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The Effects of dust particles on the performance and morphological characteristics of Rainfed grapes (case study: Fars province - Sepidan county)

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Abstract

Due to the problems of dust and environmental and agricultural challenges at a nationwide level, this research aims to quantify the impact of dust on the performance and morphology of rainfed grapes using SWOT model, in Sepidan County. After sampling, using a framework of randomized complete blocks, 36 vines were prepared. Then the growth and biochemical traits of chlorophyll a and b, and the relative leaf water content, were measured. To investigate the reproductive traits, fruit formation, cluster weight, and the number of berries per cluster were utilized. The results demonstrated that the presence of fine dust and particulate matter leads to a reduction in the levels of chlorophyll a and b. Examination of growth, biochemical, and reproductive characteristics through the Tukey test revealed that fine dust had no significant impact on growth and biochemical traits. Nonetheless, it had a statistically major effect on reproductive characteristics at a 5% significance level. The outcomes of the SWOT model indicated that the entry of fine particles from Iraq and the southwestern provinces, with an average weight of 0.861, is the most impactful threat and primary factor contributing to the decline in performance and the level of rain-fed grape production in the Sepidan County. The entry of particulate matter (PM) into grape cultivation areas, accompanied by heavy metals, may lead to their absorption and contributes to various diseases in consumers. Also, when grapes are turned raisins, PM may have their quality and quantity affected leading to an overall reduction in the yield.

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Introduction

The issue of desertification and dust aerosol is a significant global concern. In conjunction with climate change, it threatens the sustainability of ecosystems and food security worldwide (Cherlet et al., 2018). Dust aerosols are an environmental hazard for both urban and rural populations, particularly in arid and semi-arid regions like Iran (Birjandi & Ghobadi, 2021; Xiao et al., 2008). The primary factors contributing to dust storms include geomorphological features, soil type, and vegetation cover (Calvo Danta, 2020). Desertification, often driven by human activities, leads to soil erosion and reduced vegetation cover, which in turn disperses fine dust. This process has severe consequences for global climate change and the environment (Zhi Yuan et al., 2019).

Like other natural hazards, aerosols impact vegetation (Roshaninia et al., 2018) by suppressing biochemical traits such as pigments, chlorophyll, carbohydrates, and proline (Yuan et al., 2023). Dust aerosols also reduce the amount of photosynthetically active radiation that plants receive, leading to decreased biomass and lower plant productivity (Sundar & Naresh, 2017). Additionally, dust particles can affect terrestrial radiation, and the deposition of dust on plant leaves can threaten the survival of plants with low tolerance thresholds (Cheng et al., 2018). Moreover, atmospheric aerosols contribute to the climate system by reducing light intensity (Ranjbar et al., 2021).

The morphological features of plants, such as leaf area, may influence the absorption of airborne dust particles, potentially leading to stomatal closure (Kenzaq et al., 2021). This closure can increase leaf temperatures, thereby inhibiting protein synthesis. Consequently, increased dust events may depress protein content in aerial plant parts (Aalipour et al., 2023).

Fine dust also causes changes in leaf relative water content by triggering stomatal closure (Lin et al., 2019). Recent research highlights the direct impact of fine dust on various plant morphological characteristics and key physiological processes, such as chlorophyll levels, transpiration, evaporation, photosynthesis rates, stomatal conductance, leaf temperatures, and respiration (Najafi et al., 2023). Chlorophyll levels are crucial indicators of plant health and growth (Jin et al., 2021). Numerous studies have been conducted to investigate how fine dust affects the morphology and performance of various plant species. For instance, Aalipour et al. (2023) studied the impact of fine dust on multiple functional and physiological characteristics of two varieties of *Salicornia*. The study suggested that these varieties may be suitable for cultivation in regions vulnerable to fine dust accumulation due to their distinct morphological features, which help them withstand dust dispersion.

Research by Miravi et al. (2021) examined the seasonal variations of fine dust on leaf surfaces and its impact on photophysical properties. Their findings showed that high dust levels during different seasons caused stomatal blockages, elevated leaf temperatures, and disruptions in gas exchange, leading to decreased chlorophyll content and reduced photosynthetic capacity. Fine dust also contributed to decreased pollination, lower grape formation, and a threefold reduction in grape production in the Askari grape variety (Salahy & Behroozim, 2020).

Furthermore, the deposition of fine dust on leaf surfaces results in shading effects, membrane damage, lipid peroxidation, and a reduction in chlorophyll levels. Fine dust impacts the morphological and physiological aspects of various crops, including cucumber, tomato, and beans (Shirkalayeh et al., 2021). These studies indicate that fine dust negatively affects crop performance and light absorption, with tomatoes being less impacted than cucumbers and beans due to the presence of trichomes on their leaf surfaces. The hypothesis suggests that fine dust deposition leads to shading, membrane damage, and ultimately, chlorophyll reduction in leaves (Burouman & Al-Zoubi, 2015).

The western region of Iran, with its high potential for rain-fed grape cultivation, plays a significant role in the country's grape production, which currently ranks ninth globally. This study investigates the effects of particulate matter on the vegetative and reproductive characteristics of rain-fed grapes in the region.

Materials and Methods

Study Area

Sepidan County in Fars Province is the subject of this study. Its administrative center is the city of Ardkan which comprises central and Homayjan sections (Figure 1). According to the 1395 census, about 91,000 individuals made up the population. In this region, the climate is semi-arid and mountainous, with 12 peaks above 3000 meters. Generally, the county's topography slopes from north to south, with lower elevations as we approach the southern parts.

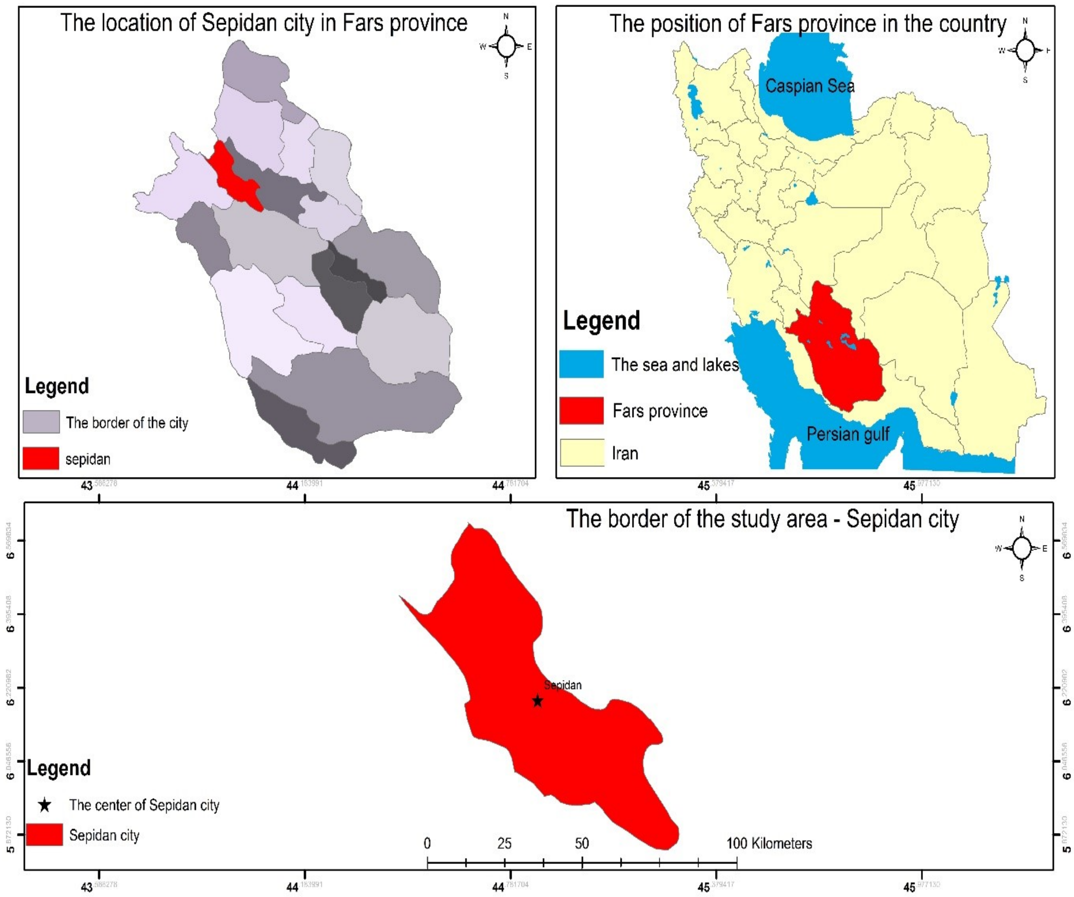

Figure 1. The location of the study area in Iran and the positioning of Fars Province and its counties.

Methodology

The primary objective of this research is to assess the impact of fine dust at the land level in Sepidan County on the morphological and functional changes in rainfed grapes, and to propose strategies for managing these changes. The study aimed to uncover the underlying factors behind variations in performance, growth traits, and reproductive characteristics of rainfed grapes within the vineyards of Sepidan County.

To achieve the research objectives, a completely randomized block design (RCBD) was applied to rainfed grapevines in Sepidan during the agricultural year 2021-2022. To minimize potential errors, grapevines of uniform age (seven years old) from disease- and pest-free vineyards were selected for the study. During the course of the research, no factors such as frost damage, drought stress, or pest infestations were observed. A total of 36 rainfed grapevines were used in the experiment, applying three different treatments: fine dust application, water rinsing, and a control treatment, with five replications per treatment.

Soil samples were collected from Mehran Plain in Ilam Province, located downstream from Iraq's desert areas, to simulate the fine dust characteristic of desert regions. Ilam Province is recognized as one of the primary sources of fine dust in the southwestern regions of Iran. X-ray scattering was used to determine the physical characteristics of the soil samples, and the composition and concentration of heavy metals were analyzed using an atomic absorption spectrophotometer (CS AAS-HR) manufactured by Analytik Jena.

Following sample preparation, a mechanical apparatus equipped with an air ventilation system and 50-centimeter tubes was used to spray fine dust onto the experimental vines. Cubic frames measuring 2 × 2 × 1.5 meters, made of wooden frameworks covered with nylon, were constructed to house the vines during the fine dust application. The frames were positioned over the experimental plots, and the fine dust was dispersed using the device for 20 minutes per treatment. Fine dust was applied to 24 vine shoots in total. After 24 hours of fine dust application, 12 vine shoots were washed with regular water to form the washing treatment group. The remaining 12 vine shoots were designated as the control group and were not subjected to any fine dust spraying.

The experimental period coincided with the growth phase of rainfed grapes, and dust storms were observed in Sepidan County from mid-April to July. To reduce potential errors, dust particles were removed from the leaves during this period. The applied treatments on the rainfed grapevines were measured during four phenological phases of the vine shoots: 1) The stage with five to six leaves, 2) The flowering stage, 3) The fruit formation stage, and 4) The stage of small berry formation.

The chlorophyll content in the vines was assessed using the Arnon method (1975). Initially, 1.0 grams of green and fresh leaf weight were combined with 80% acetone to create a consistent extract. The resulting solution was then filtered through Whatman filter paper number 1. The extracted solution was diluted to 10 milliliters and analyzed using a spectrophotometer. The light absorption intensity of the solution was measured at 663.2 and 646.8 nanometer wavelengths. Calibration was performed using an 80% acetone solution. The chlorophyll concentration was determined using Equations 1 and 2 (chla for chlorophyll a and chlb for chlorophyll b). $Chla = (12.7 \times A) - (2.96 \times B) \times 10/100$

Equation 1: $Chlb = (22.9 \times B) - (4.68 \times A) \times 10/100$

To determine the relative leaf water content (RWC), the following procedures were carried out after weighing the fresh leaves: The leaves were put through the turgid state process. Initially, the leaves were exposed to a constant temperature of 30 degrees Celsius and a light intensity of 600 to 700 lux to facilitate maximum water absorption. After a few hours (around 4-6 hours), the leaves were considered to have reached the turgid state. Then, the weight of the leaves in the turgid state was measured. In the next step, the leaves were dried in an oven at 70 degrees Celsius, and the weight of the dried leaves was determined using the following equation:

Equation 1: Relative Leaf Water Content (%) = $[(W_t - W_d) / (W_t - W_0)] \times 100$

where

W_t = Weight of leaves in the turgid state.

W_d = Weight of dried leaves.

W_0 = Weight of fresh leaves.

To determine the percentage of fruit formation at the beginning of flowering, the number of flowers in five clusters was counted before and after they turned into fruit to calculate the percentage of fruit formation. Later, five marked clusters were collected and taken to the lab, which is refractometer HRB62-T, for measuring quantitative and qualitative parameters using a refractometer. The refractometer was used to assess the sugar content of the grapes' fresh juice.

The statistical analysis and post hoc analysis of mean comparison (Tukey test) was conducted using MiniTab software. GraphPad Prism software was subsequently used to plotted the graphs. Moreover, a descriptive-analytical methodology (utilizing the SWOT method) was employed to identify the factors contributing to declining trends in SPSS (Statistic 22 edition). The SWOT analysis entailed an examination of the strengths, weaknesses, opportunities, and threats within the research area to understand performance challenges arising from dust-related issues. The grape cultivation method's advantages and disadvantages were determined through cooperative efforts with the local community, which involved conducting a survey using a questionnaire during field visits with residents and officials. The weights and importance of each category were established, and plans were suggested according to the results. The survey was conducted in Sepidan County, with a population of 91,000. A sample size of 382 was determined using the Cochran formula. The region examination, field visits, and interviews with experts, farmers, and residents helped identify the main strengths, weaknesses, opportunities, and threats. The questions were designed using the Likert spectrum and validated by experts and stakeholders. The reliability of the questionnaire was tested using the split-half method and Cronbach's alpha coefficient using SPSS software, with resulting coefficients showing strong reliability at 0.955 and 0.967, respectively.
The results are presented in Table 1.

Table 1. Reliability Results of the Questionnaire Using Cronbach's Alpha and Split-Half Method

Split Half Coefficient	Cronbach's alpha coefficients	Number of questionnaire questions	Number of questionnaires	
0.955	0.967	55	30	Sample

Results

In this study, 11 heavy metals and soluble elements were examined in particulate matter samples. The findings showed that lead had the lowest concentration of soluble elements in the soil at 0.14 mg/kg, followed by cadmium at 1.15 mg/kg. Calcium was identified as the most abundant soluble element, while manganese had the highest concentration among the heavy metals at 450.3 mg/kg. Analysis of oxide compounds in the particulate matter samples indicated that silica-sodium sulfate oxide was the predominant compound, with an average particle size of 10.07 micrometers.

Table 2. Heavy Metals and Soluble Elements Concentrations (mg/kg) in Dust Samples:

Particle size	sodium	potassium	Calcium	Magnesium	Roy	copper	cadmium	Manganese	nickel	Lead	Dominant oxides
10.0	5.79	10.16	22.70	3.32	65.234	25.74	1.15	450.3	2.34	0.14	Silica-sodium sulfate

The analysis of the fluctuation of the frequency of high particulate matter days in Sepidan county from 2005 to 2022 revealed a consistent increasing trend of occurrences. The highest frequency of high particulate matter was recorded in 2015, with a total of 54 days, while the lowest occurrence was documented in 2014, comprising only 4 days (see Figure 2).

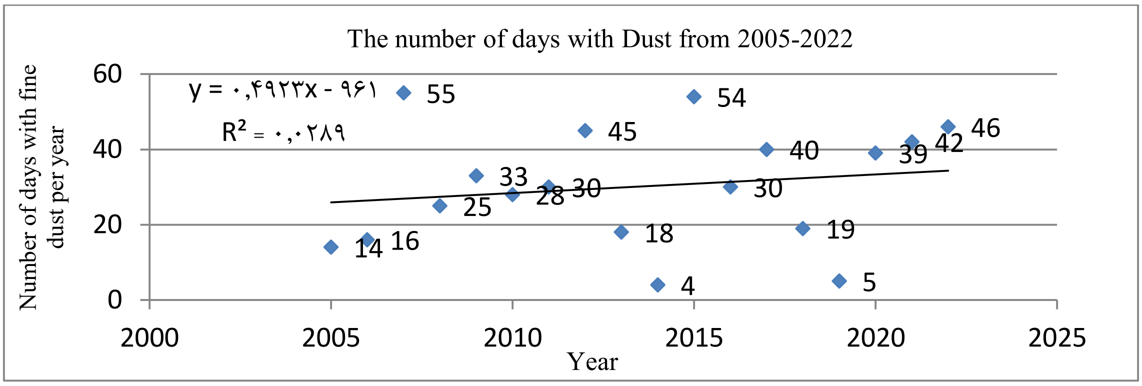

Figure 2. number of days accompanied by particulate matter from 2005 to 2022. (Meteorological Organization of Iran)

Chlorophyll Analysis

The study compared the levels of chlorophyll a and b in rainfed grapes under different conditions: control plants exposed to ambient airborne particles, plants subjected to artificially applied airborne particles, and washed plants free from fine particles on their leaves. The aim was to understand the impact of airborne particles on leaf chlorophyll content. The research revealed significant variations in chlorophyll a levels among the different treatments at four distinct phenological stages. This suggests that airborne particles may influence the chlorophyll content of rainfed grapes. The study observed a notable 1% disparity during fruit formation and a 5% discrepancy in two phenological stages when the fruit reached the stage of small berry formation and multi-leaf development (Table 3). Additionally, the washing treatment induced an increase in chlorophyll a content in the plants, leading to a comparison with the airborne particle treatment and the control group. The results highlighted the statistical significance of the differences in both cases (control vs. airborne particles). The difference between the control and washing treatments was relatively smaller than that between the control and airborne particle treatments. The evaluation of chlorophyll a levels revealed that the lowest content was found in plants treated with airborne particles, while the highest content was associated with the washing treatment. This outcome can be attributed to the washing treatment effectively removing all previously deposited airborne particles and dust from the plant surfaces, resulting in greater light absorption and an increase in chlorophyll a content. The most significant change in chlorophyll a levels, as indicated by percentage, was observed in the multi-leaf phenological stage under the airborne particle treatment, demonstrating a 26.93% increase compared to washed plants. On the other hand, the smallest change was observed in the control treatment during the flowering phenological stage, displaying an 11.85% increase (Table 4).

Table 3. The effects of different treatments on chlorophyll-a levels at different phenological stages of rainfed grapes

Mean square of chlorophyll a				Degrees of freedom	Sources of changes
The stage of fruit ripening to the size of small grains	Fruit formation	Flowering stage	multi-leaf		
0.106 ns	0.12 ns	0.054 ns	0.142 ns	3	repetition
0.0095*	0.0061**	0.040	0.0156*	3	treatment
0.010	0.006	0.04	0.016	9	Experimental error
0.178	0.182	0.226	0.215		Coefficient of variation(%)

ns means non-significant; * means significance at the five percent probability level; ** means significance at the probability level of one percent;

Table 4. Comparison of the average amount of chlorophyll a in the treatments applied to dry grapes and its percentage changes

The percentage of changes in the amount of chlorophyll a compared to the washing treatment	The ripening stage of the fruit is the size of small grains	The percentage of changes in the amount of chlorophyll a compared to the washing treatment	Stage of fruit formation	The percentage of changes in the amount of chlorophyll a compared to the washing treatment	.Flowering stage	The percentage of changes in the amount of chlorophyll a compared to the washing treatment	Multileaf stage	treatment
12.64	^{a}1.749	17.63	^{a}16.55	11.85	^{a}1.747	21.65	^{a}1.611	Witness
24.98	^{a}1.576	26.14	^{a}1.543	14.48	^{a}1.707	26.93	^{a}1.544	round
_	^{b}1.971	_	^{b}1.947	_	^{b}1.955	_	^{b}1.960	washing

** Means in each column that do not have the same letters are significant at the 5% probability level based on Tukey's test.

The study examined the photosynthetic pigment b at four different phenological stages under various treatments to assess their impact. The results showed that none of the treatments had significant differences at the 5% significance level, as indicated in Table 5. However, the washing treatment applied to the vines increased chlorophyll b levels. Furthermore, the disparity in chlorophyll b levels between the washing treatment and both the dust treatment and the examined control treatment was found to be statistically significant. The results showed that the dust treatment had the most significant effect on chlorophyll b levels, with the lowest content observed in vines treated with dust. On the other hand, the washing treatment had the highest chlorophyll b content. The percentage change in chlorophyll b levels was also analyzed at different phenological stages. The most substantial change occurred during the fruit formation stage under the dust treatment, with a percentage change of 12.05%. In contrast, the lowest change was observed in the multi-leaf stage under the control treatment, with a percentage change of 3.98%. (Table 6). The analysis of the changes in chlorophyll a and b levels in the dust and control treatments, compared to the washing treatment, revealed that both chlorophyll levels increased in the vines following the removal of dust through washing (Tables 4 and 6). The levels of both chlorophyll pigments, chlorophyll a and chlorophyll b, decreased more significantly in the vines treated with dust compared to the control vines, which had less dust and dirt on their leaf surfaces. An inverse relationship between dust levels and chlorophyll content was observed in this study.

Table 5. The effect of treatments on the amount of chlorophyll b in different phenological stages of dry grapes

Mean square of chlorophyll b				Degrees of freedom	Sources of changes
The stage of fruit ripening to the size of small grains	Fruit formation	Flowering stage	multi-leaf		
^{ns}0.005	^{ns}0.004	^{ns}0.002	^{ns}0.003	3	repetition
0.007	0.009	0.008	0.008	3	treatment
0.001	0.001	0.003	0.004	9	Experimental error
0.054	0.057	0.061	0.067	(%) Coefficient of variation	

Table 6. Comparison of the average amount of chlorophyll b in the treatments applied to dry grapes and its percentage changes

The percentage of changes in the amount of chlorophyll b compared to the washing treatment	The stage of fruit ripening to the size of small pods	The percentage of changes in the amount of chlorophyll b compared to the washing treatment	Stage of fruit formation	The percentage of changes in the amount of chlorophyll b compared to the washing treatment	Flowering stage	The percentage of changes in the amount of chlorophyll b compared to the washing treatment	Multileaf stage	treatment
5.23	[a]0.952	6.04	[b]0.936	7.39	[a]0.919	3.98	[b]0.922	the witness
10.29	[a]0.908	12.05	[a]0.886	7.83	[a]0.915	10.32	[a]0.869	round
-	[b]1.002	-	[b]0.933	-	[b]0.987	-	[b]0.959	Wash

** Means in each column that do not have the same letters are significant at the 5% probability level based on Tukey's test.

Growth and Biochemical Traits

The biochemical traits used in our study are photosynthetic pigments (chlorophylls and carotenoids), leaf relative water content, leaf soluble sugars, and fruit anthocyanins. Based on the analysis of variance, it was found that the growth parameters including leaf dry weight, leaf area, stem length, and internode length were not significantly affected by the presence of particulate matter. To do post-hoc analysis, Tukey test was used to determine if there are significant differences between the means of multiple groups. (Table 7).

Table 7. Results of ANOVA analysis of treatment effect on vegetative and biochemical traits of dry grapes

internode	branch length	leaf surface	Leaf dry weight	Degrees of freedom	Sources of changes
2.250 [ns]	87.503 [ns]	92.751 [ns]	[ns]0.004	3	repetition
4.463 [ns]	41.503 [ns]	6.501 [ns]	0.000 [ns]	3	treatment
5.646	28.081	36.467	0.003	9	Test error
2.17	6.53	5.9	0.05		Coefficient of variation

Although there is no significant correlation between the growth and biochemical traits of drought-resistant grapes with particulate matter, the results suggest slight variations in the measured parameters between the dust-exposed and control groups compared to the washing treatment. Particulate matter treatment increased the dry weight of leaves by 1.93% and 5.34% compared to control and washing treatments, respectively. Compared to both the control and washing treatments, the particulate matter treatment decreased leaf surface area, stem length, and internode length. Specifically, leaf surface area was reduced by 0.31% and stem length by 4.44% (Table 8).

Table 8. The percentage of changes in the studied parameters as a result of micro-powder treatment compared to the control and washing treatments

The percentage of changes due to micro-round treatment compared to the control and washing treatments				treatment
Changes in the percentage of internodes as a result of micro round treatment	Changes in branch length percentage due to micro round treatment	Changes in the percentage of leaf surface due to micro round treatment	Changes in leaf dry weight percentage due to micro round treatment	
-1.20	-2.67	-3.08	1.93	Control treatment
-1.54	-4.44	-0.31	5.34	wash treatment

Reproductive Traits

To examine the reproductive characteristics, four parameters were employed, namely cluster weight, sugar content of the berries, weight of the berries, and the number of berries in a cluster. A statistical technique called analysis of variance (ANOVA) was employed to analyze the data, and the Tukey test was utilized to compare the variations among treatments for each trait. One of the most vital stages in the growth of grapevines is the formation of clusters and their subsequent weight. In the last stage of grapevine growth, once pollination and fertilization have occurred, the flowers develop into berries and clusters, which eventually mature into harvestable fruit over time. ANOVA analysis indicated that the presence of FPM (FPM), or dust, has a significant decreasing effect on cluster weight, berry weight, the number of berries in a cluster, and the sugar content of the berries in comparison to the control (untreated plants) ($p \leq 0.05$, Table 9).

Table 9. The results of the analysis of variance of the effect of treatment on reproductive traits of dry grapes

Function	The number of clusters	pill weight	sugar cube	cluster weight	Degrees of freedom	Sources of changes
2.336 ^{ns}	104.625 ^{ns}	0.035 ^{ns}	17.002 ^{ns}	^{ns}125.158	3	repetition
14.9/۹ *	775.16 *	0.370 *	45.8 *	2626.5 *	3	treatment
2.292	76.903	0.010	3.983	339.237	9	Test error
2.18	12.85	0.12	2.55	26.64	Coefficient of variation	

• ns means non-significant; * means significance at the five percent probability level; ** means significance at the probability level of one percent

In table 9, the statistical analysis indicates that the experimental treatments had a significant impact on cluster weight ($p \leq 0.05$), with the fine dust treatment resulting in a 28.23% reduction and the washing treatment resulting in a 14.49% increase compared to the control. Moreover, the washing treatment had the highest increase in cluster weight while the fine dust treatment had the lowest, suggesting that fine dust has significantly influenced the cluster weight in raisin grapes. The results also showed that berry weight has changed significantly due to the treatments. Berry weight reduced by 29.08% in fine dust treatment and increased by 3.07% in washing treatment compared to the Control. Graph shows maximum increase in berry weight in washing treatment and minimum in fine dust treatment. Fine Dust has significant influence on berry weight in Raisin Grapes. (Figure 4 and Table 10). Furthermore, the number of berries have significantly changed due to the experimental treatments. The fine dust treatment caused a 23.10% decrease in berries compared to the control, while the washing treatment showed a 21.21% increase. The graph shows that the washing treatment had the highest increase in berries, while the fine dust treatment had the lowest count, presenting considerable impact of fine dust on berry formation in raisin grapes (Figure 5 and Table 10). Sugar content of raisin grape berries was also significantly influenced by experimental treatments. The fine dust treatment showed a 12.90% reduction in sugar content compared to the control, while the washing treatment had a 16.66% increase. The washing treatment had the highest increase in sugar content, while the fine dust treatment had the lowest.

The outcomes of the experimental treatments have revealed substantial effects on plant performance, suggesting fine dust has influenced plant performance. The plant performance under the fine dust treatment showed a 84.57% reduction compared to the control, while the washing treatment resulted in a 69.02% increase in plant performance (Figure 7 and Table 10).

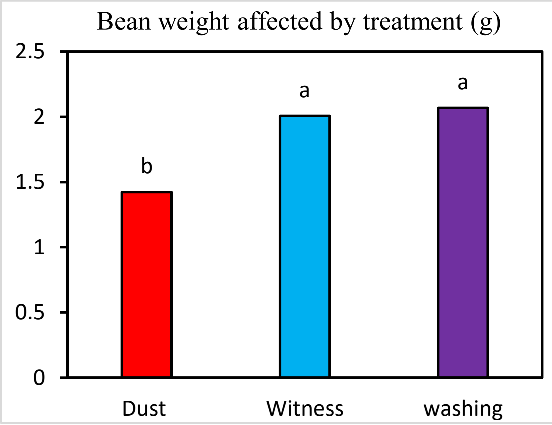

Figure 3. Results of comparison of average treatments on cluster weight

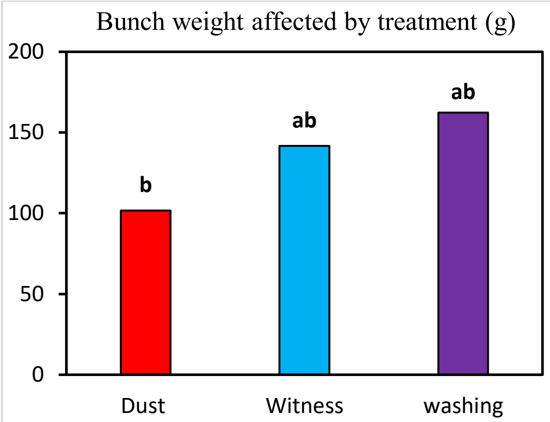

Figure 4. Results of comparison of average treatments on cluster weight

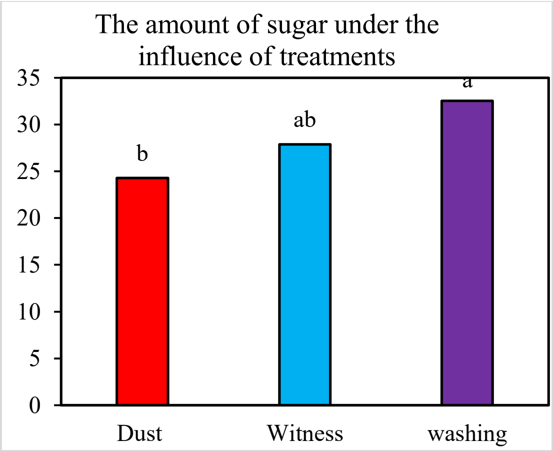

Figure 5. Comparison of average treatments on the number of beans

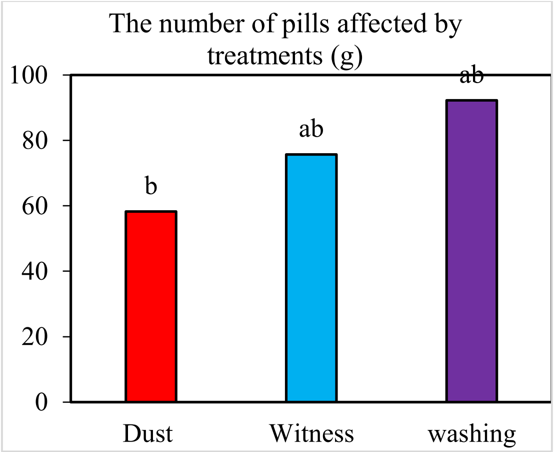

Figure 6. Comparison of average treatments on sugar amount

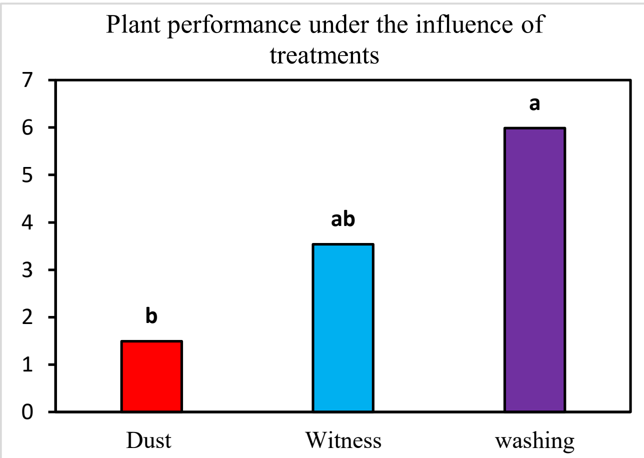

Figure 7. Results of comparison of average treatments on plant yield

Table 10. The results of the analysis of variance of the effect of treatment on reproductive traits of dry grapes

Percentage changes compared to the control treatment	Plant performance	Percentage changes compared to the control treatment	The number of clusters	Percentage changes compared to the control treatment	pill weight	Percentage changes compared to the control treatment	sugar cube	Percentage changes compared to the control treatment	cluster weight	treatment
-57.84	^{b}1.49	-23.10	^{b}58.25	-29.076	^{b}1.423	-12.90	^{b}24.3	-28.23	^{b}101.667	round
69.02	^{a}5.985	21.87	^{ab}92.25	3.076	^{a}2.068	16.66	^{a}32.55	14.49	^{ab}162.197	washing
–	3.541^{ab}	–	^{ab}75.75	–	^{a}2.007	–	^{ab}27.9	–	^{ab}141.660	the witness

SWOT Model

Using the SWOT analysis method, a comprehensive study was conducted to investigate the significant external and internal factors affecting the decline in performance of rain-fed grape cultivation in Sepidan County. The influential internal and external factors have been categorized into three dimensions: economic, social and cultural, and environmental-physical. In examining the internal factors for the environmental-physical dimension, it was identified that there are 8 opportunities available, including the presence of permanent rivers and suitable lands for rain-fed grape cultivation. However, 4 threats were also identified, such as changes in land use and the presence of pests and diseases. With regards to the social and cultural dimension, 5 opportunities were identified, including local knowledge of rain-fed grape cultivation and a sense of attachment to the lands. Similarly, 4 threats were recognized for this dimension, such as a lack of collective participation in cultivating rain-fed grape lands and neglecting them. In the economic dimension, the study identified 5 opportunities as compared to 3 threats.
Moving on to the external factors, for the environmental-physical dimension, 5 opportunities were pinpointed, including plans for organic development of grape orchards and favorable climatic conditions for rain-fed grape cultivation. However, 4 threats were also identified, including the influx of fine particles from neighboring Iraq and the southwestern provinces, as well as threats from animals such as bears to the grape orchards.
Under the context of social and cultural dimensions, 6 different opportunities were recognized, including a gardener's guild for orchard owners and arable and garden cooperatives. However, there are also 4 threats, including price fluctuations, lack of necessity assessment, and supportive pricing policies. Moving onto the economic dimension, there are 4 opportunities and 4 threats.
Upon analyzing the region's strengths and weaknesses concerning the performance and production of rain-fed grapes, a thorough examination of both internal and external factors allowed for the identification of potential opportunities and threats at the county-level within the dimensions. The results showed the presence of 18 internal and 15 external opportunities, juxtaposed with 10 internal and 12 external threats on performance and production. Considering the greater number of opportunities (strengths), with a total of 33 opportunities in contrast to 22 weaknesses, it can be inferred that the study area possesses a distinct capability to enhance the production and performance of rain-fed grapes. This emphasizes the significance of proposing appropriate strategies to address and mitigate the identified weaknesses (Tables 11 and 12).

Table 11. Domestic influencing factors on yield and cultivation of dry grapes

Threats/weaknesses	Opportunities/Strengths	Components
1 -It is difficult to move agricultural machinery and tools due to the high slope in some areas of the city. 2 -Changing the use of rainfed grape areas to residential lands, tourist areas, etc. 3 -Existence of pests and diseases, including dry grape cluster worm 4 -Difficult access roads in autumn and winter	1 .The presence of almost permanent rivers 2 .The existence of suitable agricultural lands for growing dry grapes in this city 3 .High rainfall and provision of conditions for dry growing grapes 4 .Relatively suitable access road to reach the dry grape fields 5 .Special weather conditions for dry growing grapes (cool summer and snowy winter) 6 .The existence of many lands with a suitable slope for growing dry grapes 7 .Suitable depth of soil for growing dry grapes 8 .The presence of native varieties of dry grapes	Environmental-physical
5 .Destruction of access roads to fields and not paying attention to it 6 .Non-participation of the public to cultivate dry land with a large area and prevent land fragmentation 7 .Migration of young people from village to city due to the low level of cultivated land	9 .Tendency of landowners and gardeners to cultivate dry grapes 10 .Institutionalizing the cultivation of rainfed grape farms in the society's culture 11 .Local knowledge suitable for dry grape cultivation 12 .A sense of belonging to the land of dry grapes 13 .The region has high social and cultural security regarding rainfed lands.	Social and cultural
8 .Absence of raisin production factory and rising cost of production 9 .Fertilizers and poisons are expensive 10 .Absence of industrial cold stores in order to store the product and present it to the market in the appropriate season in the city	14 .Appropriate production and income per level unit 15 .Cost reduction (less manpower compared to irrigated cultivation, etc.) and less time spent due to the dry land 16 .Raisin production with suitable cultivars and income generation from it 17 .Existence of a young workforce interested in growing dry grapes 18 .There is a potential to increase the production of dry grapes at the level of the city	Economic

Following the identification of internal and external factors, weaknesses, strengths, opportunities, and threats, the examination of these factors was conducted as follows:
The evaluation of influential strengths and weaknesses, both internal and external, on the production and performance of rain-fed grapes in Sepidan County has shown that the foremost internal strength, ordered from highest to lowest importance, is the potential of the region to increase rain-fed grape yields. This potential is accompanied by high levels of precipitation and favorable conditions for rain-fed grape cultivation, with average scores of 0.893 and 0.877, respectively. The examination of influential opportunities, both internal and external, about the production and performance of rain-fed grapes in Sepidan County has uncovered that the most crucial opportunities, ordered from highest to lowest significance, are the willingness of landowners and orchard owners to partake in rain-fed grape cultivation and the integration of rain-fed grape cultivation into the fabric of society. The average scores for these opportunities are 0.874 and 0.830, respectively.

The examination of substantial internal and external hazards that pose a threat to the production and performance of rain-fed grapes in Sepidan County, the most noteworthy threat is fine particles originating from the southwestern provinces, including Khuzestan and Ilam (Mehran) and Iraq. Additionally, the conversion of rain-fed grape areas into residential and tourist regions also poses a considerable threat. These threats have been assigned average scores of 0.861 and 0.798 respectively.

Furthermore, the most notable internal and external vulnerabilites, ranked from highest to lowest importancy, revolves around the absence of industrial factories for raisin production, the subsequent increase in production expenses combined with the lack of collective involvement in cultivating extensive rain-fed grape lands, and the prevention of land fragmentation with average scores of 0.853 and 0.814 (Table 13).

Table 12. External factors influencing on the yield and cultivation of dry grapes

Threats/weaknesses	**Opportunities/Strengths**	Components
1 .The arrival of small grains from Iraq and the southwestern provinces, including Khuzestan and Ilam (Mehran). 2 .The attack of pigs, bears, etc. on dry vineyards 3 .Non-agreement of natural resources with changing the use of low productivity pasture and stony lands to dry grape lands 4 .Dependence of grape growing on weather conditions (drought, frost)	1 .Converting steep and stony lands into dry vineyards 2 .Organic vineyard development plan 3 .Construction of conversion industries in the region and at the city level 4 .Climatic conditions suitable for the cultivation of dry grapes 5 .Importing high-quality varieties and genetically modified rain grapes from the provinces of the country	Environmental-physical
5 .Lack of prediction of grape price fluctuations and lack of need assessment 6 .Absence of a policy to support the pricing of this product 7 .Absence of gardeners' trade union system 8 .Absence of efficient institutions and organizations in the field of grape export	6 .Activating the union system of gardeners 7 .Formation of agricultural and horticultural production cooperative 8 .Getting to know the manufactured product at the regional level 9 .Consultation and guidance of gardeners using experts in the relevant field 10 .Carrying out various researches regarding cultivars, pests and diseases of dry grapes by research and academic centers 11 .Cooperation of agricultural extension and training experts of the province to increase production and performance	Social and cultural
9 .The high perishability of grapes and, as a result, damage to the products and decrease in profit 10 .Absence of government investments 11 .The low quality of dry grapes compared to the production of other provinces and abroad 12 .Weakness in the country's export infrastructure	12 .Economic development of the region and creation of sustainable employment 13 .Garden development plan and credit attraction in this field 14 .Being well-known and willing to buy grapes produced in the city at the level of the province and region 15 .Payment of bank facilities by the government	Economic

Table 13. SWAT analysis

S/W/O/T	SWOT analysis table	total weight	Average weight	rank
S1	The existence of suitable agricultural land for growing dry grapes in this city	312	0.817	5
S2	The presence of almost permanent rivers	230	0.602	14
S3	High rainfall and provision of conditions for dry growing grapes	335	0.877	2
S4	Relatively convenient access road to reach the dry vineyards	245	0.641	12
S5	Special weather conditions for dry growing grapes (cool summer and snowy winter)	304	0.796	6
S6	There are plenty of lands with a suitable slope for growing dry grapes	198	0.518	19
S7	Suitable soil depth for growing dry grapes	211	0.552	16
S8	The presence of native varieties of dry grapes	238	0.623	13
S9	Appropriate production and income per unit area	301	0.788	7
S10	It reduced the cost (less manpower compared to irrigated cultivation, etc.) and spent less time due to the arid nature of the land	294	0.770	8
S11	The existence of a young workforce interested in growing dry grapes	316	0.872	3
S12	There is a potential to increase the production of dry grapes at the level of the city	341	0.893	1

S13	The climatic conditions are suitable for the cultivation of dry grapes	315	0.825	4
S14	Organic vineyard development plan	256	0.670	11
S15	Construction of conversion industries in the region and at the city level	213	0.558	15
S16	Importing high-quality cultivars and genetic modification of dry grapes from the provinces of the country	204	0.534	17
S17	The region has high social and cultural security .regarding rainfed lands	263	0.688	10
S18	Economic prosperity of the region and creation of sustainable employment	199	0.521	18
S19	Being well-known and willing to buy grapes produced in the city at the level of the province and region	278	0.728	9
O1	The desire of landowners and gardeners to cultivate dry grapes	334	0.874	1
O2	Institutionalization of dry land grape cultivation in the culture of the society	317	0.830	2
O3	Indigenous knowledge suitable for dry grape cultivation	288	0.754	4
O4	A sense of belonging to the land of dry grapes	297	0.777	3
O5	Raisin production with suitable cultivars and income generation from it	186	0.487	14
O6	The possibility of converting steep and stony lands into dry vineyards	231	0.605	8
O7	Activating the union system of gardeners	260	0.681	6
O8	Formation of agricultural and horticultural production cooperative	213	0.558	9
O9	Getting to know the product at the regional level	265	0.694	5
O10	Consultation and guidance of gardeners using experts in the relevant field	192	0.503	11
O11	Conducting various researches on cultivars, pests and diseases of dry grapes by research and university centers	188	0.492	13
O12	Cooperation of agricultural extension and training experts of the province to increase production and performance	190	0.497	12
O13	Garden development plan and attracting credit in this field	251	0.657	7
O14	Payment of bank facilities from the government	211	0.557	10
T1	Changing the use of rainfed lands to residential .lands, tourist areas, etc	305	0.798	2
T2	The presence of pests and diseases, including the dry grape cluster worm	289	0.757	4
T3	Migration of young people from village to city due to the low level of cultivated land	270	0.707	6
T4	Destruction of access roads to fields and neglecting it	191	0.500	8
T5	Small-scale arrival from Iraq and southwestern provinces including Khuzestan and Ilam (Mehran)	329	0.861	1
T6	The attack of boars, bears, etc. on dry vineyards	274	0.717	5
T7	dependence of grape growing on weather conditions (drought, frost)	298	0.780	3
T8	High perishability of grapes and as a result damage to the products and decrease in profit	214	0.560	7
W1	It is difficult to move agricultural machinery and tools due to the high slope in some lands of the .city	283	0.741	7
W2	Access roads are difficult to pass in autumn and winter	287	0.751	6
W3	Non-participation of people to cultivate dry land with a large area and to prevent fragmentation of land	311	0.814	2

W4	Absence of industrial raisin production factories and rising production cost	326	0.853	1
W5	Expensive fertilizers and pesticides	279	0.730	8
W6	Absence of industrial cold stores in order to store the product and present it to the market in the appropriate season in the city	309	0.809	3
W7	Non-agreement of natural resources with changing the use of low productivity pasture and stony lands to dry grape lands	264	0.691	10
W8	Failure to predict grape price fluctuations and lack of need assessment	220	0.576	14
W9	Lack of support policy for the pricing of this product	243	0.636	12
W10	Absence of gardeners' trade union system	267	0.699	9
W11	Absence of effective institutions and organizations in the field of grape export	262	0.686	11
W12	Lack of government investments	296	0.775	5
W13	Low quality of dry grapes compared to the production of other provinces and abroad	231	0.605	13
W14	Weakness in the country's export infrastructure	299	0.783	4

Discussion

Plant growth is invariably influenced by various environmental factors including air quality, soil composition, fluctuations in climate, and the availability of water resources. One crucial aspect of plants, chlorophyll, undergoes changes in response to these environmental factors (Katyar & Dubey, 2000). Hence, the determination of leaf chlorophyll content serves as a fundamental parameter for investigating the effects of air pollution and levels of FPM (Vaughn et al., 2006). Particulate matter, as a significant pollutant, can have extensive effects on agricultural products. This article examines the impacts of particulate matter on the performance and production of grapes. These effects may influence various aspects of the reproductive and vegetative characteristics of grapes (Bahrouzi et al., 2018).

Leaf chlorophyll a and b contents in grapevine were assessed throughout four distinct growth stages, namely the multi-leaves stage, flowering stage, fruit formation stage, and fruit maturation stage with small seeds. The results clearly demonstrated the significant influence of FPM on leaf chlorophyll a and b across all growth stages. Similar results were also observed in previous studies carried out by Sharana & Tripathi (2009), Boro Román & El-Zobi (2015), Miravi et al. (2021), and Salahhi & Behroozi (2020), which documented a decrease in leaf chlorophyll content as a repercussion of FPM. Furthermore, the responses of plant morphological and biochemical traits are also important to understand the effects of FPM (Lin et al., 2019). Despite the absence of significant correlation between the grapevines morphological and biochemical traits with FPM, the findings indicated the slight variations in the measured parameters among the control, washing, and FPM treatments. The FPM treatment exhibited a 1.93% and 34.5% increase in dry leaf weight compared to the control and washing treatment, respectively. The investigations conducted by Younes & colleagues (2013) and Nanos & Elias (2007) demonstrated an increase of dry leaf weight in the examined species, which are *Olea europaea* L and *Ficus carica* L , due to FPM. The contradictory results were reported by Broomand & Mahmoudi (2020), reporting a decline in dry leaf weight because of FPM.

Considering all above matters, FPM influenced the weight of grape clusters and individual berries, the number of berries per cluster, and the berries sugar content, causing a decreasing trend compared to the control (Bahrouzi et al., 2018). The presence of FPM has been linked to the reduction in leaf protein and fruit sugar contents (Ali Pour et al., 2023). FPM caused a sharp decline in plant yield in Sepidan county. This finding is consistent with the research conducted by Chen and colleagues (2015) as well as Arvin and colleagues (2013), who reported that the presence of FPM on corn and sugarcane leaves resulted in yield reduction. The investigation into grapevine performance in the study area demonstrated that the infiltration of FPM poses the most notable threat to grapevine yield within this region. Sultanimoqadas and Khouran (2021), in their study evaluating the suitability of grapevines for cultivation in rural areas of Marivan county, identified FPM as a significant environmental hazard for dry farming in the region. Also, The evaluation matrix of external factors with a total score of 44.3 percent shows that in the current situation, the development of rainfed grape cultivation and production in Sarkal district can work well by strengthening opportunities against threats. Finally, using the matrix (QSPM), the strategy (SO6) was selected and introduced as the construction of conversion and complementary industries to store grapes and reduce waste. The most crucial parameter that can be considered for achieving this goal during the three-year experiment was the performance of grapevines. Unfortunately, atmospheric dust adversely affected grape performance through various methods, and the difference was statistically significant compared to the control. Accumulation of atmospheric dust on leaves led to a reduction in light and photosynthesis rates, coupled with an increase in respiration, resulting in the consumption of stored energy. The decrease in photosynthesis rates affected carbohydrate production, ultimately impacting the production of healthy clusters and ripened berries, leading to a decline in grapevine performance.

On the other hand, the impact of dust on fruit formation resulted in a decrease in the number of berries per cluster and, ultimately, a reduction in vine performance. Dust-laden vines showed a 30% decrease in yield efficiency compared to the control. However, in this study, a strategy was employed to mitigate the impact of atmospheric dust on grapes, not only eliminating the dust effect but also enhancing performance compared to the control. In the event of dust storms, the implementation of this strategy is expected to yield the best results.

Conclusion

Over the past 15 years, there has been a general increase in the percentage of fine particulate matter (FPM) in the region, which has restricted grapevine growth and yield. FPM has induced morphological, biochemical, and reproductive changes in grapevines in Sepidan County. The results suggest that environmental issues have worsened with the increasing number of days with FPM. In general, days with FPM reflect unhealthy environmental, economic, and social conditions, leading to a reduction in both the quality and quantity of products in the area.

One of the key factors investigated in this research, which affects the changes in dry grapes, is micro dust. An increase in the number of days with fine dust in the region contributes not only to environmental, economic, and social crises but also causes severe stress on dry grapevines. As a result of this stress, production levels, performance, and product quality are reduced. Ultimately, by identifying these changes in agricultural products, such as dry grapes, across both temporal and spatial scales, awareness of the harmful effects of fine dust on products can be heightened. The findings of this research can be applied to management practices, optimizing strategies for the sustainable development of agricultural lands.

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