Foliar application of chelated sugar alcohol calcium fertilizer for regulating the growth and quality of wine grapes

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Abstract: The eastern foothills of Helan Mountain are a production area of high-quality wine grapes, but the low content of water-soluble calcium in the alkaline soil in this area has become an important limiting factor for the production of high-end wines. In this study, 7-year-old *Cabernet Sauvignon* grapes grown at Lilan Winery, which is located at the eastern foot of Helan Mountain in Ningxia, China, were used to examine the effect of exogenous calcium supplementation on fruit growth and berry quality. Calcium sugar alcohol was applied as a foliar spray at 1.2 L/hm^2 (T1), 2.4 L/hm^2 (T2), 3.6 L/hm^2 (T3), 4.8 L/hm^2 (T4), and 6.0 L/hm^2 (T5) concentrations at the fruit expansion stage, the early stage of grape veraison, the middle stage of grape veraison, and the later stage of grape veraison. Water control was used for comparison. The results showed that foliar calcium supplementation can significantly enhance the photosynthetic characteristics of wine grape leaves, increase the chlorophyll content of leaves, and improve the quality of grape berries. Under the T3 (3.6 L/hm^2) concentration of exogenous calcium, the transverse diameter, the longitudinal diameter, and fruit shape index of grapes were the highest, which were increased by 1.71%, 5.33%, and 3.92% compared to the control, respectively. The application of high calcium concentrations (T4 and T5) inhibited the physiological development of grapes. The spike length, hundred-grain weight, yield of wine grapes, sugar-acid ratio, tannin, and total phenols were the highest in the T2 (2.4 L/hm^2) treatment. The results of principal component analysis based on multiple indicators showed that foliar application of 2.4-3.6 L/hm^2 chelated sugar alcohol calcium on the leaf surfaces of grape leaves was the most suitable for improving the physiological characteristics and berry quality of wine grapes.

Keywords: wine grapes, chelated sugar alcohol calcium, mineral elements, berry quality, Helan Mountain
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1 Introduction

The eastern foothills of Helan Mountain in Ningxia, China, are located between the Yellow River alluvial plain and the Helan Mountain alluvial fan. The terrain is flat, the light quality is sufficient, and the soil structure is good, which creates favorable conditions to produce high-quality wine grapes[1]. The geology is predominantly limestone which means the soil has a high calcium carbonate content[2]. The nutrient availability of various minerals is extremely low in this alkaline calcareous soil environment. Although the total calcium content is high, the water-soluble calcium content that can be absorbed and used by grapes is low which, in turn, affects grape growth and berry quality, and it has become one of the important limiting factors for high-quality wine production in this region. Therefore, the addition of exogenous calcium to improve calcium absorption, promote growth, and improve grape berry quality, has become an important research objective for this region.

As a component of plant cell walls and intercellular layers, calcium directly affects the mechanical strength of tissues and influences plant tolerance to biotic and abiotic stresses, thereby affecting fruit quality. It is an indispensable mineral nutrient for fruit tree growth and development[3-6]. Calcium can promote root growth by controlling nutrient uptake, enhancing fruit flavor, and increasing disease resistance. However, calcium is a less mobile nutrient in plant xylem. After grape veraison, only a small fraction of calcium can flow into the fruit due to the nonfunctionally of grape lignin, the low mobility of calcium in the phloem, and the low fruit transpiration rate[7]. This means that additional calcium supplementation during fruit tree growth can be beneficial. Because plant roots absorb nutrients from the soil and transport them to other organs, it has been found that supplementing calcium fertilizers by irrigation or soil fertilization has achieved good results on a variety of fruit trees. Wang et al.[8] showed that the titratable acidity, anthocyanin, and total phenolic content of grape berries were significantly increased after drip irrigation with $Ca(NO_3)_2·4H_2O$ at a concentration of 3.0 kg/hm^2. At this dose, it effectively prevented grape cracking, inhibited cell wall disintegration, promoted cell wall strengthening[9], and prolonged the effective storage time of grapes after harvesting[10]. Some studies have found that the application of calcium fertilizer

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can reduce the titratable acid content of apple fruit and increase yield[11,12]. However, because calcium is relatively immobile, only a small proportion of calcium fertilizer applied to roots can reach the fruit, so root fertilization has only limited benefits to fruit development. Therefore, in recent years, foliar calcium sprays have been used to improve the efficiency of uptake and good results have been achieved in some fruit trees. Wang et al.[13] showed that foliar supplementation of Kangpo Gaimei (calcium fertilizer) treatment can significantly improve fruit hardness, soluble solids content, soluble sugar content, single fruit weight, and other indicators of Fuji apples. Askin et al.[14] found that the yield of pomegranate under foliar application of calcium fertilizer was higher than in the foliar application of boron fertilizer. However, most studies have focused on fresh fruit production and there are few studies on the effect of foliar calcium application on fruit growth and berry quality in wine grapes.

The type of calcium fertilizer applied is an important factor. Currently, the main calcium fertilizers used are calcium citrate, calcium acetate, calcium nitrate, calcium chloride, and calcium sugar alcohol. Calcium sugar alcohol is a chelated calcium fertilizer and it has the advantages of good water solubility and easy absorption. It can improve stress resistance in fruit trees, and its effect is fast and durable. Also, it minimizes the damage caused by traditional calcium fertilizers. For example, Li et al.[15] increased potato yield by more than 10% by foliar application of calcium sugar alcohol. Yu et al.[16] showed that foliar application of calcium sugar alcohol significantly increased the calcium nutrient content in peach leaves and pulp at the peach expansion stage. However, there are few studies on the effect of foliar application of calcium sugar alcohol on wine grapes. To address this gap, the objectives of this research were to examine 1) if foliar spraying of calcium sugar alcohol can improve the growth of wine grapes; 2) if exogenous calcium supplementation can improve the quality of grape berries, and 3) the dosage required to improve the quality of wine grapes. This study provides valuable guidance to improve the quality of wine grapes and wine caused by calcium deficiency in the eastern foothills of Helan Mountain.

2 Materials and methods

2.1 Ethics statement

All plots (105°58'20"E, 38°16'38"N) were distributed at Lilan Winery, Minning Town, Ningxia, China, and all plots were approved by the landowner. All the sampling sites were in vineyards and no endangered or protected species were affected.

2.2 Study area

The experiment was located at the Lilan Winery vineyard (105°58′20″ E, 38°16'38"N) in the wine geographical indication production area at the eastern foot of Helan Mountain. The total solar radiation in this region is 6100 MJ/m^2, the annual average temperature is 8.9°C, the accumulated temperature is 3289°C, the annual rainfall is about 200 mm, the frost-free period is 176 d, and the average altitude is 1129 m. The soil type of the vineyard is limestone with gravel, the soil texture is loamy sandy soil, the pH value is about 8.5, the soil is alkaline, and the organic matter content is low. The wine grapes under investigation were 7-year-old Cabernet Sauvignon (*Vitis vinifera* L. Cabernet Sauvignon), which were planted in a north-south direction. The shaping method was "plant-shaped", the row spacing was 0.6 m×3.5 m, and the planting density was 4760 hm^{-2}. The entire vineyard was organically planted, the irrigation method was drip irrigation, and the irrigation quota was 3000 m^3/hm^2.

2.3 Experimental design

Liquid calcium fertilizer-chelated sugar alcohol calcium was used, with a calcium content of 18%. A single-factor randomized block design was adopted. Foliar spraying with water was used as the control (CK). The experiment tested foliar spraying at a concentration of 1.2 L/hm^2 (T1), 2.4 L/hm^2 (T2), 3.6 L/hm^2 (T3), 4.8 L/hm^2 (T4), and 6.0 L/hm^2 (T5) calcium inositol. Each treatment was replicated three times. There were a total of 18 plots. The upper and lower surfaces of grape leaves were evenly sprayed four times during the fruit expansion stage, the early stage of grape veraison, the middle stage of grape veraison, and the later stage of grape veraison.

2.4 Grape properties measurement

In the middle of fruit color change, the net photosynthetic rate (Pn), stomatal conductance (Gs), intercellular CO_2 concentration (Ci), and transpiration rate were measured using an LI-6400 portable photosynthesis instrument at 9:30-10:30 am for three consecutive days. To measure water use efficiency (WUE), five plants were selected from each treatment and five values were measured from leaves in the same position for each plant. Chlorophyll was determined by an ethanol extraction method[17].

One hundred wine grapes were randomly selected during the grape ripening period to measure the hundred-grain weight of grape berries. A vernier caliper was used to measure the horizontal and vertical diameters of each grape. A tape measure was used to measure the length of the spike. Individual grapes were picked and tested for the yield of wine grapes, and the yield was obtained by conversion, using the following conversion formula: yield (kg/hm^2) = mass (kg/plant) × number of plants per hectare.

Fifteen representative fruit bunches were randomly collected during the grape ripening stage, and 35 fruits were randomly collected from the upper, middle, and lower parts of each bunch for juice extraction. The acid content was titrated[18], the tannin content was determined by the Folin-Dennis method, the total phenolic content was determined by the Fulin-Shorka method, and the anthocyanin content determined by the pH differential method[19].

2.5 Statistical analysis

Microsoft Excel 2010 software was used for sorting and drawing. SPSS 21.0 software was used for statistical analysis and principal component analysis. Each index of wine grapes under each treatment was tested for significance at the significance level of p<0.05.

3 Results

3.1 Effect of foliar spraying calcium sugar alcohol on the photosynthetic characteristics of wine grape

Foliar application of calcium sugar alcohol can effectively promote a net increase in the photosynthetic rate of leaves. T3 treatment increased the photosynthetic rate by 16.31% compared to the water control, but the photosynthetic rate decreased when the concentration of calcium sugar alcohol was too high. The stomatal conductance of leaves was the highest under T2 treatment, followed by T3 treatment. At a concentration of 6.0 L/hm^2 (T5 treatment), stomatal conductance was the same in the treated and control plants. Leaf transpiration rate increased in the treatments compared to the control, particularly at a concentration of 2.4 L/hm^2 (T2 treatment). The intercellular CO_2 concentration was lower in treated plants compared to the control; the T2 treatment showed the largest decrease at 7.12% lower than the control, followed by T3 treatment, which was 4.93% lower than the control. Water use efficiency was highest in the T3 treatment, with a 42.29% increase compared to the control, followed by T4, T2, and T5, which increased by 39.20%, 29.07%, and 26.43%, respectively, compared to the control treatment.

Table 1 Effects of different treatments on wine grape photosynthetic characteristics

Treatment	Pn/μmol·m^{-2}·s^{-1}	Gs/mmol·m^{-2}·s^{-1}	Tr/mmol·m^{-2}·s^{-1}	Ci/μmol·mol^{-1}	WUE/%
Control	9.32±0.09^{c}	0.13±0.00^{c}	3.27±0.10^{b}	234.73±9.12^{a}	2.27±0.10^{c}
T1	9.53±0.39^{bc}	0.14±0.00^{bc}	3.38±0.15^{ab}	227.59±1.52^{a}	2.83±0.17^{b}
T2	10.47±0.51^{ab}	0.16±0.00^{a}	3.58±0.17^{a}	218.02±6.04^{ab}	2.93±0.03^{ab}
T3	10.84±0.12^{a}	0.15±0.00^{ab}	3.37±0.14^{ab}	223.15±10.42^{ab}	3.23±0.12^{a}
T4	10.77±0.30^{a}	0.14±0.00^{bc}	3.41±0.13^{ab}	227.18±11.14^{a}	3.16±0.05^{ab}
T5	9.89±0.23^{abc}	0.13±0.00^{c}	3.45±0.10^{ab}	226.46±9.25^{a}	2.87±0.15^{ab}

Note: After the same column of data, different letters indicate significant differences (p<0.05).

3.2 Effect of foliar spraying with chelated sugar alcohol calcium on the chlorophyll content of wine grape

Chlorophyll is the main photosynthetic pigment in plants and its content directly affects the rate of photosynthesis. The results showed that foliar spraying of calcium sugar alcohol on wine grapes influenced the chlorophyll content of wine grape leaves. The chlorophyll content of all foliar-treated leaves was significantly higher than the control. The SPAD, chlorophyll a, chlorophyll b, and total chlorophyll of wine grape leaves showed the same changing trend under different calcium sugar alcohol concentrations. The SPAD value and chlorophyll content on the leaf surfaces were lowest in the control plants and highest in the T3 treatment (3.6 L/hm^2). The chlorophyll content of leaves in T2 (2.4 L/hm^2) and T4 (4.8 L/hm^2) was slightly lower than in T3 (3.6 L/hm^2), but the difference was not significant.

3.3 Effects of foliar spraying with calcium sugar alcohol on the morphological indices of wine grapes

Foliar application of calcium sugar alcohol significantly affected the morphological indicators of wine grapes (Table 3). The spike length of all treated grapes was significantly higher than in the control treatment. The longest spike length was recorded in the T2 treatment, which expanded the surface area of the fruit. Both the transverse diameter and the longitudinal diameter increased. The transverse diameter under the T2 and T3 treatments was significantly higher than in the control, and the longitudinal diameter under the T3 treatment was significantly higher than in the control treatment. The highest berry weight per 100 seeds was recorded in the T2 treatment compared to the control, with a significant increase of 16.62%. The fruit shape index of different treatments varied from 0.99 to 1.06. T3 treatment showed an increase of 7.07% compared to the control, but the other treatments had little effect on the fruit shape index. Grape yield slightly increased in all treatments with the largest increase in the T2 and T3 treatments, but the differences were not significant compared to the control.

3.4 Effects of foliar spraying with calcium sugar alcohol on the quality of wine grapes

Calcium sugar alcohol treatments improved the quality of grape berries (Table 4). The content of soluble solids in grape berries was the highest under T2 treatment, which showed an increase of 7.85% compared to the control, followed by T3, T4, and T1, which showed increases of 7.17%, 6.10%, and 4.26%, respectively, compared to the control. Treatments increased the acid content which could be titrated, but the effect was not significant. The T2 treatment had the highest sugar-acid ratio at 3.50% higher than the control. The sugar-acid ratios of the other treatments were in a descending order of T3, T1, T4 and T5. The tannin content was highest under the T2 treatment, which increased by 21.12% compared to the control. The anthocyanin content was also highest under T2 treatment, which was 24.32% higher than the control, but the higher concentrations of foliar treatment caused a downward trend in anthocyanin content. The performance of total phenols in each treatment showed the same trend as tannins, with the content of total phenols increasing significantly under T2 treatment, at 16.69 mg/g.

3.5 Principal component analysis of leaf spraying calcium sugar alcohol and photosynthesis, and quality of wine grapes

When considering the comprehensive effects of foliar spraying of calcium sugar alcohols on photosynthesis, yield, and quality of wine grapes, it was found that spraying concentration and the effect of spraying calcium sugar alcohol made a significant difference in the evaluation of a single index using principal component analysis. Principal component analysis was conducted on 21 evaluation indicators, including photosynthesis, chlorophyll, hundred-grain weight, transverse diameter, longitudinal diameter, spike length, yield, and quality. The contribution rates of the first principal component, the second principal component, and the third principal component to the total variance were 75.87%, 13.81%, and 5.13%, respectively, and the cumulative contribution rate of the three principal components was 94.81%>85.00%. This shows that these three principal components basically covered all the information from the 21 indicators. Table 5 shows that the comprehensive scores of T1, T2, T3, T4, and T5 treatments were all higher than the control, and the ranking of the comprehensive scores was in a descending order of T3, T2, T4, T1, T5 and Control. This indicates that the T3 treatment (3.6 L/hm^2) was the most effective.

Table 2 Effects of different treatments on wine grape chlorophyll content

Treatment	SPAD	Chl a content/mg·L^{-1}	Chl b content/mg·L^{-1}	Total Chl content/mg·L^{-1}
Control	38.53±1.34^{c}	9.84±2.04^{b}	2.87±0.28^{b}	11.11±0.45^{c}
T1	40.28±0.67^{c}	10.39±1.43^{ab}	3.06±0.37^{ab}	13.26±0.86 b
T2	44.10±0.53^{ab}	11.25±1.72^{ab}	3.62±0.50^{a}	14.26±1.25^{ab}
T3	46.63±1.27^{a}	12.57±0.86^{a}	3.71±0.41^{a}	15.42±1.32^{a}
T4	44.60±1.20^{ab}	11.59±1.63^{ab}	3.64±0.41^{a}	14.70±2.33^{ab}
T5	41.28±1.10^{bc}	10.15±1.59^{ab}	3.13±0.07^{ab}	12.55±1.66^{b}

Note: After the same column of data, different letters indicate significant differences (p<0.05).

Table 3 Effects of different treatments on wine grape morphological indices

Treatment	Spike length/cm	Transverse diameter/mm	Longitudinal diameter/mm	Hundred grain weight/g	Fruit shape index	Yield/kg·hm^{-2}
Control	11.75±0.25^{b}	11.24±0.14^{b}	10.70±0.38^{d}	110.77±3.52^{b}	0.99±0.01^{b}	7865.31±23.81^{a}
T1	12.67±0.33^{b}	11.84±0.23^{b}	11.56±0.60^{cd}	112.87±2.51^{b}	1.02±0.01^{b}	8109.57±98.85^{a}
T2	14.33±0.33^{a}	12.59±0.24^{a}	12.56±0.14^{abc}	129.18±10.13^{a}	1.02±0.01^{b}	8455.46±25.96^{a}
T3	13.00±0.58^{ab}	12.42±0.30^{a}	13.23±0.17^{a}	117.93±1.64^{ab}	1.06±0.03^{a}	8395.23±55.45^{a}
T4	13.67±0.67^{ab}	11.90±0.27^{b}	12.50±0.37^{bc}	114.25±5.53^{ab}	1.01±0.02^{b}	8157.18±73.19^{a}
T5	13.33±0.33^{ab}	12.21±0.26^{ab}	11.91±0.21^{cd}	112.52±1.29^{b}	1.02±0.01^{b}	7919.13±66.77^{a}

Note: After the same column of data, different letters indicate significant differences (p<0.05).

Table 4 Effects of different treatments on wine grape berry components

Treatment	Soluble solids/%	Titrate acid/%	Sugar-acidity ratio	Tannin/mg·g^{-1}	Anthocyanin/mg·g^{-1}	Total phenol/mg·g^{-1}
Control	25.10±0.10^{b}	0.61±0.05^{a}	41.74±1.34^{b}	14.25±0.15^{b}	1.85±0.08^{c}	14.70±0.05^{b}
T1	26.17±0.35^{b}	0.62±0.03^{a}	42.39±1.14^{ab}	15.63±0.30^{ab}	2.23±0.11^{ab}	15.60±0.23^{ab}
T2	27.07±0.14^{a}	0.63±0.02^{a}	43.20±1.25^{a}	17.26±0.75^{a}	2.30±0.21^{a}	16.69±0.87^{a}
T3	26.90±0.69^{ab}	0.64±0.04^{a}	42.61±1.38^{ab}	15.84±0.64^{ab}	2.24±0.17^{ab}	15.58±0.19^{ab}
T4	26.63±0.25^{ab}	0.64±0.06^{a}	41.97±4.70^{ab}	15.71±0.60^{ab}	2.23±0.24^{ab}	15.85±0.59^{ab}
T5	26.01±0.24^{b}	0.62±0.02^{a}	41.95±2.01^{ab}	15.30±0.54^{ab}	2.05±0.08^{b}	15.97±0.47^{ab}

Note: After the same column of data, different letters indicate significant differences (p<0.05).

Table 5 Principal component analysis of photosynthesis and quality indices of wine grape

Treatment	First principal component score (F_1)	First principal component contribution Ratio/%	Second principal component score (F_2)	Second principal component contribution Ratio/%	Third principal component score (F_3)	Third principal component contribution Ratio/%	Composites sore	Rank (F)
Control	−4.97	75.87	0.26	13.81	0.67	5.13	−3.70	6
T1	−1.24		−0.37		0.42		−0.97	4
T2	2.96		−0.24		0.74		2.25	2
T3	3.47		0.32		−0.08		2.67	1
T4	1.44		−0.41		−1.16		0.97	3
T5	−1.65		0.44		−0.60		−1.22	5

Note: After the same column of data, different letters indicate significant differences (p<0.05).

4 Discussion

4.1 Effects of calcium application on the growth of wine grapes

This study addressed the problem of low water-soluble calcium content in the soil at the eastern foothills of Helan, which restricts the development of wine grapes. Foliar spraying of chelated sugar alcohol calcium was tested at different concentrations to observe the effect of exogenous calcium supplementation on the growth and quality of wine grapes. Calcium participates in physiological and biochemical reactions in plant cells as a signal molecule, regulating plant metabolism and development[20]. The addition of an appropriate amount of calcium can improve photosynthetic metabolism and maintain a high photosynthetic performance. The results of this study show that foliar spraying of an appropriate amount of calcium fertilizer can significantly increase the net photosynthetic rate, stomatal conductance, and transpiration rate of grape leaves. The highest photosynthetic characteristics were obtained when the concentration was 2.4 L/hm^2 calcium sugar alcohol. This is optimal, as shown in the research of Ren et al.[21]. Ren et al. found that calcium can improve the photosynthetic characteristics of *Fraxinus mandschurica*. With increased calcium concentration, the net photosynthetic rate, transpiration rate, and stomatal conductance of *F. mandschurica* tended to increase first and then decrease. When the calcium concentration reached 200 mg/kg, the photosynthetic characteristics of *F. mandschurica* reached an optimal value.

Adding an appropriate amount of calcium will increase chlorophyll content, which directly affects photosynthesis. Across a certain range, the content of chlorophyll is positively correlated with the photosynthetic rate[22]. Exogenous calcium can regulate the closure of leaf stomata to maintain a high stomatal conductance and, when a certain concentration of exogenous calcium is applied by foliar spraying, it can prevent the degradation of chlorophyll and significantly increase the content of chlorophyll[23]. In this study the results were similar, and it was found that under a concentration of 3.6 L/hm^2, the stomatal conductance and total chlorophyll content of grape leaves were higher, and the total chlorophyll content increased by 38.79% compared to the control.

4.2 Effects of calcium application on the yield and quality of wine grapes

Grape is a calcium-loving plant. Calcium affects the cell division of fruit, maintains the permeability and integrity of cells, and has a substantial impact on grape physiology and quality. It is an essential nutrient element in the growth and development of grapes and a major regulator of grapevine metabolism and development[24-27]. Therefore, calcium supplementation is an important measure to improve fruit quality[28]. This study shows that foliar application of calcium sugar alcohols can increase the particle size, hundred-grain weight, and yield of wine grapes, which is similar to the results of Wang et al.[8] The increase in diameter, hundred-grain weight, and yield reached 2.66%-21.97%, 2.59%-63.08%, and 10.25%-30.72%, respectively. Zhang et al.[26] concluded that the application of calcium fertilizer increases the soluble solids in wine grapes and improves the sugar-acid ratio. The results confirmed these findings, and the experiment found that, after spraying calcium sugar alcohol, the soluble solid content of wine grapes increased by 3.62%-7.85%, and the sugar-acid ratio increased by 0.50%-3.50%. The research results of Shi et al.[29] showed that the application of calcium fertilizer can significantly increase the content of tannins, anthocyanins, and total phenols in grape berries, which has a positive effect on wine grape quality; The results confirm these findings, and the experiment showed that, after applying chelated calcium sugar alcohol, the tannins, anthocyanins, and total phenols of grape berries increased by 7.37%-21.12%, 10.81%-24.32%, and 5.99%-13.54%, respectively, compared to the control.

4.3 Determination of appropriate levels of calcium fertilizer

In this study, five concentrations of chelated calcium sugar alcohol were set up to observe the effect of spraying exogenous calcium on the growth and quality of wine grapes. The results demonstrated that spraying calcium is not only conducive to the growth of wine grapes, but also the improvement of grape quality. However, the concentration of calcium is critical. High concentrations can be harmful to the growth and quality of wine grapes. Specifically, from the perspective of grape morphology and yield, the hundred-grain weight, the yield per plant, and the total yield were increased at the T2 concentration, and the spike length was reduced, but there was a decreasing trend at the T3 concentration. Based on the morphology and yield, T2-T3 should be selected as the most appropriate application rate. The quality index of wine grapes and the soluble solids increased most at the T2 concentration. The sugar-to-acid ratio was significantly increased, and the tannin also increased to a certain extent in the T2 treatment, but these indicators deteriorated at the T3 concentration. Therefore, based on the quality indicators of wine grapes, the concentration of T2-T3 should also be selected as the most appropriate concentration. The research indicated that the recommended calcium application rate for improving the quality of wine grapes in the study area was in the range of 2.4-3.6 L/hm^2.

5 Conclusions

Foliar application of chelated calcium sugar alcohol is an effective way to improve the yield and quality of wine grapes. The application of calcium fertilizer improves the photosynthetic characteristics of wine grapes, increases the content of soluble solids and tannins in the fruit, reduces the sugar-to-acid ratio, and increases the accumulation of anthocyanins and other phenolic substances. At the same time, it can effectively improve the quality of grape berries. The comprehensive evaluation showed that the optimum foliar spraying dose of calcium sugar alcohol was 2.4-3.6 L/hm^2.

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[References]

[1] Ma L W, Li J P, Han Y J, Li W C. Meteorological conditions and rating method of quality formation of 'Cabernet Sauvignon' grape in eastern foothills of Helan Mountain. Chinese Journal of Eco-Agriculture, 2018; 26(3): 453–466. (in Chinese)

[2] Kuai C H, Liu S J. Causes of calcium deficiency in grapes and calcium supplement techniques. China Fruit, 2008; 2: 74–75. (in Chinese)

[3] Karnopp A R, Margraf T, Maciel L G, Santos, J S, Granato, D. Chemical composition, nutritional and in vitro functional properties of by-products from the Brazilian organic grape juice industry. International Food Research Journal, 2017; 24(1): 207–214.

[4] Helper R K, Wayne R O. Calcium and plant development. Annu Rev Plant Biol, 2003; 36: 397–439.

[5] Arrobas M, Ferreira I Q, Freitas S, Verdial J, Rodrigues M. Guidelines for fertilizer use in vineyards based on nutrient content of grapevine parts. Scientia Horticulturae, 2014; 172: 191–198.

[6] Hocking B, Tyerman S D, Burton R A, Gilliham M. Fruit calcium: Transport and physiology. Frontiers in Plant Science, 2016; 163(7): 569.

[7] Arguello D, Chavez E, Lauryssen F, Vanderschueren R, Smolders E, Montalvo D. Soil properties and agronomic factors affecting cadmium concentrations in cacao beans: A nationwide survey in Ecuador. Sci Total Environ, 2018; 649: 120–127.

[8] Wang R, Qi Y B, Wu J, Shukla M K, Sun Q. Influence of the application of irrigated water-soluble calcium fertilizer on wine grape properties. PloS One, 2019; 14(9): e0222104. doi: 10.1371/journal.pone.0222104.

[9] Yu J. Effect of calcium on relieving berry cracking in grape (*Vitis vinifera* L.) 'Xiangfei'. Peer J, 2020; 8: e9896–e9896.

[10] Miceli A, Ippolito A, Linsalata V, Nigro F. Effect of preharvest calcium treatments on decay and biochemical changes in table grape during storage. Phytopathol Mediterr, 1999; 38(2): 47–53.

[11] Locascio S J, Bartz J A, Weingartner D P. Calcium and potassium fertilization of potatoes grown in North Florida I. Effects on potato yield and tissue Ca and K concentrations. American Potato Journal, 1992; 69(2): 95–104.

[12] Asgharzade A. Effect of Calcium Chloride ($CaCl_2$) on some quality characteristics of apple fruits in Shirvan region. African Journal of Microbiology Research, 2012; 6(9): 2000–2003.

[13] Wang F L, Ding N, Li H N, Zhou L, Men Y G, Ge S F, et al. Effects of spraying different calcium fertilizer on the quality of 'Fuji' apple fruit and mineral element content. Journal of Anhui Agricultural Sciences, 2013, 41(6): 2403–2406. (in Chinese)

[14] Askin M A, Korkmaz N. Effects of calcium and boron foliar application on pomegranate (*Punica granatum* L.) fruit quality, yield, and seasonal changes of leaf mineral nutrition. Acta Horticulturae, 2015; 1089: 413–422.

[15] Li Y P, Yang G, Li F, Bai L Y, Huang M L, Liu K Z, et al. Effects of sugar alcohol chelated calcium fertilizer on yield, quality and nutrient uptake of potato. Soils, 2020; 52(4): 773–780. (in Chinese)

[16] Yu H L, Si P, Shao W, Qiao X S, Gao D T, Yang X J, et al. Effects of spraying calcium fertilizer on calcium content and quality of peach. Chinese Agricultural Science Bulletin, 2017; 33(22): 63–67. (in Chinese)

[17] Zhang J L, Guo F, Meng J J, Yang S, Geng Y, Yang D Q, et al. Effects of calcium fertilizer on physiological characteristics at late growth stage and pod yield of peanut on dryland. Chinese Journal of Oil Crop Sciences, 2016; 38(3): 321–327. (in Chinese)

[18] Wang R, Sun Q, Chang Q R. Soil types effect on grape and wine composition in Helan Mountain Area of Ningxia. PloS One, 2015; 10(2): e0116690–e0116701.

[19] Prado R A, María Y R, Xavier S, Cristina A L, Mireia T, Rosa M L R. Effect of soil type on wines produced from *Vitis vinifera* L. cv. Grenache in commercial vineyards. Journal of Agricultural and Food Chemistry, 2007; 55(3): 779–786.

[20] Yang S, Wang F, Guo F, Meng J J, Li X G, Wan S B. Calcium contributes to photoprotection and repair of photosystem II in peanut leaves during heat and high irradiance. Journal of Integrative Plant Biology, 2015; 57(5): 486–495.

[21] Ren C S, Li H, Weng X H, Zhang S Z, Liu L Y, Zhou Y B. Effects of exogenous calcium on the growth, photosynthetic characteristics and water use efficiency of *Fraxinus mandshurica*. Journal of Shenyang Agricultural University, 2020; 51(6): 663–669. (in Chinese)

[22] Helper R K, Wayne R O. Calcium and plant development. Annu Rev Plant Biol, 2003; 36: 397–439.

[23] Li C Z, Tao J, Sun Y, Kong F, Geng Q P, Du B. Effects of spraying calcium on the inflorescence stem quality and leaf photosynthesis of herbaceous peony (*Paeonia lactiflora* Pall.). Chinese Journal of Ecology, 2012; 31(11): 2817–2822. (in Chinese)

[24] Dunn J L, Able A J. Pre-harvest effects on sensory quality and calcium mobility in strawberry fruit. V International Strawberry Symposium,

2006; 708: 307–312.
[25] Bush D S. Calcium regulation in plant cells and its role in signaling. Annual Review of Plant Physiology & Plant Molecular Biology, 1995; 46(1): 95–122.
[26] Zhang L, Jiang P, Wang J, Gu C F, Wang R. Effects of foliar application of sugar alcohol calcium on quality and yield of wine grapes. Soil and Fertilizer Sciences in China, 2020; 6: 227–232. (in Chinese)
[27] Thomas T, Zioziou E, Koundouras S, Navrozidis I, Nikolaou N. Effect of prohexadione-Ca on leaf chlorophyll content, gas exchange, berry size and composition, wine quality and disease susceptibility in *Vitis vinifera* L. cv Xinomavro. Scientia Horticulturae, 2018; 238: 369–374.
[28] Montanaro G, Dichio B, Xiloyannis C. Significance of fruit transpiration on calcium nutrition in developing apricot fruit. Journal of Plant Nutrition and Soil Science, 2010; 173(4): 618–622.
[29] Shi M, Si H L, Zhu Y, Guo J, Zhang X J, Sun Q. Effect of calcium, magnesium and sulphur fertilizer on wine grape in Eastern Foot of Helan Mountain. Hubei Agricultural Sciences, 2013; 52(20): 4878–4881, 4897. (in Chinese)