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Mitigating the constraints of high temperature and low humidity conditions of climate change on grapevine physiology and grape quality with iron and calcite pulverizations

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Abstract

Analysis of physiological adaptive mechanisms developed by grapevines to deal with environmental adversities is of prime strategy to maintain more efficient viticulture. In this context, certain exogenous treatments have been tested for effectiveness on enhancement of the grapevine growth against to constraints such as climatic extremes among which drought and high temperature predominate. Iron and micronized calcite pulverizations were performed three times during the vegetation period to soilless grown five years old grapevines of 'Italia' cultivar in controlled glasshouse in order to assess their possible effects on certain physiological and agronomic features of the vines imposed to mild stress condition of elevated air temperature (with midday means around 37.5±5.6 5 °C), decreased humidity in both air and growth substrate. Fe treatment increased the stomatal conductance in the hottest period of the experiment. The treatments did not affect the leaf temperature, while the chlorophyll and relative water contents of the leaves were improved by all the applications. The leaf mass and pruning residue measurements revealed that the individual application of Fe or calcite induced the vegetative development of the vines. Fe pulverization, with calcite in particular, remarkably increased the cluster mass and the size, although the biochemical features of the must were not affected by the treatments. Therefore, the use of Fe chelates supplemented with micronized calcite would be recommended to enhance grapevine development and grape quality on the face of ever-increasing global warming incidence.

Keywords: Table grapes, Climatic extremes, Vine physiology, Grape quality

Introduction

Water shortage and depletion of soil fertility are among the most essential constrains restricting the agricultural productivity worldwide. As the agricultural productivity has already impacted by climate change characterized by elevated temperature and decreased humidity (Webb et al., 2007), adapting agricultural practices to changing environment is essential as its trends will continue. Adaptation to changing environment is prime consideration in coping with the climate change besides to alleviating strategies across the world (Hinkel, 2011). Since the adaptation to climate change incidences is the prime development concern in developing countries, it is a key to have really affordable and feasible methods in the area. In this context, many crop management strategies and applications based on land and water use that fit with necessities of climate resilient development in agricultural are being examined and promoted across the world (Hu et al., 2018; Sabir et al., 2020).

Conventionally developed methods of producers have to be considered as the initial point in enhancing new approaches for adaptation to have feasible and applicable techniques in the agricultural area. However, the effects of global climate change

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on agricultural lands will be locally unique and hard to measure because of the environmental variations and complications in production techniques. Nonetheless, assessment of climate change effects at land level can be improved by scrutinizing the local experiences and applications (Tiyo et al., 2015; Debela et al., 2015). It is not intensively evaluated at conventional level how adaptation is applied, because the plants have been showing potentially different responses when the climate is getting warmer. However, in order to alleviate the harmful influences of climate change, the selection of adapted genotypes is a better strategy besides many other cultural practices employed simultaneously to obtain better results.

Grapes are commonly cultivated in regions having a warm temperature and dry climate across the world. Although such conditions contribute to good productivity in general, they also cause the decrease in grape quality when, in particular, climate extremes occur. Therefore, to ensure profitable yield and quality, it is often necessary to apply certain exogenous treatments. Grape growers are frequently familiar with the application of Fe chelates to cure or safeguard the grapevines against the stress condition (Ozdemir and Tangolar, 2007). Physiologically, Fe mediates the development stages of plants based on the fact that chlorophyll synthesis and the photosynthetic chain reaction are closely related to Fe status of the plant (Katyal and Sharma, 1980). For this reason, under the stressful environmental condition, Fe chelate pulverization may mitigate the adverse effects of stress factors on plants. Therefore, this study was carried out to investigate the possible effects of micronized calcite and Fe chelate on the physiology, vegetative development and grape quality of table grape cultivar ‘Italia’ imposed to mild stress conditions of high temperature and low humidity established in controlled glasshouse.

Materials and Methods

Experimental Design

The present experiment was performed in the research glasshouse of Selcuk University, Konya Province, using a soilless culture established with plastic pots (about 70 L in solid volume) containing a growth substance of peat and perlite mixture. The five years old healthy vines of ‘Italia’ cultivar grafted on 99 R Rootstock (*Berlandieri* x *Rupestris*) were drip irrigated using irrigation lines equipped with individual dropper of 4 L h^{-1} for every grapevine. The vines were designed with east-west orientation with a rectangular configuration of 0.5x1.0 m intervals. In the winter season prior to shoot growth, the grapevines were spur pruned to leave spurs having two buds each according to fruitfulness feature of the cultivar. In early spring, five or six shoots per vine were ensured to elongate to maintain homogenous vine development for optimum assessment of application influences. Nine healthy grapevines for each application were chosen based on the homogeneity in plant growth. Long term mild water stress condition was established with using tensiometers for long term tracking of substrate matrix potential as defined by Satisha et al. (2006) and Sabir and Sari (2019). The climate change events were simulated by simultaneous occurrence of elevated temperature with decreased relative humidity inside the glasshouse with the prolonged summer period and the restricted irrigation in growth substance. The mean of midday temperature, recorded with data logger (Ebro EBI 20 TH1) in the experiment area, was 37.5±5.6 °C, while air relative humidity was around 34.0±8.1%. The tensiometer readings were maintained between 30 and 42 cb. Slight wilting of fresh shoot tips at around 40±2 cb level indicated that the vines experienced mild stress conditions sometimes in midseason. The experimental grapevines were fertilized with the same amount of fertilizers during the summer season (approx. 30 g N, 20 g P, 30 g K, and equal mixture of microlements per vine).

The experimental grapevines were divided into four rows according to the treatments as 1) control (no pulverization), 2) micronized calcium, an organic produce containing 40% $CaCO_3$, (0.5%), 3) iron [Fe chelates (FeNaEDTA), 0.3%], and 4) mixture of calcite and iron. The first application was carried out just before flowering, followed by the second when the berry width was around 3 mm and the last one fifteen days later the second treatment according to the directions of manufacturer using a hand pressure sprayer.

Measurements and Analyses

The stomatal conductance (gs) and leaf temperatures (T_{leaf}) determinations were performed from 09:30 to 11:30 h (using twelve leaves (6th leaf) using six grapevines Sabir and Yazar, 2015), at three different dates with a porometer (SC-1 Leaf Porometer) (Zufferey et al. 2011) and was recorded as mmol H_2O m^{-2} s^{-1}. Near the central vein of the leaf blade (Stavrinides et al., 2010) of the newly expanded and sun-exposed leaves were selected for analysis (Johnson et al., 2009). The same surface of the leaves were analyzed (Miranda et al., 2013), as the gs might be heterogeneous on the large leaf like grapevines. Chlorophyll density of the same leaves was recorded, using a mobile chlorophyll meter (Minolta SPAD-502, Japan).

At around véraison, twelve mature leaves of each grapevines per treatment were harvested from the middle of the summer shoots (OIV, 1997) of each experimental vines in the early morning to obtain fresh and dry masses was obtained from (Tramontini et al., 2013). The fresh leaves were weighed with an analytical scale, with sensitivity of 0.0001 g to record fresh mass (FM). Afterwards, they were hydrated to about the highest turgor by dipping in distilled water for four two days to ensure full rehydration (Yamasaki and Dillenburg, 1999). Before the measurements, the water on the leaf was slightly wiping by using a tissue paper. After the rehydration period, the samples were weighed to record turgid mass (TM) and placed in an oven (Turner 1981), at 70 °C for 48 h to find dry mass DM. Values of FM, TM, and DM were employed to find RWC, using the equation of Gonzalez and Gonzalez-Vilar (2003):

$RWC (\%) = [(FM – DM)/(TM – DM)] \times 100$. Instantaneous air temperature, air relative humidity (using mobile data logger EBRO EBI 20) and light intensity (using light meter Lutron LX-105) inside the study glasshouse were obtained simultaneously with the leaf temperature (Hirayama et al., 2006).

Twelve representative clusters per treatment were harvested according to the norms of the O.I.V. (1983) when the grape berries reached at least 16.5 °Brix grape juice (must) total soluble solid content (SSC) to find cluster and berry growth feature. The length, width and mass of the clusters were recorded. Sixty berries for each treatment were randomly collected from the middle of the clusters to find berry weight. The mass of the berry and clusters were recorded using an analytical scale. The must of the berries was obtained with hand press and filtered through cheesecloth and the supernatants were collected for the biochemical investigations. SSC was obtained with a hand-held temperature compensated refractometer (Atago 9313). Titratable acidity (TA) was analized by titrating 10 mL of the must with 0.1 N NaOH to an endpoint of pH 8.1 and recorded as the percentage of tartaric acid (Valero et al., 2006).

In the following winter, one year-old canes of each grapevine were weighed to obtain pruning residue mass for a logical comparison of vine vegetative development response to the treatments.

Statistical analysis

Numerical data from the analyzed features were subjected to analysis of variance. Comparisons of means were carried out by Tukey's multiple range tests at $P < 0.05$ significance level. The analyses were carried out with SPSS software package v. 15.0 for windows.

Results and Discussion

The stomatal conductance (gs) response of 'Italia' table grapevines in soilless culture was illustrated in Figure 1. In the first measurement, the gs values did not show significant variation ranging from 293.0 (calcite+Fe) to 307.4 mmol H_2O m^{-2} s^{-1} (control). The values are well adjusted to those of the previous investigations performed on different grapevine cultivars (Zsófi et al., 2014; Sabir and Yazar, 2015). This case indicates that the treatments did not adversely affect the gas exchange of the leaves. The second measurement was performed in one of the hottest (around 38 °C) and the driest days (at a relative humidity around 32%) of the experimental season to understand the effects of the treatments on leaf gs under extreme temperature conditions. General investigations on gs in this date indicated that the environmental extremes resulted in the imposition of the progressive decrease in gas exchange of the stomata. However, the gs in this case displayed significant variation from 100.7 (calcite) to 187.8 H_2O m^{-2} s^{-1} (calcite+Fe). The gs increase was most probably due to the Fe, because the Fe application alone gave the similar value 179.7 (H_2O m^{-2} s^{-1}) to that of combined application. The final measurement, when the shoot growth was near to terminate, the gs values across the treatments were at the lowest values with no significant variation.

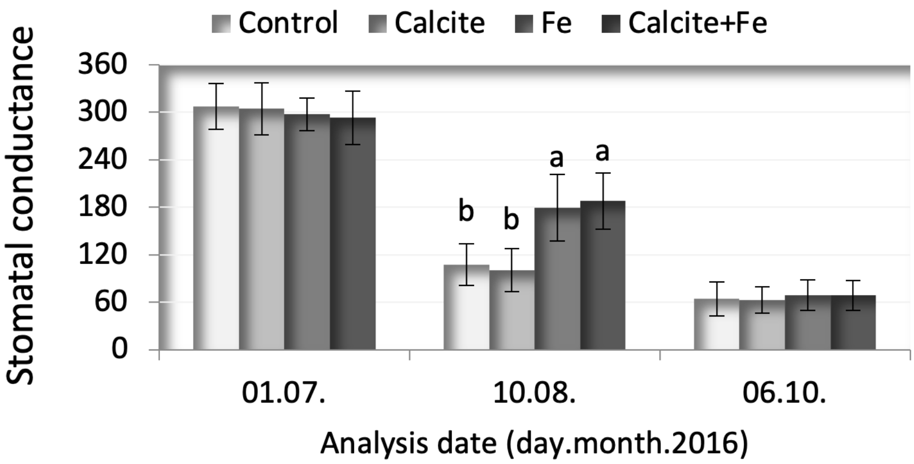

Figure 1. Seasonal changes in stomatal conductance (mmol H_2O m^{-2} s^{-1}) in response to Fe and calcite pulverizations. Values of bars indicated by different letters indicate significant difference ($P < 0.05$).

As depicted in Figure 2, the T_{leaf} did not significantly respond to the treatment throughout the vegetation period. In general, the T_{leaf} of overall grapevines displayed changes depending on seasonal ambient conditions. Nonetheless the obtained values on T_{leaf} were similar to those of literature investigations on grapevines (Düring and Loveys, 1996; Rogiers et al., 2009). Overall values across the experimental grapevines indicated that the range of T_{leaf} was within the recommended values for optimum photosynthesis (25-30 °C) as previously suggested by Greer (2012). This also implies that the treatment did not impair the T_{leaf}.

Chlorophyll concentration of mature leaf was significantly improved by the treatments (Figure 3). The positive effects of the treatments on chlorophyll concentration of the vines were evident from the first measurement to the end of the summer season, except for the Fe application alone in last investigation. Improvement in leaf chlorophyll concentration of grapevines in response to iron was also reported in the previous studies conducted on various cultivars (Chen et al., 2004), studying on the response of the vines to iron supply. Iron could induce the electron transport systems in mitochondria and chloroplasts (Bertamini and Nedunchezhian, 2005) which may ultimately improve the chlorophyll synthesis. Furthermore, Katyal and Sharma (1980) have already revealed that Fe regulates the plant growth through the chlorophyll synthesis as the photosynthetic chain reaction is related to plant Fe status.

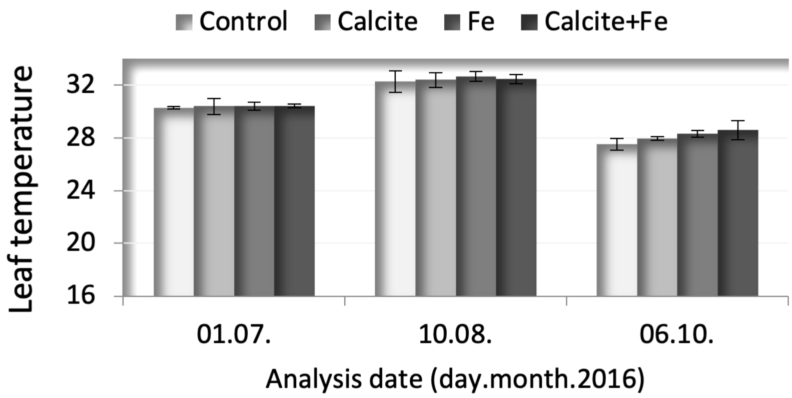

Figure 2. Seasonal changes in leaf temperature (°C) in response to Fe and calcite pulverizations.

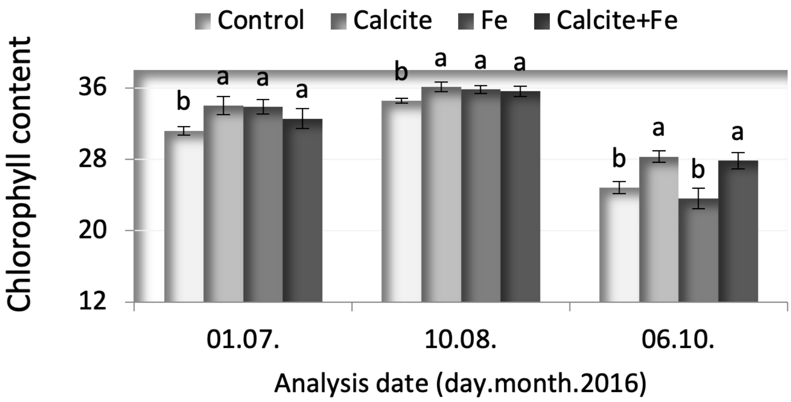

Figure 3. Seasonal changes in leaf chlorophyll content (SPAD meter readings) in response to Fe and calcite pulverizations. Values of bars indicated by different letters indicate significant difference (P < 0.05).

The leaf treatments led to significant improvement in relative water content of (RWC) the leaves as can be seen in Figure. 4. The highest RCW was determined in Calcite+Fe pulverization (91.2%) which was followed by Fe (89.3%) and calcite treatments (88.3%). The RWC values were quite similar to those previously determined in the leaves of various grapevine rootstocks (Karaca and Sabir, 2018). Significant increases in fresh and dry weights of the leaves were also determined in response to the treatments (Table 1). The highest improvement in both fresh and dry weights were recorded in vines received the calcite pulverization, followed by Fe application. On the other hand the lowest values were found in control vines.

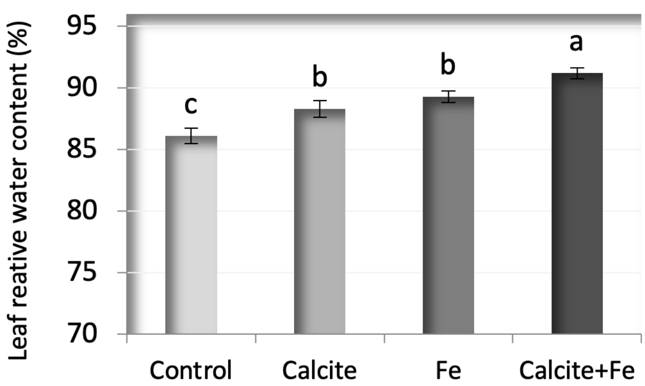

Figure 4. Changes in leaf relative water content (%) in response to Fe and calcite pulverizations. Values of bars indicated by different letters indicate significant difference (P < 0.05).

Table 1. Changes in leaf fresh and dry masses (g) in response to Fe and calcite pulverizations. Values of means indicated by different letters identify significantly different means (P < 0.05).

Treatments	Leaf fresh mass (g)	Leaf dry mass (g)
Control	1.73±0.07 c	0.55±0.05 c
Calcite	2.19±0.12 a	0.83±0.05 a
Fe	2.01±0.11 ab	0.72±0.06 b
Calcite+Fe	1.88±0.08 bc	0.64±0.06 bc
LSD	0.18	0.09

Means with different letters in a column are significantly different according to Student's t test (P<0.05).

Pruning residue mass, as a good determinant parameter for vegetative development of grapevines, was significantly affected by calcite (120.9 g per vine) and Fe treatments (116.6 g per vine) as can be found in Figure 5. The pruning residue mass in the vines of calcite and Fe pulverizations were 15.1 and 12.0%, respectively, higher than that of the control vines (102.6 g per vine), with the highest value obtained from the calcite pulverization. Electron-microscopical studies performed by Yamazki et al. (2008) have displayed that calcium is necessary for the construction of lamellar structures in cell organelles, a fact which might describe its indispensability for meristematic development in plants. A well-balanced vegetative development with early and complete cane maturity support the vines cope with winter freeze. This issue, in particular, is essential for the ecosystems characterized with cold winters like Konya province in Central Anatolia. Fe and calcite treatments induced the vegetative growth of the vines, which, in turn, may be anticipated to help the vines endure cold injuries.

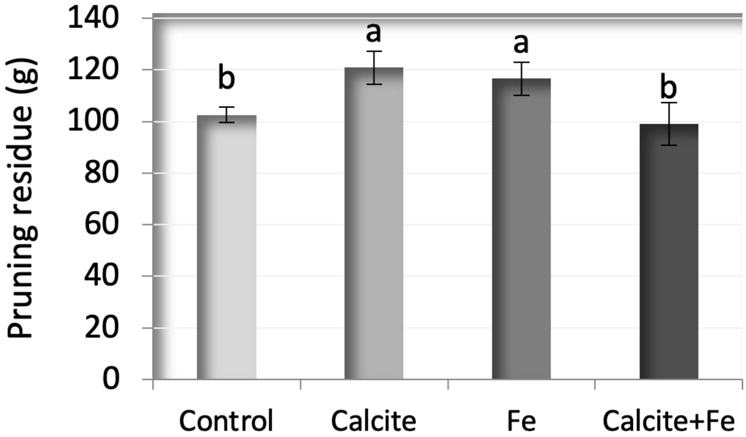

Figure 5. Changes in pruning residue (g) in response to Fe and calcite pulverizations. Values of bars indicated by different letters indicate significant difference (P < 0.05).

Combined application of calcite and Fe led to remarkable increase in berry mass, although single use of these substances were ineffective on berry development (Figure 6). Improvement in berry growth in response to calcite plus Fe treatment resulted in increased cluster weight as indicated in Table 2. The increase in cluster mass was 8.4% higher in vines of combined application that that of the control. This means a significant yield improvement emerging from this treatment, as the cluster number per vine (data not shown) was similar across the experimental vines. The greatest changes in length and width of the clusters were also found in the vines received the calcite plus Fe pulverization. Such remarkable increase in the agronomic characters would most probably be emerging from the vital role of Fe in photosynthesis reactions (Val et al., 1987), as well as its duty as constituents of essential enzymes associated with saccharide metabolism and photosynthesis (Bertamini and Nedunchezhian, 2005).

Changes in biochemical components of the grape must as influenced foliar treatments are presented in Table 3. Total soluble solid content, acidity and pH of the must were not manipulated by the treatments.

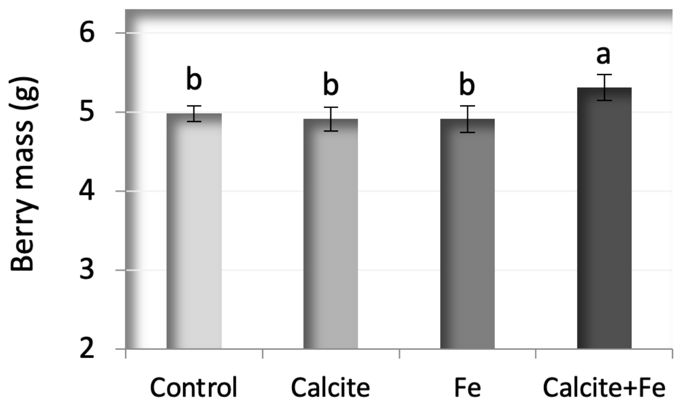

Figure 6. Changes in berry mass (g) in response to Fe and calcite pulverizations. Values of bars indicated by different letters indicate significant difference (P < 0.05).

Table 2. Changes in cluster mass (g), cluster length (cm) and cluster width (cm) in response to Fe and calcite pulverizations. Values of means indicated by different letters identify significantly different means (P < 0.05)

Treatments	Cluster mass (g)	Cluster length (cm)	Cluster width (cm)
Control	217.4±13.0 b	14.8±1.1 b	12.8±1.4
Calcite	212.2±5.9 b	15.5±0.9 b	13.9±0.8
Fe	225.9±4.7 ab	14.7±1.0 b	13.1±1.9
Calcite+Fe	237.4±2.4 a	17.7±0.2 a	13.4±0.6
LSD	14.26	1.56	ns

Means with different letters in a column are significantly different according to Student's t test (P<0.05). ns: not significant.

Table 3. Changes in SSC (°Brix), TA (%) and pH in response to Fe and calcite pulverizations. Values of means indicated by different letters identify significantly different means (P < 0.05).

Treatments	SSC (°Brix)	TA (%)	pH
Control	16.9±0.31	0.42±0.03	2.94±0.05
Calcite	16.9±0.17	0.47±0.01	3.10±0.09
Fe	16.6±0.32	0.46±0.00	3.07±0.03
Calcite+Fe	16.8±0.06	0.47±0.03	3.13±0.18
LSD	ns	ns	ns

ns: not significant.

Conclusion

Multidisciplinary studies indicate that climate change incidences are forecasted to affect agricultural productivity primarily due to rise in temperature and extremities in the droughts. Such stress factors cause crop limitation in lands with rain fed viticulture. Thus, the cultural practices to mitigate such constraints should be developed to match the food demands of the growing population. Iron and micronized calcite pulverizations, performed three times during the vegetation period, remarkable supported the physiology and growth of the soilless grown 'Italia' grapevines imposed to mild stress condition of elevated air temperature and decreased humidity. In the hottest period of the summer, Fe chelate increased the stomatal conductance which may provide a continuous photosynthesis reaction. The chlorophyll and relative water contents of the leaves were also improved by all the applications. Fe or calcite induced the vegetative development of the vines by increasing the leaf and pruning mass values. The cluster features were enhanced by combined application of Fe and calcite. Overall findings show that the use of Fe chelates supplemented with micronized calcite would be recommended to support grapevine development and to maintain grape quality on the face of global climate change events.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Not applicable.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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