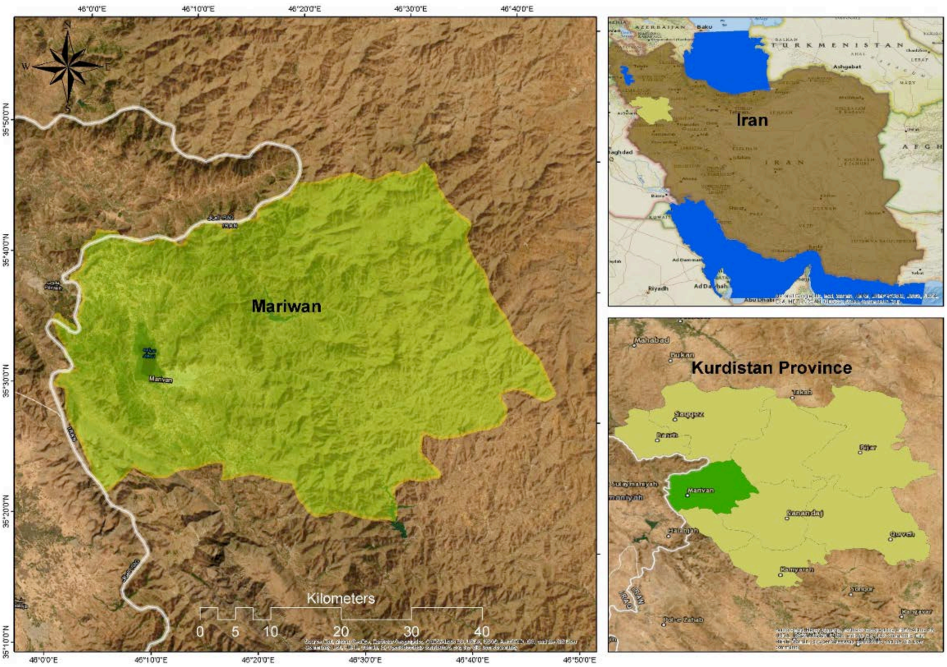

Figure 1: Location of the studied sites in Mariwan County, Kurdistan Province, Iran.

Abbildung 1: Lage des Untersuchungsgebietes in Mariwan, Provinz Kurdistan, Iran.

2.2 Field design and statistical analysis

To assess the effects of dust, three-year-old seedlings of oak trees *Quercus brantii*, *Q. libani* and *Q. infectoria* were used. The potted seedlings from Rikhlan nursery in Mariwan (Iran) were transferred to the study region in Chenare district of the Mariwan forests (Spring, 2017). Seedlings were divided into two groups of 45 pots. Fifteen potted seedlings of each species were placed in individual groups. One group was set as the dust treatment and the other was assigned as control. The seedlings were irrigated once every 4 days from 9th April until 10th July. To irrigate the pots, every three days 0.5 liter of water was applied to each pot. The leaves of seedlings in the control pots were washed during irrigation to remove dust while water was only poured in the pots with no leaf contact in the dust treatment pots. To increase the accuracy in the research procedure, the direction of wind on the pots was marked. To evaluate the real impact of dust particles on the studied species of seedlings, the studied species were exposed to the dust in a part of the forests of Chanare Marivan. No artificial pollination was done on the seedlings, and they were exposed to dust during the dust period. For this purpose, five-year-old seedlings of three studied species were used. For this purpose, the seedlings were transferred to the study area in April (before the beginning of the growing season and before the dust storms). The seedlings were divided into two groups after establishment in the study area. Group one as dust treatment and one group as control. To increase the accuracy in the research process, the direction of pollen blowing was marked on the pots.

Figure 2: Three-year-old seedlings of oak trees Quercus brantii, Q. libani and Q. infectoria.

Abbildung 2: Drei Jahre alte Bäume der Eichenarten *Quercus brantii*, *Q. libani* und *Q. infectoria*.

2.3 Photosynthesis, chlorophyll, proline and mineral elements assessment

IRGA (Infrared Gas Analyzer, ADC Company) was used to measure the photosynthesis rate for the studied species. The Arnon (1949) method was used to investigate the possible effect of dust on leaf chlorophyll content. To evaluate the status of the species exposed to dust compared to control samples and whether the dust caused stress in the studied plants, the Bates (1973) method was used to measure leaf proline content. Leaf nitrogen content was measured using the Kjeldahl method, a spectrophotometer was used to measure phosphorus level, and other mineral elements were measured using an atomic absorption spectrophotometer (AAS) to evaluate the effects of dust on mineral elements of the leaves.

Assess the amount of dust deposited on leaves

To estimate the amount of deposited dust, 20 leaves from the plucked leaves containing dust of each species were washed separately with distilled water (both sides of the leaves). Then the resulting dust solution was placed in a centrifuge (for 15 minutes at a speed of 5000 per minute) and its precipitated part was separated by depositing dust particles. Then, the separated sediment part (dust particles) was placed in an oven at a temperature of 70 °C for 48 hours. After drying, the dust particles were carefully weighed for each species separately in the laboratory. Then, using the average area of the collected leaves, the weight of the amount of dust deposited in the average area of the leaf was estimated separately for each of the species.

2.4 Statistical analysis

After checking the normality of the data and residuals using the Kolmogorov-Smirnov test, data were analyzed in a factorial approach with two factors: type of species (*Q. branti*, *Q. libani* and *Q. infectoria*), and dust at two levels (one containing dust and the other without dust as control). Then, a Duncan test was performed to study the difference between means when the assumption of the equality of variances was confirmed. All analyses were conducted using SPSS software, version 23.

3 Results

3.1 The amount of dust deposited per leaf

Table 1 shows the amount of dust deposited per leaf and tree surface area. As it can be seen, the highest deposited dust was recorded for *Quercus brantii* with 12 mg per leaf.

Table 1: The amount of dust deposited deposited (mean ± standard deviation) per leaf per leaf by species. Similar Roman letters after parameters indicates no difference at 5% level (same applies for the following tables).

Tabelle 1: The Staubmenge pro Blatt und die Blattfläche (Mittelwert ± Standardabweichung) für die untersuchten Arten. Ähnliche Buchstaben nach Parameter zeigen keine signifikanten Unterschiede auf 5-%-Niveau an (das selbe gilt für die folgenden Tabellen).

Variables	*Q. infectoria*	*Q. libani*	*Q. brantii*
Dust (mg/leaf)	5.5±0.01 b	5.0±0.00 b	12.00±0.02 a
Dust (mg/cm^2)	0.23±0.01 b	0.21±0.00 b	0.30±0.02 a
Mean leaf area (cm^2)	23.21±0.98 b	23.27±0.89 b	39.73±2.10 c

3.2 Leaf photosynthesis rate

The results showed that the type of species had a significant effect on the level of photosynthesis, with photosynthesis rates among the three species being significantly different. In addition, results showed that the presence of dust had a significant effect on the photosynthesis of the different oak species. It was also found that the interaction of species and dust at the level of the studied variable was not statistically significant, that is, each factor (species and dust) had an independent effect on photosynthesis.

The results in Table 2 showed that dust deposition on the leaves of the three studied species reduced photosynthesis rates (Figure 3). This reduction was statistically significant in the *Q. brantii* and *Q. infectoria* species, but not in *Q. libani*.

Table 2: Photosynthesis rates (mean ± sd) of the species studied exposed to dust.

Tabelle 2: Photosyntheseraten (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Photosynthesis	**Dust**	12.83±0.53 bc	8.77±1.05 a	9.86±1.59 ab
(µmol $CO_2/m^2/s^1$)	**control**	14.75±0.65 c	12.85±0.91 bc	15.91±0.44 c

3.3 Leaf chlorophyll content

The results revealed that in general, species type had no significant effect on the leaf chlorophyll content, that is, the difference in chlorophyll a, b and total chlorophyll among the three studied species (Figure 3) was not statistically significant. In relation to the presence or absence of dust on the leaves of the studied trees, the presence of dust had no significant effect on the amount of chlorophyll a, b and total chlorophyll pigment (α = 5%). It was also observed that species and dust interacted in the amount of chlorophyll and total chlorophyll pigments, but in the case of chlorophyll b, each factor (species and dust) had an independent effect.

The results in Table 3 and Figure 3 show that only in the *Q. infectoria* species did dust deposition on the leaves have a significant effect on the amount of chlorophyll pigment, in that dust significantly reduced the chlorophyll a, b and total chlorophyll in *Q. infectoria*. In other species, especially in *Q. brantii*, although there was a difference between the control and dust treatments in terms of chlorophyll pigments, this difference was not statistically significant compared to other examined species.

Table 3: Mean (±sd) Chlorophyll content (mg/g fresh tissue) in the studied species under the influence of dust.

Tabelle 3: Chlorophyllgehalt (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Chlorophyll a	Dust	1.66±0.15 bcd	1.09±0.14 a	1.33±0.14 abc
	Control	1.67±0.07 bcd	1.86±0.08 d	1.79±0.07 cd
Chlorophyll b	Dust	0.48±0.06 ab	0.31±0.04 a	0.37±0.03 ab
	Control	0.41±0.04 ab	0.55±0.03 b	0.47±0.03 ab
Chlorophyll Total	Dust	2.17±0.21 bc	1.42±0.18 a	1.72±0.18 ab
	Control	2.10±0.11 bc	2.44±0.12 c	2.29±0.10 bc

3.4 Leaf proline content

As indicated in Table 4, dust deposition on tree leaves had a significant effect on the leaf proline content only in *Q. infectoria*, with dust in *Q. infectoria* leaves increasing proline content. Dust had the same effect on *Q. brantii*, but the difference was not significant. In *Q. libani*, the amount of proline in the dust treatments and control was almost equal (Table 4 and Figure 3).

Table 4: Mean (± sd) of proline (mg/g dry weight) in the leaves of the studied species under the influence of dust.

Tabelle 4: Prolingehalt (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Proline	Dust	3.5±0.25 a	8.8±0.21 b	3.1±0.16 a
	Control	3.4±0.42 a	3.2±0.26 a	2.9±0.12 a

3.5 Leaf mineral element contents

The current results showed that all the studied elements in the three species had a significant difference with each other at the level of 1% probability. Except for phosphorus, nitrogen and manganese, exposure to dust had a significant effect on all elements. Species and particulate matter factors interacted with phosphorus, sodium, magnesium, calcium, iron, and zinc, but each factor (species and particulate matter) had an independent effect on nitrogen, potassium, manganese, and copper.

Examination of the differences between the means of measured elements in leaves showed that the amount of magnesium in the three oak species increased significantly when exposed to dust. Potassium levels increased in all three species, but it was significant only for *Q. libani*. Iron levels also increased in all three species, although this increase was significant only for *Q. infectoria*. Conversely, copper and zinc elements showed a decreasing trend under the influence of dust. Also, calcium was significantly reduced in *Q. brantii* and *Q. libani* species. Phosphorus significantly increased in *Q. infectoria* under the influence of dust. Nitrogen showed a decreasing trend under the influence of dust, but only in *Q. libani* was this decrease significant (Table 4). Manganese, however, increased under the influence of dust but not significantly.

Table 5: Amount (mean ± sd) of mineral elements in leaves of the studied species under the influence of dust.

Tabelle 5: Mineralelemente (Mittelwert ± Standardabweichung) in Blättern der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
P (%)	Dust	8.8±0.82 bc	7.9±0.51 b	9.5±0.49 bc
	Control	8.0±0.84 b	2.1±0.60 a	12.7±0.84 a
N (%)	Dust	0.63±0.02 a	0.57±0.04 a	0.69±0.04 ab
	Control	0.97±0.05 b	0.58±0.03 a	0.62±0.06 a
Na (ppm)	Dust	1.12±0.13 bc	1.72±0.18 d	0.67±0.03 a
	Control	1.37±0.14 c	1.34±0.09 c	0.83±0.06 ab
Mg (ppm)	Dust	23.18±0.75 c	30.10±0.34 e	27.05±0.65 d
	Control	20.17±0.58 b	23.25±0.73 c	16.91±0.77 a
K (ppm)	Dust	61.51±1.93 a	67.55±1.07 de	43.24±9.34 abc
	Control	38.32±1.54 ab	56.05±4.17 bcd	23.79±12.99 a
Ca (ppm)	Dust	0.61±0.06 cd	1.67±0.18 cd	0.71±0.04 a
	Control	0.89±0.34 e	1.24±0.14 de	0.72±0.07 de
Mn (ppm)	Dust	0.61±0.06 a	1.67±0.18 c	0.71±0.04 a
	Control	0.89±0.34 ab	1.24±0.14 bc	0.72±0.07 a
Fe (ppm)	Dust	1.23±0.33 ab	1.86±0.46 b	0.51±0.08 a
	Control	0.59±0.21 a	0.45±0.02 a	0.39±0.04 a
Cu (ppm)	Dust	0.01±0.00 a	0.02±0.01 a	0.01±0.00 a
	Control	0.02±0.01 a	0.07±0.02 bc	0.04±0.01 ab
Zn (ppm)	Dust	0.23±0.00 a	0.27±0.01 ab	0.23±0.01 a
	Control	0.33±0.02 b	0.29±0.01 ab	0.31±0.05 ab

3.6 Relative effect of dust removal in percent by species for photosynthesis, chlorophyll and proline

The results showed that dust particles reduce the amount of photosynthesis in oak species. dust particles have the greatest effect on the photosynthesis of the species of *Q. brantii* and *Q. Infectoria* (38 and 31.8%, respectively) (Fig. 3). Although the effects of dust on Q. libani was not as great as the other two species, it effects on the *Q. libani* was 12.8 percent. The greatest relative effect of dust on chlorophyll content was observed in two species *Q. brantii* and *Q. Infectoria*. In *Q. libani* species, it has no effect on the amount of chlorophyll (Fig. 3). Dust particles had the highest effect in increasing proline in *Q. Infectoria* species. The relative increase in this species was 177% (Fig. 3).

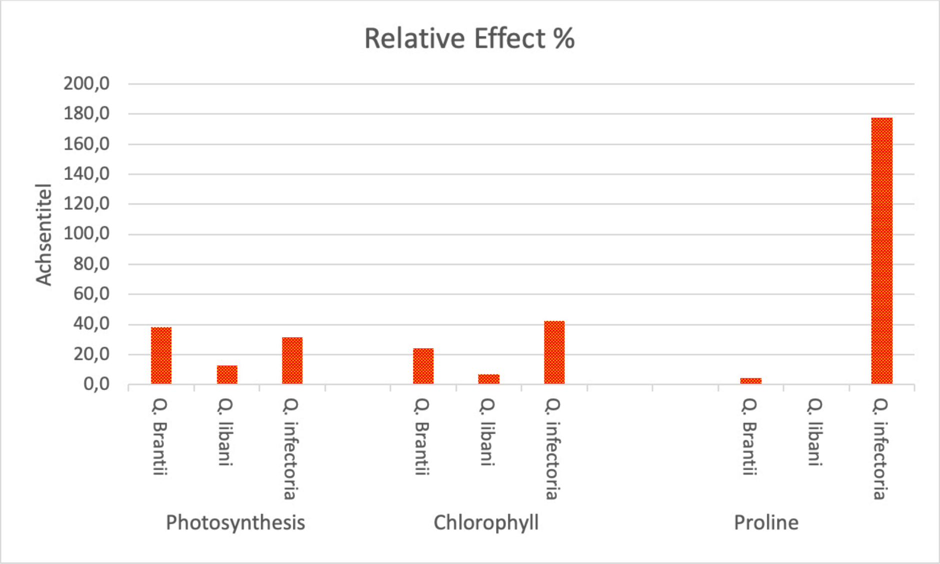

Figure 3: Relative effect of dust removal in percent by species for photosynthesis, proline and chlorophyll.

Abbildung 3: Relativer Effekt von Staubexposition in Prozent pro Baumart hinsichtlich Photosynthese, Prolin- und Chlorophyllgehalt.

Figure 4 shows the relative effect of dust on leaf nutrients. As this figure shows, the most changes are in the Fe, P, K and Cu elements.

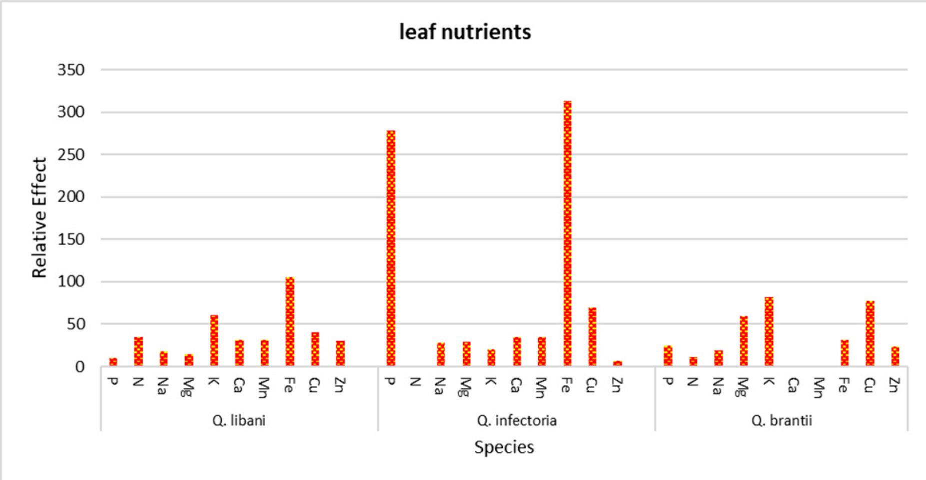

Figure 4: The relative effects on leaf nutrients for different Oak species.

Abbildung 4: Relativer Effekt von Staubexposition in Prozent pro Baumart hinsichtlich Mineralelemente in Blättern.

4 Discussion

4.1 Photosynthesis

The present study provides insight into the physiological responses of different oak species to dust exposure in Northern Zagros in the western oak forests in Iran. Based on our results, photosynthesis rates among the studied species were significantly different and were also significantly affected by dust deposition. Dust in all three studied species reduced the photosynthesis rates of the leaves (Table 1). In general, one of the reasons for decreases in plant growth is the limitation of photosynthesis due to various stresses, including air pollution (Eller, 1997; Thompson *et al.*, 1984). Photosynthetic limiting factors are divided into the two categories of stomatal factors, which reduce the entry of CO_2 into the intercellular space, and non-stomatal factors that limit photosynthesis through the direct effect on biochemical manufacturing processes. Fischer *et al.*, (1998) confirmed that closure of stomata is one of the most important factors in reducing photosynthesis, which in turn, reduces the stomatal conductance and ultimately the amount of photosynthesis. In addition to reducing the rate of photosynthesis, stomatal restriction also reduces the concentration of carbon dioxide in the intercellular space of the leaf, which consequently reduces plant biomass (Lawlor and Cornic, 2002). In the present study, the stomatal apertures were probably closed by dust particles and consequently the amount of gas exchange was significantly reduced, which may be an important reason why the rate of photosynthesis in all three species exposed to dust was lower than the control. The rate of reduction in photosynthesis depends both on the obstruction in stomata and the rate of reduction of light absorption by the plant leaves. Plants which are exposed to large and chronic sources of dust are at risk abiotic stresses. Photosynthesis and consequently a decrease in growth (Takashi, 1995; Woo *et al.*, 2007).

Previously published electron microscope images show that the type of leaf wax coating in *Q. infectoria* species is of an irregular platelet type which causes the retention of dust particles on the leaf and also traps dust particles between parts of this wax, and as a consequence blocks the stomata (Moradi *et al.*, 2017). In addition, a high accumulation of dust on the leaf surface causes leaf temperature to rise and as a result, photosynthesis in the leaves is reduced (Javanmard *et al.*, 2020).

Several investigations have pointed to differences in the shape and density of the trichome and also the special shape of the wax surface of the leaf in different oak species (Panahi *et al.*, 2012; Moradi *et al.*, 2017). These different leaf structures can determine the amount of dust settling on the leaf, so it can be concluded that the leaf structure along with the amount of dust on the leaf determine the degree of obstruction of the stomata in and following dust storms. Moradi *et al.* (2017) found that the rate of obstruction of leaf stomata due to dust was 61.6%, 48.4% and 38.1% in *Q. infectoria*, *Q. libani* and *Q. brantii*, respectively. The results of the present study are in agreement with this research and show that *Q. infectoria* species is more sensitive to dust than the other examined species.

It should also be noted that in all three studied species, depending on the position of the leaf, mass accumulation of dust particles occurred, causing stomata to be completely blocked, disrupting gas exchange, reducing the absorption of light over leaf surfaces and finally raising leaf temperature (Sharifi, 1997; Wijayratne *et al.*, 2009; Javanmard *et al.*, 2020). Blocked stomata lead to a reduction in photosynthesis and plant production (biomass). Sharifi *et al.* (1997) reported that the uncontrolled accumulation of dust on plants changes the air flow on plant organs and, most importantly, when the dust load becomes greater, a significant percentage of the stomates are blocked and consequently a reduction in gas exchange and an increase in leaf temperature takes place.

The results of the present research are consistent with those described by Darley (1966), Eveling (1969), and Borka (1980). In these studies, it was mentioned that one of the potential effects of dust on photosynthesis is that a thick coating of dust on the leaf surface reduces stomatal conductance, decreases evapotranspiration, and finally increases leaf temperature and reduces growth. According to Thompson *et al.* (1984), photosynthesis decreases dramatically when 5 to 10 grams of dust per square meter is deposited on the leaves. The results of another study showed that an ash covering of 1 mm on the leaf surface reduces the photosynthesis process by up to 90% (Sett,

2017) At thicknesses less than 1 mm, the reduction rate varies between 25 and 33%. Of course, this effect will be different depending on the conditions and type of plant. The presence of dust on the leaf surface, in addition to reducing photosynthesis, will cause premature leaf aging and delay in plant growth and consequently reduce plant yield (Arvin and Cheraghi, 2014).

Seyyed Nejad *et al.* (2011) noted that air pollution stress causes the stomata to close, thereby reducing the CO_2 content in the leaves and inhibiting carbon, which is consistent with the results of this study that indicate the important role of stomatal behavior in responding to the effects of dust.

Roshanfekr *et al.* (2012) stated that the most sensitive indicator for examining the physiological condition of the plant, especially under stress conditions, is the behavior of the stomata. Another important factor in the discussion of dust is the size of the leaf stomata (Liang *et al.*, 2016). Some studies have shown that very fine particles (<0.1 microns) can enter the leaves through the stomata (Song *et al.,* 2015; Lehndorff *et al.*, 2006), but larger particles are deposited on the stomata when they are open, disrupting the gas exchange process which in turn affects photosynthesis, water retention, and overall growth (Rai *et al.,* 2010). Heavy metals are transported into the stomata openings directly into the leaf, while to move through the cuticle heavy metals must be in ionic form (Uzu *et al.*, 2010).

4.2 Leaf chlorophyll content

One of the most common effects of air pollution is a gradual decrease in chlorophyll and yellowing of the leaves, which may be due to a decrease in the photosynthetic capacity of the leaves (Joshi and Swami, 2009). The results of this study showed that there was no significant difference in chlorophyll a, b and total chlorophyll pigments between controls of the three studied species, but the presence of dust on the leaves had a significant effect on the amount of chlorophyll a, b and total chlorophyll pigments (α=5%). The shadow effects caused by the deposition of dust particles on the leaf surface probably reduced light absorption and consequently the chlorophyll concentration. Sediment particles may block the stomata, thereby disrupting gas exchange and increasing leaf temperature, as well as reducing chlorophyll content (Sandelius *et al.*, 1995; Banerjee *et al.*, 2003). These findings are in agreement with some studies which reported a decrease in chlorophyll content under dust particles and air pollution (Prusty et al. 2005; Seyyednejad, 2011; Chen *et al.*, 2015; Tiwari *et al.,* 2006; Joshi and Swami, 2007; Tripathi and Gautam, 2007; Joshi *et al.*, 2009; Agbaire and Esiefarienrhe, 2009).

The results of this study showed that only in *Q. infectoria* did dust deposition on the leaves have a significant effect on the amount of chlorophyll pigment, significantly reducing chlorophyll a, b and total chlorophyll in this species. Similarly, a decrease in the amount of chlorophyll pigments has been reported due to air pollution (Sharma and Tripathi, 2009). A substantial reduction in chlorophyll between 35% and 60% has been noted in some tree and shrub species due to contamination in industrial areas (Nayek *et al.*, 2011). A relationship has also been found between contamination density and photosynthetic activity, total chlorophyll content, and premature leaf aging (Honor *et al.*, 2009). Decreased photosynthesis rates may be due to insufficient production of chlorophyll or oxidation of chlorophyll by free radicals (Shiazaki *et al.*, 1980). According to the current results, in the other two species, especially in *Q. brantii*, there was a difference between control and dust in terms of chlorophyll pigments, but this difference was not statistically significant. Chlorophyll synthesis in *Q. infectoria* was more sensitive to dust than the other two examined species.

4.3 Leaf proline content

Some studies have shown that free proline content increases in response to various environmental stresses in plants (Levitt, 1972) such that, under different stresses, the amount of proline in different plants increases. For example, in plant leaves exposed to SO_2, heavy metals and other environmental stresses (Wang, 2011), leaf proline level increased. In fact, proline accumulation is one of the metabolic methods used by plants in response to stress (Hua *et al.*, 1997; Levitt, 1972). In general, the amount of proline in the leaves of the species in this study were substantially different from each other. Dust had a significant effect on the leaf proline content of *Q. infectoria*, increasing the proline content. It had the same effect in *Q. brantii*, although this effect was not significant. Since proline content increases in response to various stresses in plants, it may play a role in plant defense mechanisms. However, in this study proline increased in response to dust exposure and the impact on the proline content among the examined species was different. *Q. infectoria* showed a significant increase in proline content compared to the control, which indicates the high sensitivity of this species to dust in comparison to the other two species.

Proline has been reported to act as a free radical scavenger to protect plants from oxidative stress damage (Wang, 2011). Numerous studies have reported an increase in reactive oxygen species (ROS) due to environmental stresses such as air and soil pollution, low and high temperatures, and drought. The ROS produced is highly reactive and toxic for all plants (Pukacka and Pukacki, 2000; Woo *et al.*, 2007; Alscher *et al.*, 2002). Since there was a significant decrease in photosynthesis and chlorophyll, and an increase in proline in *Q. infectoria* species under the effects to dust exposure, it can be concluded that the decrease in photosynthesis rate is possibly due to insufficient production of chlorophyll or oxidation of chlorophyll by free radicals. This is in agreement with the findings of Shimazaki *et al.* (1980). Accumulated proline in plants has a role in actions such as osmotic composition, nitrogen storage composition, free radical scavenging, regulation of cellular oxidation potential, pH regulation and maintenance of cellular turbulence, which ultimately makes plants more tolerant in facing different stresses (Hua *et al.*, 1997; Levitt, 1972; Nakashima *et al.*, 1998).

4.4 Leaf mineral elements

Examination of the results of EDS dust on the leaves as well as EDS of soil samples showed that the elements of iron, silica and calcium were present in many repetitions. Due to the increase in the concentration of iron, magnesium and potassium in the leaves of the species treated with dust, it can be concluded that dust has increased these elements. The current results are consistent with the findings of Zarasvandi *et al.* (2012), however, these researchers mentioned an increase in the concentration of the heavy metals by dust. Although considerable research has been conducted on the amount of leaf mineral elements of species under other stresses such as salinity, the trend of changes in leaf mineral elements under the influence of dust has not previously been reported.

In general, the observed increase or decrease of leaf elements under the influence of dust in this research was such that it can be concluded that dust did not have a significant effect on these elements in the investigated trees. It is important to note that the amount of leaf elements varies during the growing season and different ages of the plants and they are different from each other. Therefore, it is necessary to conduct further investigations to identify and assess the impacts of the changes in leaf mineral elements under the influence of dust.

5 Conclusions

Plants act as air pollution absorber. Air pollutant particles are deposited on the surfaces of plants and affect their morphological and physiological characteristics. Trees improve air quality by absorbing suspended air particles, but they are also negatively affected by the accumulation of dust particles on leaf surfaces. In turn, air pollution can reduce tree growth as well as crop yield, reduce photosynthesis, inhibit physiological processes, functional and metabolic changes. The results of the present study also showed the adverse effect of dust deposition on the growth and performance of selected tree species in the northern Zagros forests. Dust deposition may result in a reduction of biodiversity and the loss of goods and services provided by the forest ecosystems in dust-affected regions.

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