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Effect of Dust on Growth and Reproductive Characteristics of Grapevine (*Vitis vinifera*)

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ABSTRACT

To investigate the effects of dust particles on physiological and yield characteristics of grapevine cv. Bidaneh Safid, a field experiment in randomized complete block design (RCBD) was conducted on 40 plants at the Malayer Grape Research Station, Iran, during 2015-2017. The treatments comprised of: 1) artificial dust (4.3 micron, on average), 2) washing vine by well water, 3) washing vine by soluble-in-water dioctyle solution (dioctyl sulfosuccinate under the brand name dioctyl) one day after spraying artificial dust, 4) washing vine after the occurrence of natural dust storm in the region with no artificial dust applied, and 5) control, dust was not applied and after dust storm vines were not washed. Analysis of variance revealed that dioctyl and dust treatment had the highest and lowest yields of 12 and 4.5 kg/vine, respectively. In addition, dust particles significantly decreased fruit set (by 21.7% as compare to dioctyl treatment), berries per bunch (57 berries per bunch as compared to dioctyl treatment (82 berries/bunch)) and weight of bunch (85 g as compared to dioctyl which was 110 g). Moreover, dust had adverse effects on lengths of shoot (decrease up to 62 cm), leaf dry weight (1.28 to 1.39 g as compared to dioctyl treatment which ranged between 1.45 and 1.55 g) and photosynthetic pigments. (e.g. chlorophyll a reduced by 1.26 mg g^{-1}). In conclusion, washing grapevine with dioctyl and water removed dust from surface of the leaves and dust could not damage the growth and yield of the grapevine.

Introduction

Air pollution is a major problem associated with modern urbanization, transportation and industrialization, resulting in undesirable environmental effects on humans, animals and agricultural production (Wilson et al., 2004; Mittler, 2006). About 26.8% of global atmospheric dust is due to deserts of the Middle East and Central Asia (Akhtar et al., 2018). An increasing trend in dust storm in the Middle East has been reported in the 21st century (Cao et al., 2015). Dust particles are lifted to the atmosphere by a strong wind and this condition reduces the horizontal visibility to less than 1000 (De Villiers and Heerden, 2007) to 2000 m

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(Danyali et al., 2014). Atmospheric dust particles, smaller than 10 µm, can cause changes to the biochemical features by inducing irregularity in plant leaf (Kumar Rai and Panda, 2014). Alavi et al. (2014) found that chemical and physical properties of dust could affect shoot biomass. Blocking of leaf stomata is the fastest reaction of a plant to the presence of dust particles which can disrupt the photosynthetic process and promote the production of free radicals to induce formation of reactive oxygen species such as superoxide anions and hydroxyl radicals (Poma et al., 2002). Dust particles deposition onto the leaves may alter leaf surface optical properties and therefore some dusts may increase leaf temperature and blocking the stomata which reduces the photosynthesis (Maletsika et al., 2015; Roy Squires, 2016). Creation of shade on the surface of the leaf by dust also leads to diminution in the content of leaf pigments (Leghari et al., 2013; Kumar Rai and Panda, 2014; Bao et al., 2015). Damages caused by air pollution have been reported in vineyards in developed and industrialized countries as it mainly affects the growth of plants (Doulati Baneh, 2016). Dust reduces the relative water content (RWC) and increases the pH of leaf (Kumar Rai and Panda, 2014; Gami et al., 2015). A negative correlation coefficient between RWC of leaf of different roadside plant species and deposition of dust on leaf from -0.406 to -0.831 in Aizawl, Mizoram, India has been reported. Aerosol sediment on the leaf of plants leads to metamorphosis of ultra-structural components, including increase of lipid droplets, swelling of cellular components and thylakoid degeneration (Paoli et al., 2015). Zia- Khan et al. (2015) reported that dust storm caused 28% decline in cotton yield in the north western part of China. Various studies have focused on the effects of dust particles on the physiological characteristics of forest (Santos et al., 2017), urban and ornamental plants (Zhang et al., 2015; Sett, 2017), vegetables (Gajanan and Awande, 2013), and fruit trees (Mandal et al., 2016) but little known on the effects of dust on the garden trees and plants consumed by human including olive (Nanos and Ilias, 2007), grapes (Leghari et al., 2013), peach (Maletsika et al., 2015) and mango (Mandal et al., 2016). Grapevine (*V. vinifera* L.) is the only domesticated and edible grape which have many cultivars and because of their quality and quantity is commonly cultivated in most parts of the world. In Iran, a wide variety of grape called Sultana or another clone called Thompson seedless in the USA, Australia, Turkey, and Greece is commonly cultivated as compared to other grape cultivars (Jackson, 2008). The growth period of this variety is from May to September in Iran (Kanani Notash and Khorshidi Benam, 2012). During this period, vegetation and rainfall in arid and semi-arid areas are minimal. Therefore, the loose particles from soil surface enter the atmosphere depending on the speed, direction and durability of wind and affect the surrounding area. These particles can have different impacts when deposited on vines. Suspended dust particles create serious environmental problems and natural hazards at the southwest Asia. The sources of dust storm in the southwest Asian region are classified into two main groups, including the Shamal dust storms and the frontal dust storms (Hamidi et al., 2013). Soil types, land cover and climate of Iraq and Syria have potential of dust production due to association with low and high pressure atmospheric system in the summer months, resulting in transportation of dust particles to the west of Iran (Zoljoodi et al., 2013). Washing of plants has been used to reduce the effects of dust (Arvin et al., 2013). Arvin et al. (2013) were used different washing methods and dioctyl solution to reduce the effects of dust on grapevine. Dioctyl solution has a remarkable ability to remove the effects of fungi, soot, excrement from nutrition and extinction of insects, atmospheric pollutants, and the heavy metals from smoke of factories. It is in fact a surfactant based on sodium sulfosuccinate with the chemical formula of $C_{20}H_{37}NaO_7S$, a compound based on sodium salt extracted from organic acids, and along with polarized solutions reduces the surface tension and increases the absorbance of pesticides in plants (Al-Sabagh et al., 2009). Abroon et al. (2016) studied the effects of dioctyl on the efficiency of hexitiazox mites in controlling cucumber on Tetranychus urticae Koch. They showed that addition of dioctyl sodium sulfosuccinate to mite increases efficiency (by 25% compared to the recommended dose at 15 days after spraying).

Iran’s grape production under cultivation is 316,000 hectares, 1945930 tones of global production and ranked 11th in the world (FAOSTAT, 2019). Hamedan province average grape yield is 19 tons per hectare and ranked second in the country after Fars province. However, the province suffers from dust events in recent years (The Ministry of Agriculture-Jahad, 2018). Therefore, the present study aimed to evaluate the relationships among dust particles deposition and physiological and reproductive attributes of grapevines (*V. vinifera* L.) and to reduce the damage of dust to grapevine using appropriate solutions..

Materials and Methods

Location of experiment

Experiment was conducted in Malayer Grape Research Station (35° 15’ N, 48° 51’ E) in Hamadan province, west of Iran. The total precipitation in the study area is 319.8 mm with an average temperature of 13.2 °C. The annual dust storm rate is averagely 16 events, most of which occurring in the spring season. Trajectory of transportation of dust particles to Malayer was plotted by HYSPLIT Model. The model shows the direction of dust movement at altitudes of 500, 1000 and 1500 m in the atmosphere (Draxler et al., 2009). The directions of dust particles movement illustrate that dust mainly arises from deserts of Iraq and reaches the Malayer Station at the west of Iran (Fig. 1).

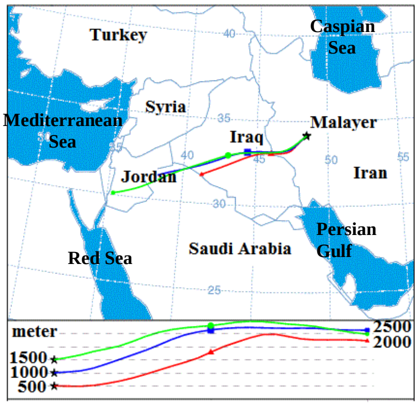

Fig. 1. Trajectory direction of main source of dust to Malayer at the west of Iran.

The physical and chemical characteristics of the top soil (depth of 0-60 cm) and irrigation water in the experimental site are presented in Tables 1 and 2, respectively.

Table 1. Physical and chemical characteristics of soil in the experimental site

Description	Depth	EC*10^3	P^H	T.N.V	Organic Carbon	P	K	Sand	Silt	Clay
	cm	ds m^{-1}		%	%	Mg. kg^{-1}	Mg. kg^{-1}	%	%	%
First layer	0-30	0.70	8.1	20.16	0.56	29.6	442	27.1	48.7	24.2
Second layer	30-60	0.65	8.1	20.16	0.47	13.4	355	30.6	46.1	23.3

Table 2. Characteristics of irrigation water in the experimental site*.

Description	EC*10^6	pH	CO_3^{2-}	CO_3H-	Cl^-	SO_4^{2-}	Anions	Ca^{2+}	Mg^{2+}	Na^+	Cations	S.A.R
	µs/cm		mEq/L	mEq/L	mEq/L	mEq/L	mEq/L	mEq/L	mEq/L	mEq/L	mEq/L	
Experiment	640	7.5	0	5	0.8	0.55	6.35	3	2.3	1.05	6.35	0.64

* Well water used for irrigation of vine

Experimental design and treatments

Farmers grow grape above ground without training system and they put vines in the ground to protect them from cold injury in winter. Experiments were implemented on 40 grapevines *V. vinifera* L. cv. Bidaneh Sefid in the form of RCBD with drip irrigation during 2015-2016 and 2016-2017 from late April to October when the buds break until the harvest.

The treatments performed in four stages: growth of vine represented by appearance of 2 to 3 leaves (first stage), flowering (second stage), fruit set (third stage) and berries ripening phases (forth stage). At each stage, the water required to wash the vines varied. At the first stage 1 L of water and 3 mL of dioctyl, at the second stage 2.5 L of water and 7 mL of dioctyl, at the third stage 5 L of water and 14 mL of dioctyl, and at the fourth stage 7 L of water and 20 mL of dioctyl were used to wash the leaves of vines. The amount of dioctyl depended on the amount water used for washing.

Treatments included:

T_1) artificial dust sprayed on canopy of vine by a manually operated duster,

T_2) washing canopy of vines using well water in

the field one day after spraying artificial dust,
T_3) washing vines by dioctyl solution one day after spraying artificial dust,
T_4) washing vines after the occurrence of natural dust storm in the region with no artificial dust applied,
and T_5) control, without applying artificial dust and without washing vines after happening natural dust in the study area.

The experimental design was a randomized complete block with five treatments and four blocks, two vines for treatment per block, eight vines for each treatment, and ten vines per block (Fig. 2). The treatments performed in four growth stages, including appearance of 2 to 3 leaves (first stage), flowering (second stage), fruit set (third stage) and berries ripening (forth stage).

Block 1	Block 2	Block 3	Block 4
A	B	C	D
B	C	A	E
C	E	D	B
D	A	E	C
E	D	B	A

Fig. 2. Experimental design: A) Artificial dust, B) Washing vines using well water, C) Washing vines using dioctyl solution, D) Washing vines after the occurrence of natural dust storm, and E) Control

Dioctyl (dioctyl sulfosuccinate under the brand name dioctyl) is a hydrocarbon radical which is formally derived from octane and is highly efficient in elimination of pollution and used as a pesticide with a chemical formula of $C_{20}H_{37}NaO_7S$ (Mercer and Cohen, 1990).
At each growth stage, the amount of water for washing the vines varied. At the first stage (2 to 3 leaves are fully expanded with a visible collar) 1 L of water and 3 mL of dioctyl, at the second stage (flowering) 2.5 L of water and 7 mL of dioctyl, at the third stage (fruit set) 5 L of water and 14 mL of dioctyl, and at the fourth stage (berries ripening) 7 L of water and 20 mL of dioctyl were used to wash the leaves of vines. The amount of dioctyl depended on the amount of water used for washing plant. Figure 3 shows experimental site with drip irrigation. Artificial dust particles were collected from uncultivated areas of Azadegan plain in Khozestan province, southwest of Iran, where is known as the local source of dust storm in the country.

Fig. 3. The experimental site with drip irrigation

To provide suitable fine particles, the soil was grinded, milled and sieved using a mesh size of 200 opening per inches. The physical and chemical tests were performed using an X-ray diffraction device. The particle size was between 1 and 12 µm and the chemical composition of these particles included Silicon Dioxide, Sodium Sulfate, Na = 7.254 mg/L, K = 12.48 mg/L, Ca = 28.8 meq/L and Mg = 4.4 meq/L. A dust chamber and a dust generator were constructed to simulate dust. A mechanical apparatus consisted of a 50-cm pipe and a ventilation fan was also used. The chamber was made of a plastic sheet with 2× 2×2 m dimensions (Fig. 4). Calibration of dust chamber was done by spraying dust with a concentration of 1 g/m^3 per hour.

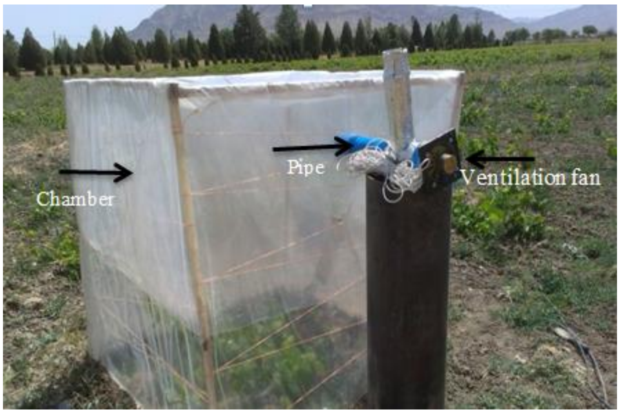

Fig. 4. Dust chamber for simulation of dust

In 2015-2016, dust was artificially applied on 24 vines and after one day, 8 vines were washed by soluble dioctyl as a solution treatment (T_3), 8 vines were washed by well water (T_2) and 8 vines remained dusty as a dust treatment (T_1). T_2 and T_3 treatments (16 vines) were considered as treatment solutions. Two treatments including washing 8 vines with water after the occurrence of natural dust storm (T_4) and 8 vines remaining with natural dust as a control treatment (T_5) were added to other treatments. In addition, no artificial dust was sprayed on T_4 and T_5. It should be mentioned that 11 dust events happened during the experiment from 2015 to 2017, according to Malayer meteorological station.
The treatments performed in four stages consisting of appearance of 2 to 3 leaves (first stage), flowering (second stage), fruit set (third stage) and berries ripening phases (forth stage). At each stage the amount of water for washing the vines varied.

Measurements

Since each pigment has an absorption spectrum, absorbance can be used to estimate the pigment concentration (Arana, 2012). Therefore, photosynthetic pigments concentrations including chlorophylls *a*, *b* and total chlorophyll were evaluated by harvesting the same leaf of each treatment, homogenized with acetone (80%) and filtered using a filter paper. To evaluate pigments concentration, the final solutions subjected to spectrophotometry and absorption of solutions was measured in wavelengths of 647 nm and 663 nm for chlorophylls *a* and *b* concentration, respectively. Equations 1 and 2 were used to calculate chlorophylls *a* and *b* contents in mg/g of fresh weight of the sample (Seydi et al., 2016).

$$\text{Chl a} = (19.3 \times A663 - 0.86 \times A645)V/100 \quad (1)$$

$$\text{Chl b} = (19.3 \times A645 - 3.6 \times A663)V/100 \quad (2)$$

Where, A is the maximum absorbance wavelength and V is the solution volume flattened. The youngest fully expanded leaves were collected from each vines in the morning. The leaves were weighted immediately to obtain the fresh weight. Afterwards, the leaves were rehydrated by floating in a covered water bath cap for 12 hours at approximately 23 °C under the conditions without light. All leaves were oven-dried for 72 hours at 70 °C and RWC (Relative Water Content) was calculated by dividing the amount of water in fresh leaf tissue by water in leaf tissue after rehydration multiplied by 100 (Equation 3) (Canavar et al., 2014).

$$RWC = \left(F_W - D_W / S_W - D_W\right)*100 \quad (3)$$

Where, F_W is fresh weight (g); D_W is dry weight (g), and S_W is saturated weight (g). Single Leaf Area Index (LAI) was calculated by image processing method Win-Area-Ut_10 system (Ebrahimi et al., 2009) that developed by Mirasheh (2006). The sugar content of grapes was determined by measuring the Refrectometer BME center index of their juice sugar. In grapevine, fruit set percentage is determined by genetic and environmental factors. Temperature, humidity and nutrients are the most important environmental factors in fruit set. Percentage of fruit composition in each treatment was calculated after 21 days of pollination based on the number of berries formed into the number of flowers. Other parameters such as length of shoot (cane), length of petiole, number of bunch, berries and yield were measured at the field. Analysis of variance was performed with the help of two factors, treatment and date, using the

SPSS statistical package (SPSS 22.0). Simple and combined analysis of variance were implemented and Tukey's test was also used to compare the treatment means.

Results

Photosynthetic pigments

Chlorophyll contents of the grapevine changed with respect to different treatments. The highest (1.88 mg g^{-1}) and the lowest (1.26 mg g^{-1}) amounts of chlorophyll *a* were recorded in dioctyl treatment and dust treatment, respectively. Moreover, other treatments also had a different chlorophyll *a* content and a significant difference ($P<0.05$) was observed for chlorophyll *a* as compared to the other treatments. In addition, dust treatment (1.26 mg g^{-1}) had a significantly different chlorophyll *a* content as compared to control (1.38 mg g^{-1}) only at the fruit set stage (Fig. 5).

Chlorophyll *b* content increased by dioctyl and washing grapevine by well water treatments and decreased by dust treatment throughout the phenological stages of grapevine. The lowest chlorophyll *b* content (0.722 mg g^{-1}) was observed at dust treatment, while its highest content (0.912 mg g^{-1}) was observed at dioctyl treatment. However, the chlorophyll *b* content was not significantly different as compared to control treatment (0.751 mg g^{-1}) (Fig. 5).

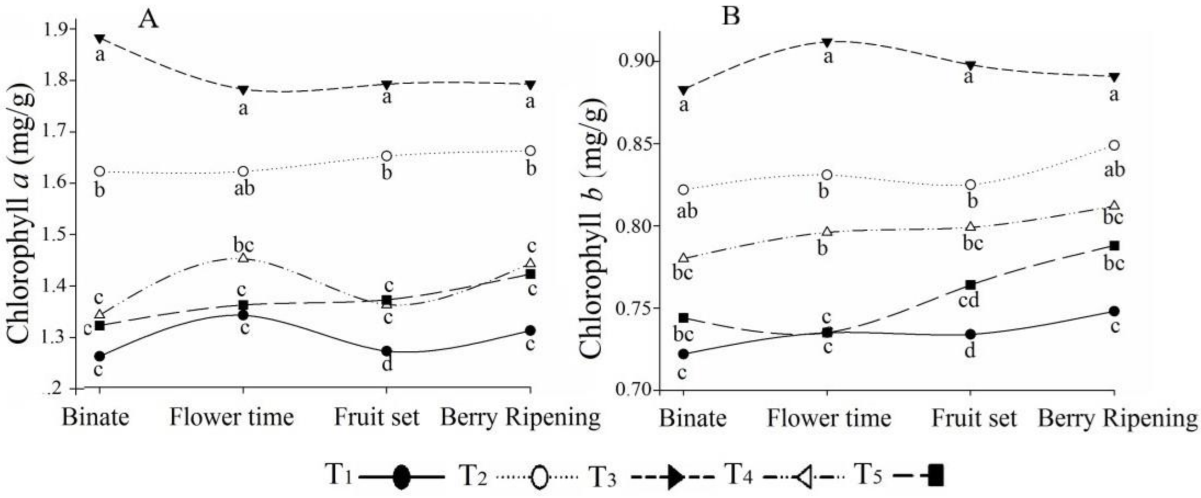

Fig. 5. Variations of chlorophylls *a* (A); *b* (B) contents. T_1: Artificial dust, T_2: Washed by well water, T_3: Washed by di-octyl, T_4: Washed by water after natural dust storm, T_5: Control.

The results demonstrated that the total chlorophyll increased in the phenological stages and reached the maximum amount at berries ripening growth stage. The total chlorophyll content varied in the treatments and there was a significant difference at 5% level. Washing grapevine by well water and dioctyl solution increased the total chlorophyll content. Grapevine leaves covered with dust had the lowest total chlorophyll content. The control grapevines had significantly different total chlorophyll content in the dust treatment at the third (fruit set) and fourth (berries ripening) growth stages. The maximum total chlorophyll (2.6 to 2.8 mg g^{-1}) was observed in the dioctyl treatment at the different plant stages, but it was in the range of 1.8 to 2.2 mg g^{-1}in the dust treatment. The most important finding in this study was detecting the difference between the control and dust treatments at the fruit set stage. Washing grapevines, especially by dioctyl, also increased the amount of photosynthetic pigments ($P < 0.05$). Surprisingly, at the first and second stages of growth (appearance of 2 to 3 leaves and flowering), the difference between chlorophyll contents in the control and dust treatments was not significant, implying that dust could not damage plant photosynthetic pigments at the early stages of growth (Fig. 6).

Physiological parameters

Relative water content (RWC) was affected by dust stress (Fig. 6). Dust had a significant effect on the RWC ($P < 0.05$). The maximum RWC (66%) was obtained in the dioctyl treatment at the berries ripening stage. The minimum RWC (44%) was obtained in the dust treatment at the fruit set stage. RWC was reduced in the dust treatment as compared to the control treatment ($P < 0.05$). RWCs were equal in the washing and control treatments (55%) and significantly different in the dust treatment.

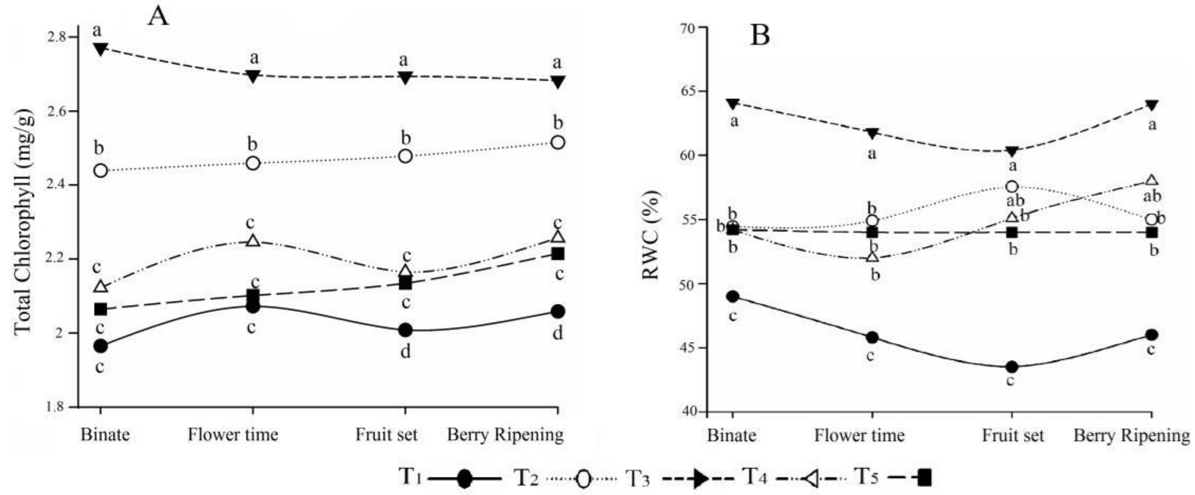

Fig. 6. Variations of total chlorophyll (A); relative water content (B). T_1: Artificial dust, T_2: Washed by well water, T_3: Washed by dioctyl, T_4: Washed by water after natural dust storm, T_5: Control.

The leaf area index of grapevines decreased in the dust treatment as compared to the control. Figure 7 represents the maximum leaf area (131 to 142) in the dioctyl treatment and the minimum leaf area (118 to 134) in the dust treatment. In addition, the leaf area of 125 to 140 in the control treatment was significantly different as compared to the dust treatment ($P < 0.05$). In several stages (third and fourth stages), the leaf areas of grapevines were significantly different from those in the dioctyl and control treatments.

Leaf dry weight (LDW) was reduced by deposition of dust particles on grapevine leaves as compared to control. The difference between averages in the dust and control treatments was significant at 5% level mainly in the first and second stages (Fig. 7). The maximum (1.45 to 1.55 g) and the minimum (1.28 to 1.39 g) LDWs were observed in the dioctyl and dust treatments, respectively. Moreover, LDW was in the range of 1.31 to 1.47 g in the control treatment with a significant difference ($P < 0.05$) as compared to the dust treatment.

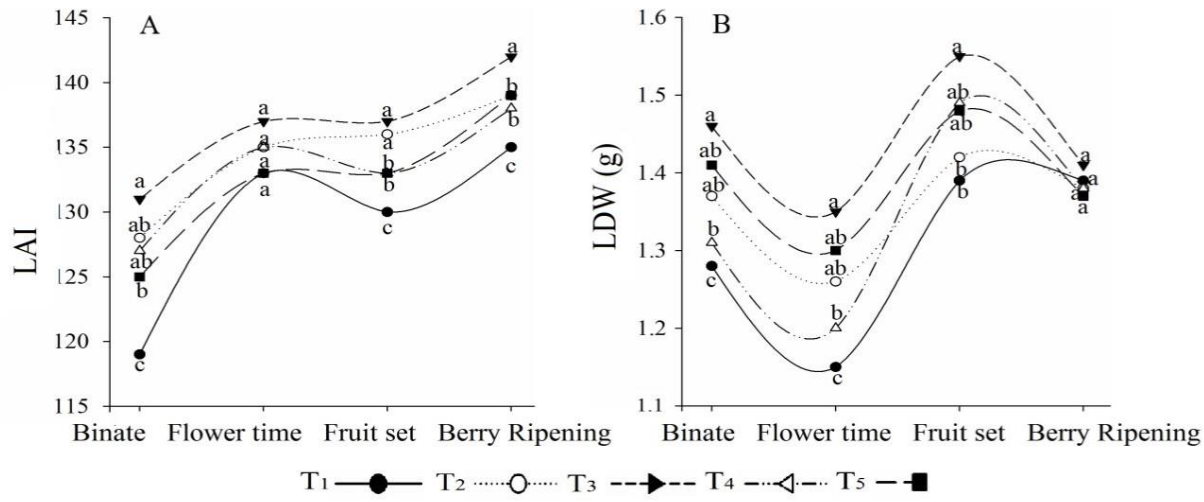

Fig. 7. Variations of leaf area index [LAI (A)]; leaf dry weight [LDW (B)]. T_1: Artificial dust, T_2: Washed by well water, T_3: Washed by dioctyl, T_4: Washed by water after natural dust storm, T_5: Control.

Figure 8 shows the effect of dust on lengths of shoot (cane), petiole and internode in vines treatments. According to the results, the shoot (cane) length changes and dust treatment has a significantly negative effect on grapevine shoot (cane) length as compared to control. The maximum (75 to 210 cm) and minimum (62 to 180 cm) lengths of cane were observed in the dioctyl and dust treatments, respectively. However, a non-significantly decreased length of petiole was noticed in the dust treatment as compared to the control treatment.

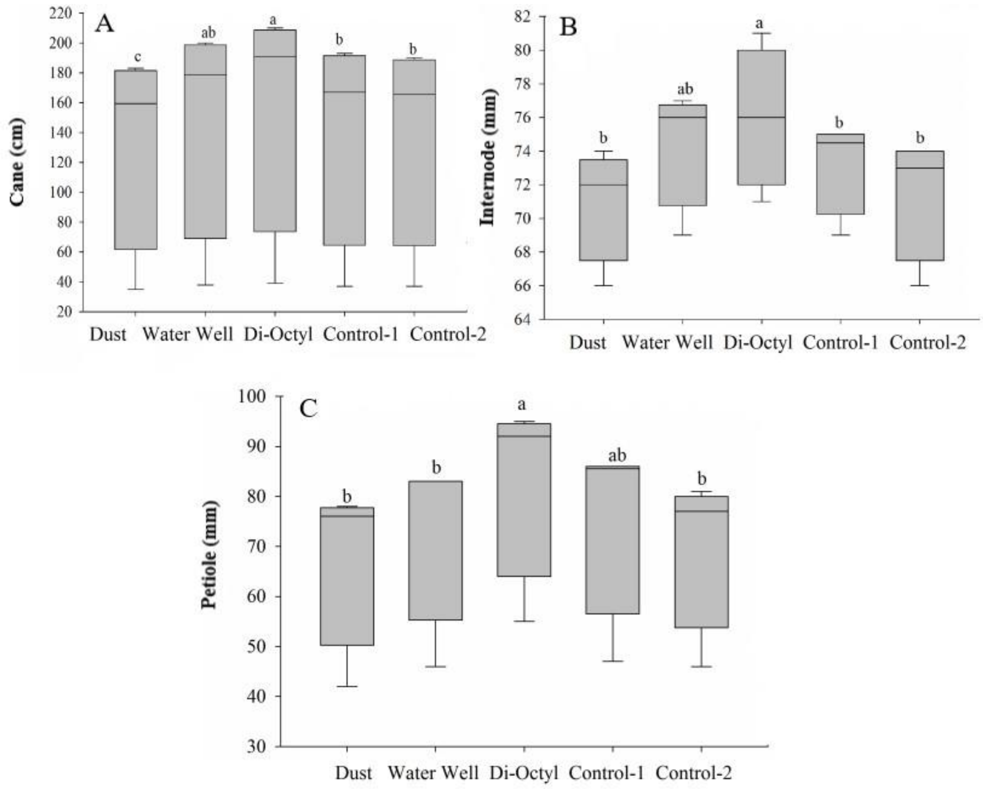

Fig. 8. Comparison of the mean lengths of shoot (cane) (A); internode (B); petiole (C) in grape (*Vitis vinifera* L.) under different treatments

Reproductive traits

The berries were counted 21 days after pollination. The results of variance analysis (Fig. 9) showed that there was a significant difference among the means obtained in the treatments for fruit set at 5% level of significance. The maximum percentage of fruit set was obtained in the dioctyl treatment (30%). The percentages of fruit set in well water and control treatments were 27.2% and 25%, respectively. The lowest fruit set trait (21.7%) was found in the dust treatment. Decrease of fruit set in the dust treatment led to reduction in total number of berries in bunches. The difference among the numbers of berries among treatments was significant ($P < 0.05$). The highest and the lowest numbers of berries were observed in the dioctyl treatment (82 berries per bunch) and the dust treatment (57 berries per bunch). Totally 68 and 66 berries appeared on each bunch in the washing vines by well water and control treatments, respectively.

The obtained results demonstrate the significant effect of dust deposition on decrease of bunch weight as compared to the control treatment. The heaviest bunch was observed in the dioctyl treatment (110 g), while a bunch weight of approximately 105 g was equally found in the control and washing by well water treatments. The lightest bunch weight (85 g) was observed in the dust treatment. Total soluble solid (TSS, Brix degrees) is an important qualitative index which has a direct relationship with the quality of the fruit, and the fruits with high TSS rates are highly desired by consumers (Burdon et al., 2004). The sugar content (°Bx) of *V. vinifera* L. was significantly different in the control and dust treatments, indicating the negative effects of dust on sugar content. The highest TSS (25.5%) was observed in the dioctyl treatment and the lowest TSS (21%) was seen in the dust treatment. Therefore, deposition of dust particles on canopy and flowers of vine led to the decrease of TSS in the berries.

Dust deposition was studied to investigate the effect of dust particles on the grapevine yield. The results of ANOVA represent a significant difference among the treatments. More importantly, the difference of ANOVA results in the dust and control treatments was meaningful.

The highest yield (12 kg/vine) was observed in the dioctyl treatment and the lowest yield (4.5 kg/vine) was observed in the dust treatment. Washing grapevine by well water produced 10.5 kg/vine, whereas control produced 6.5 kg/vine, averagely.

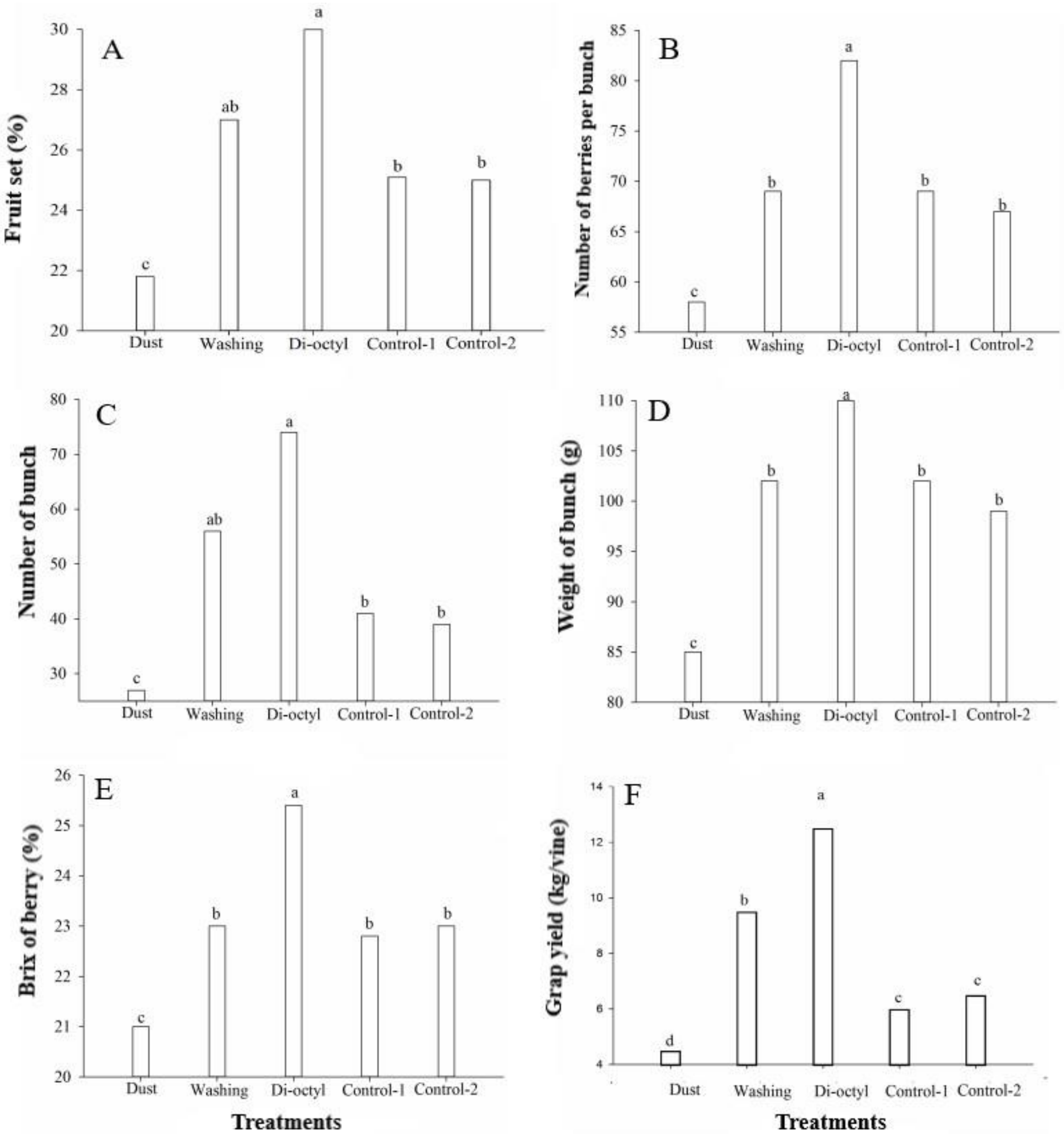

Fig. 9. Comparison of reproductive traits, including fruit set (A); number of berries per bunch (B); number of bunch (C); weight of bunch (D); brix of berries (E); grape yield (F); under different treatments

Table 3 shows the Pearson correlation coefficients for different variables. The high correlation among some of these traits allows to measure each correlated attribute. There was a positively significant correlation between number of bunch and yield (r =0.95, $p < 0.01$). The maximum correlation coefficients were found between chlorophyll *a* and grape yield (r = 0.715, $p < 0.05$) and between chlorophyll *b* and fruit set (*r*= 0.786, $p < 0.5$). The correlation among the plant canopy, foliar morphological traits and amount of dust was significant ($p < 0.05$) (Singh and Pal, 2017). There was a significant correlation between chlorophylls *a* and *b* with fresh and dry weights of vine (Sarani et al., 2013).

Table 3. Pearson correlation coefficients among photosynthetic pigments, biometric and reproductive traits in *Vitis vinifera* L.

	Cane	LDW	Chl *a*	Chl *b*	N. bunch	Yield	W. bunch	brix	Fruit set
Cane	1								
LDW	0.425*	1							
Chl *a*	0.532*	0.412*	1						
Chl *b*	0.541*	0.586*	0.747*	1					
N. bunch	0.367*	0.115 ns	0.563*	0.651*	1				
Yield	0.523*	0.192 ns	0.715*	0.636*	0.953**	1			
W. bunch	0.509*	0.657*	0.659*	0.698*	0.474*	0.450*	1		
Brix	0.395*	0.481*	0.445*	0.597*	0.430*	0.528*	0.556*	1	
Fruit set	0.563*	0.621*	0.674*	0.786*	0.536*	0.573*	0.746*	0.672*	1

LDW: Leaf Dry Weight, N: Number of bunch, chl a: Chlorophyll a, chl b: Chlorophyll b
* Correlation is significantly different p≤ 5 %, **, correlation is significantly different p≤ 5%, ns: non-significant.

Discussion

Biomarkers are changes in plant attributes that allow for environmental quality assessment of an area at a given time. Plants can respond to various environmental stresses with the most conspicuous response exhibited by the leaves. The chlorophylls, key molecules in photosynthesis in green plants, has been identified as a biomarker parameter for higher levels of pollution (Skinder et al., 2015). The present study demonstrated that there was a direct negative relationship between dust and most of the parameters associated with leaf physiology, such as main leaf pigments. Chlorophyll *a*, *b* and total chlorophyll decreased in dust treatment as compared to control treatment. However, chlorophyll *a* had a density higher than chlorophyll *b* in the structure of plant photosynthetic system. Previous studies showed that dust accumulation on leaf surfaces reduces the photosynthesis activity which impedes growth of vines (Sharma et al., 2017; Mir et al., 2021).

Mitra and Banerjee (2010) reported that chlorophyll *a* is more sensitive to environmental stresses as compared to chlorophyll *b.* Reduced density of chlorophylls under dust treatment could be attributed to decline of the light reaching the mesophilic tissue of the leaf (Kumar and Thambavani, 2012), or shading of leaf surfaces caused by dust particles (Abu-Romman and Alzubi, 2015). Several researchers have reported the decrease of chlorophylls *a*, *b* and total chlorophyll is in association with dust particles (Nunes et al., 2004; Nanos and Ilias, 2007; Lone et al., 2011; Chaturvedi et al, 2013, Sharma et al., 2017). Leaves are the most important part of the plant that are in direct contact with the surrounding area (Lata et al., 2010). Deposition of dust particles on the leaf poses damage to the tissues and reduces the leaf area of plants (Agbaire and Esiefariehrhe, 2009). significant reduction of leaf surface area and number were observed in plants exposed to dust pollution (Al-faifi and El-Shabasy, 2021). They found that dust pollution is one of the limiting factors associated with plant stress physiology and determines production and plant growth rate. In the current study, reduction of leaf area led to depletion of leaves dry weight. The same result was reported by Zia-khan et al. (2015) about reduction of leaves dry weight after five to six days of dust application, due to the reduction of stomata conductance or photosynthetic rate.

In the present study, the RWC in dust treatment was lower than in control treatment. RWC decreased in polluted areas (Chaturvedi et al., 2013) and had a negative correlation with dust treatment (Kumar Rai and Panda, 2014). Dust particles by deposition on the flowers, disrupted germination of pollen and led to fall of flowers and production of little berries. Climatic factors have a significant effect on fruit set. Moreover, result of this study indicated that dust particles, as an environmental stress, affect the fruit set. The number of berries in the dust treatment was lower than in the control treatment. Following the fruit set stage, immature berries were subjected to dust treatment, after which they fell down due to lack of proper fertilization. The reduced fruit set as a result of dust particles deposition on flower led to a reduced yield in this study. Therefore, the yield in dust treatment was lower than in control with a decrease of 35%.

Deposition of dust particles on the leaf surface can block the stomata (zia-khan et al., 2015) and reduce the photosynthetic products. Moreover, decrease of sugar content in the leaf can lead to less sugar translocate into the berries (Chaurasia et al., 2013). Effects of dust on the physiology of plants have been studied previously (Saini et al., 2011; Maina et al., 2015). Therefore, in this study, it was attempted to analyze the effect of dust on fruit set and yield. It was observed that the accumulation of dust particles on grapevine affect the physiological parameters and reduce the yield. The effects of different washing solutions on the grapevine were investigated. Well water and dioctyl were used to wash the leaf samples as a part of preparation for analysis. The obtained results showed that each washing method had a specific effect on the traits of grapevine. Dioctyl solution was used as the strongest dust cleaner and contaminant remover from the surface of the leaves. The results proved that dioctyl was the best material to remove dust. In most studies, washing of plants was considered as a control treatment, but in this study, washing of grapevine by well water, dioctyl and control treatments were examined (Thompson et al., 1984; Arvin et al., 2013). The results demonstrated that the difference among the treatments was significant at 0.05% level of significance. The effects of dust on the fruit set were identified, but the washing method reduced the effects of dust. Therefore, it was concluded before the flowers are opened, the plant should be washed. If the grapevine is washed after opening of flowers, moisture and water on the flower will reduce the fruit set. Stroe et al. (2017) demonstrated that increase of humidity led to the decrease of fruit set in *V. vinifera* cv. Muscat. Thus, rain during bloom can physically inhibit pollination and fertilization by dilution of the stigmatic surface which is to receive pollen from the flower's anthers (Vasconcelos et al., 2009). In addition, it should be noted that in case of dust storms, the solution should be used before opening of the flowers, because if the flowers are opened, water may reduce fruit set (Xi Li et al., 2014).

Conclusion

In the present experiment, different treatments, including artificial dust, washing vines by well water, washing vines by dioctyl, washing vines after dust storm and control treatment, were performed to investigate the effects of dust on grapevine *V. vinifera* L. Bidaneh Sefid. It was found that dust accumulation on the surface of leaf induces some physiological changes such as a reduction of photosynthetic pigments, relative water content and leaf area index. Deposition of dust particles on flower of grape led to decrease of reproductive trait, but washing vine by dioctyl and even by well water led to improvement of production. As a result, washing of vine also increased grape production as compared to the control treatment. According to the obtained results, dust particles reduced fruit set by deposition on flower and they were identified as an environmental stress on grapevine. Therefore, deposition of dust particles on canopy and flowers of vine decreased TSS in the berries. More importantly, the results revealed that yield of grapevine was adversely affected by dust deposits over a short interval of time during the fruit set. Therefore, the fruit set stage, in which the fruit is formed, was recognized as the most important stage in plant production. It was also found that removal of dust particles from the plant leaves by washing methods can reduce the effects of dust particles. Dioctyl solution was found as the best solution to remove dust from the surface of the leaves, though it could be extensively used at the timing of dust storm in the vineyard. Furthur studies are needed to investigate the reduction of dust deposition on the plants by dioctyl solution on other plant species such as apple, peach, dates, oranges, lemons, persimmons, and pomegranates that grow in hot and dry areas.

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Conflict of Interest

The authors indicate no conflict of interest for this work.

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