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Evaluation of the effect of the application of two potassium fertilizers on the production and quality of ungrafted 'Isabel' grapes

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Abstract: Potassium is a macronutrient responsible for regulating plants' metabolic processes and water balance. In grapevines, this nutrient strongly influences the production and quality parameters of the berries, consequently affecting the quality of the juices and wines produced. Potassium can be supplied differently, impacting vineyard productivity and grape properties. The present study aimed to evaluate the effect of applying two different fertilizers on the production and quality of ungrafted 'Isabel' vines. The experiment was carried out in the 2016/2017 cycle in the Serra Gaúcha region. Three treatments were tested: control without fertilization (T1), addition of 80 kg·ha^{-1} of K_2O in the form of KCl, and addition of 80 kg·ha^{-1} of K_2O as the compound fertilizer form 04-18-08 (N-P-K). Yield per plant, potassium content in leaf petioles, soluble solids, titratable acidity, SS/TA ratio, must pH, and total phenolic compounds and anthocyanins content were determined. The results showed that fertilization did not influence the yield per plant nor the soluble solids content, regardless of the fertilizer used. The application of KCl caused a reduction in the titratable acidity, with a consequent increase in the SS/TA ratio. On the other hand, applying the 04-18-08 fertilizer promoted a growth in the total anthocyanin content and pH without affecting the titratable acidity. According to the results, the studied fertilizers can be used in the vine culture without damage to the productivity of the plants or the quality of the berries. Considering the use of these fruits as a feedstock for wines and juices, the 04-18-08 fertilizer would be an interesting option aiming to increase the contents of bioactive compounds, such as anthocyanins.

Keywords: fertilization, macronutrients, potassium, viticulture, Vitis labrusca.

Resumo: O potássio é um macronutriente responsável pela regulação de processos metabólicos e pelo balanço hídrico nas plantas. Nas videiras, este nutriente apresenta forte influência sobre os parâmetros produtivos e de qualidade das bagas, afetando consequentemente a qualidade dos sucos e vinhos produzidos. O potássio pode ser fornecido de diferentes formas, com impactos distintos sobre a produtividade do vinhedo e as propriedades das uvas. O presente estudo visou avaliar o efeito da aplicação de dois fertilizantes distintos sobre a produção e qualidade de videiras Isabel pé franco. O experimento foi realizado no ciclo 2016/2017, na região da Serra Gaúcha, sendo testados três tratamentos: controle sem fertilização (T1), adição de 80 kg·ha^{-1} de K_2O na forma de KCl e adição de 80 kg·ha^{-1} de K_2O na forma do fertilizante composto 04-18-08 (N-P-K). Determinou-se a produção por planta, teor de potássio nos pecíolos foliares, teor de sólidos solúveis, acidez titulável, razão SS/AT, pH do mosto e os teores de compostos fenólicos e antocianinas totais. Os resultados obtidos mostraram que a produção por planta e o teor de sólidos solúveis não foi influenciado pela adubação, independentemente do tipo de fertilizante utilizado. A aplicação de KCl causou redução da acidez titulável, com consequente aumento da razão SS/AT. Por outro lado, a aplicação do fertilizante 04-18-08 promoveu aumento do teor de antocianinas totais e do pH, sem efeito sobre a acidez titulável. De acordo com os resultados, os fertilizantes estudados podem ser empregados na cultura da videira, sem prejuízos à produtividade das plantas, nem à qualidade das bagas. Considerando a utilização dessas frutas como matéria-prima para vinhos e sucos, o fertilizante 18-04-08 seria uma opção interessante visando aumentar o teor de compostos bioativos, como as antocianinas.

Palavras-Chave: adubação, macronutrientes, potássio, vitivinicultura, Vitis labrusca.

Introduction

Viticulture is one of the most important agricultural activities for the State of Rio Grande do Sul, especially for the Serra Gaúcha region. According to data from the Brazilian Institute of Geography and Statistics (IBGE), Brazilian grape production in 2021 was 1.75 million tonnes, with an average productivity of 23.11 t·ha^{-1}. In the same period, the State of Rio Grande do Sul produced 951,254 t of grapes, corresponding to 54.4 % of the national production, with an average productivity of 20.55 t·ha^{-1} [1]. Serra Gaúcha produced 845,790 t of grapes, totaling 88.9 % of state production [2].

Among the essential nutrients for plant growth and development, potassium (K) is vital in viticulture. The demand for this element by the vines is quite high, especially in the fruiting and ripening periods [3-5].

K is a macroelement that has several physiological and biochemical functions in the grapevine, such as the regulation of cellular osmotic potential, control of cellular water balance, activator and enzymatic cofactor in many metabolic routes, and aid in the transport of ions and substances through the phloem, among other functions [6-7].

In berries, potassium influences the soluble solids content and the titratable acidity, with an effect on the pH of the must. The influence of this element on the levels of phenolic compounds is also observed, increasing the nutraceutical quality of grapes and wines and juices derived from them [8-9].

In viticultural practices, potassium can be provided in different ways, depending on the fertilizer type and application form [10]. Depending on the composition of the fertilizer used and the state of the application, the supply of this nutrient can be rapid or gradual, with an important influence on the development of the berries and the nutritional status of the vines [11].

Among the various fertilizers used in viticulture, potassium chloride (KCl) is considered a highly soluble source of potassium, whose dissolution does not change the pH of the soil solution or the nutrient solution in hydroponic and/or semi-hydroponic systems [11-13]. However, this fertilizer also releases large amounts of chloride ions (Cl^-), which may intensify soil salinity or cause imbalances in plant nutrition and/or soil microbiota due to the excess of this anion, with cumulative effects in the case of repeated applications. [14-15].

Compound fertilizers containing NPK macroelements are commonly used in viticulture [11]. This class of fertilizers has the advantage of the simultaneous contribution of the macroelements with the greatest impact on the development of the vines, with a reduction in the amount used regarding the use of fertilizers containing only one nutrient. However, care is needed when adjusting the doses used to avoid imbalances in the supply of nutrients [16-17].

Few works in the literature specifically address the type of fertilizer on the development and quality of grapes. Pushpavathi et al. [18] evaluated the effect of different potassium salts on 'Sharad Seedless' grapes and reported differences in the contents of K in petioles and phenolic compounds. Belal et al. [19] observed that the joint use of mineral and organic fertilizers enhanced the growth and production of Thompson Seedless grapes, probably because of the additional N supply from the organic fertilizer. Mostafa et al. [20] observed that applying a fertilizer containing magnesium, potassium, and fulvic acids had the best performance regarding the growth parameters of King Ruby grapevines.

Thus, the present work aimed to evaluate the effect of applying two different fertilizers, considering the equivalent dose of 80 kg·ha^{-1} of K_2O, on the yield and quality parameters of 'Isabel' unripe grapes in the Serra Gaúcha region, southern Brazil.

1. Materials and methods

1.1 Experimental conditions and treatments

The experiment was conducted in the productive cycle of 2016/2017 in a commercial vineyard located in the municipality of Nova Pádua (RS), whose geographical and climatic details are presented in a previous work by the authors [5].

The commercial vineyard consisted of ungrafted Isabel vines (*Vitis labrusca* L.) in a pergola system, with a spacing of 2.5 m between rows and 1.5 m between plants, with a density of 2,667 plants per hectare.

The management of the cultural treatments in the area and the evaluation of the fertility level of the vineyard soil are presented in previous work [5], being followed in the same way in the present work.

Three treatments were tested, defined as T1 – control (no fertilizer), T2 – potassium chloride, and T3 – mineral fertilizer 04-18-08 (4 wt.% N, 18 wt.% P_2O_5, and 8 wt.% K_2O). The amount of fertilizer added was adjusted to correspond to a dose of 80 kg·ha^{-1} of K_2O in both treatments. Fertilizers were applied manually in the planting line, without incorporation, in both treatments. Treatments were applied at vegetative stage 27 (bunch cleaning), according to the classification by Eichorn and Lorenz [21].

1.2 Sampling for the determination of the quality parameters of the grapes

The petiole samples were collected 30 days after the treatments were applied, and the sampling was carried out according to the recommendations of the Soil Chemistry and Fertility Commission for the states of RS and SC [22].

The grape bunches were harvested separately per treatment and placed in identified plastic bags, being stored under refrigeration (4±2 °C) until the analyses were carried out. The samples were collected and separated when the grapes were at the industry's ripening point on March 03, 2017.

1.3 Determination of the qualitative and production parameters

Yield per plant was determined by collecting and weighing bunches using a digital scale, as described by Fugalli et al. [5]. The potassium content in the petioles was determined according to the procedures of Malavolta et al. [23].

Sample preparation for quality tests followed the procedures described by Fugalli et al. [5]. Using an analog refractometer, the soluble solids content was determined according to the IAL 315/IV method [24]. The results were expressed in degrees Brix (°Brix).

The pH of the juice was determined by the IAL 201/IV method [24], using a Digimed DM-22 pHmeter. The titratable acidity was determined according to the IAL 312/IV method [24], and the results were expressed in gram-equivalents of tartaric acid per 100 mL of sample (% w/v).

The extracts were prepared to determine phenolic compounds and anthocyanins according to the method described by Fugalli et al. [5]. The determination of the content of phenolic compounds was performed by the Folin-Ciocalteu method, following the procedure described by Pereira et al. [25]. The results were expressed in milligrams of gallic acid equivalents per 100 g sample. The total anthocyanin content was determined by the AOAC 2005.02 method [26]. The results were expressed in milligrams of cyanidin-3-glucoside equivalents per 100 g sample.

1.4 Experimental design and statistical analysis

The experiment followed a completely randomized design, whose evaluation factor corresponded to the type of fertilizer, with four replications for each treatment, each repetition being considered a plant.

The results obtained were evaluated for homoscedasticity (Levene's test) and normality of residues (Shapiro-Wilk test), followed by Analysis of Variance (ANOVA) and Tukey's post hoc test at a 5 % error probability ($\alpha = 0.05$). Statistical analyses were performed using the AgroEstat software®.

2. Results and discussion

The results regarding production parameters per plant and soluble solids content, which showed no statistical difference between treatments, are presented in Table 1.

Table 1. Parameters of production per plant (yield) and soluble solids content, which showed no statistical difference between the treatments evaluated for 'Isabel' vines treated with two types of potassium fertilizers in the productive cycle of 2016/2017 in the Serra Gaúcha region.

Parameter	Yield ($kg \cdot plant^{-1}$)	Soluble solids (°Brix)
Mean	8.58±0.60	14.13±0.91
F value	0.066	1.753
p-value	0.937	0.251
Coefficient of variation (%)	7.00	6.37

Fonte: Authors (2022).

As seen in Table 1, the parameters of production per plant and soluble solids content were not influenced by the type of fertilizer used, not differing statistically from the control. One of the reasons for this behavior may be due to the high levels of K and P in the soil of the vineyard studied, as observed in the soil analysis presented in a previous study [5], being these nutrients in sufficient amounts for the growth and production of the vines in the cycle. Thus, adding supplementary K (T2) or NPK (T3) did not significantly interfere with these parameters.

The yield values per plant observed in the present study (8.6 $kg \cdot plant^{-1}$) were lower than those observed by Dalbó et al. [3] (11.2 $kg \cdot plant^{-1}$) but higher than that reported by Assis et al. [27] (2.9 $kg \cdot plant^{-1}$) for vines of the Isabel cultivar. These variations in vineyard production are related to the productive characteristics of the variety, crop management, and climatic conditions in the period of flowering and maturation, as well as in the period of dormancy and formation of reserves during the intercycle period [4,27].

According to data from the literature, the levels of soluble solids are pretty variable and dependent on a combination of factors, such as the variety of cultivated vine, edaphoclimatic conditions, and cultural management. The mean SS values observed in this study were lower than those reported by Rombaldi et al. [28] (16.5 – 18.5 °Brix), Dalbó et al. [3] (17.1 – 17.5 °Brix), and by Ciotta et al. [4] (21.1 – 23.7 °Brix), with results like those observed by Fugalli et al. [5] (13.3 – 15.2 °Brix) and Assis et al. [27] (15.3 °Brix).

Regarding the use of different fertilizers, a similar behavior to that observed in the present study was reported by Fugalli et al. [5], Ciotta et al. [4], and Dalbó et al. [3]. Adding K did not increase the berries' yield or soluble solids content in these studies. This behavior was attributed to the fact that the K levels present in the soil were already considered sufficient for the full development of the vines.

On the other hand, Belal et al. [19] reported an increase in the yield and vegetative growth parameters of Thompson Seedless vines when a blend of mineral and organic potassium fertilizers was used compared to a mineral potassium fertilizer. Although there is no consensus on the need for maintenance fertilization, Ciotta et al. [4] recommend the application of 100 $kg \cdot ha^{-1}$ of K_2O between production cycles to maintain K levels and the productivity and quality of the grapes.

The results referring to the potassium content in the petioles, titratable acidity, SS/TA ratio, pH of the must, and phenolic compounds and anthocyanin contents are presented in Table 2.

Table 2. Compilation of results regarding the potassium content in the petioles, titratable acidity, SS/TA ratio, pH of must, and the contents of phenolic compounds and anthocyanins of 'Isabel' grapes treated with two types of potassium fertilizers in the productive cycle of 2016/2017 in Serra Gaúcha region.

Treatment	K content in petioles ($g \cdot kg^{-1}$)	Titratable acidity (% m/v)[1]	SS/TA ratio	pH of must	Phenolic compounds ($mg \cdot 100\ g^{-1}$)[2]	Anthocyanins ($mg \cdot 100\ g^{-1}$)[3]
T1	3.05±0.34 b	0.74±0.04 a	18.55±1.48 b	3.01±0.05 b	99.73±11.85 b	4.58±1.95 b
T2	4.63±0.54 a	0.63±0.02 b	22.49±2.26 a	3.12±0.04 ab	196.01±38.84 a	7.64±2.10 ab
T3	3.88±0.34 a	0.76±0.04 a	19.29±0.70 ab	3.15±0.06 a	153.81±29.38 ab	8.66±1.80 a
F value	13.549	24.181	8.452	6.842	6.597	8.369
p-value	0.006	0.001	0.018	0.028	0.031	0.018
Coefficient of variation (%)	6.93	9.26	11.46	1.58	4.72	21.55

T1 – Control; T2 – KCl applied at 80 $kg \cdot ha^{-1}$ de K_2O; T3 – 04-18-08 (N-P-K) fertilizer applied at 80 $kg \cdot ha^{-1}$ de K_2O. [1] – Gram equivalents of tartaric acid. [2] – Gram-equivalents of gallic acid. [3] – Gram-equivalents of cyanidin-3-glucoside. Means in column followed by the same letter do not differ statistically by Tukey's test at 5 % error probability. Source: Authors (2022).

According to Table 2, the addition of both fertilizers caused an increase in the levels of K in the leaf petioles of the treated vines compared to the control, indicating that the application of potassium fertilizer at this phenological stage allows the absorption and transport of this nutrient to the tissues of the plant [5]. Mpelasoka et al. [8] and Brunetto et al. [29] noted that K is a highly mobile element in the phloem, with quick absorption and translocation to different plant tissues due to its water and metabolic regulation functions.

Regarding the titratable acidity, applying KCl fertilizer reduced this parameter, while applying fertilizer 04-18-04 had no influence. Dalbó et al. [3] also observed a reduction in titratable acidity by using potassium fertilization up to 180 $kg \cdot ha^{-1}$ of K_2O. A similar behavior was reported by Fekry and Aboel-Anin [10], who also observed a reduction in titratable acidity in grapes cv. 'Early Sweet', from 0.72 % w/v in control to 0.58 % w/v in the foliar application of potassium thiosulphate at 500 $mg \cdot L^{-1}$. On the other hand, Ciotta et al. [4] have not observed differences in titratable acidity values for Cabernet Sauvignon grapes with the application of up to 200 $kg \cdot ha^{-1}$ of K_2O in the form of KCl.

Similar behavior can be observed for the pH values, which were increased by applying the 04-18-08 fertilizer. In contrast, the application of KCl did not differ from any of the treatments. Dalbó et al. [3] also observed an increase in the pH of the must with the application of K up to 180 $kg \cdot ha^{-1}$ of K_2O. However, Ciotta et al. [4] have not reported significant differences, even with 200 $kg \cdot ha^{-1}$ of K_2O application.

As commented by Mpelasoka et al. [8] and Delgado et al. [9], there is a potentiated effect in the joint application of N and K, increasing the rates of vegetative growth and production of complex photoassimilates, such as phenolic compounds and sugars. In addition, such compounds are synthesized by using the organic acids in the berry pulp. Consequently, this process reduces the acidity levels of the berries, as observed with the application of the fertilizer 04-18-08.

According to Mpelasoka et al. [8], high levels of K in the must tend to neutralize the tartaric and malic acids, resulting in higher pH values and lower titratable acidity. The same authors also commented that musts with higher pH values are less stable, generating wines and juices with less pronounced flavor and color and a propensity to chemical and/or microbiological degradation.

The SS/TA ratio values were higher in berries whose vines were treated with the KCl fertilizer, whereas the 04-18-08 fertilizer did not differ from the control. Ciotta et al. [4] reported that applying K_2O did not influence Cabernet Sauvignon grapes' SS/TA ratio values.

The SS/TA ratio is considered a parameter for assessing the degree of ripeness of the berries and is also associated with acceptability by consumers [5]. Jayasena and Cameron [30] observed a direct relationship between SS/TA values and the acceptability of 'Crimson Seedless' grapes, commenting that the optimal range for this parameter would be 35 – 40.

As observed by Assis et al. [27], Brazilian legislation establishes that the SS/TA ratio range required for grapes for processing is 15 – 45. For Isabel grapes, literature data show SS/AT ratio values between 9.5 and 27.5. This amplitude is attributed to edaphoclimatic conditions, vineyard management practices, and physiological and genetic characteristics of the vines [5,31-32].

Regarding the levels of phenolic compounds, adding KCl promoted an increase in levels, while applying fertilizer 04-18-08 did not differ from the control. Fugalli et al. [5] and Delgado et al. [9] observed that adding K did not affect the levels of total phenolic compounds in Isabel and Tempranillo grapes.

As pointed out by Gobbo-Neto and Lopes [33], Pushpavathi et al. [18], and Vilas Boas et al. [31], potassium is an essential nutrient, influencing the synthesis and storage of phenolic compounds and their derivatives, especially in situations of stress, both biotic and abiotic. Thus, the lower content of phenolic compounds can be attributed to the presence of N and P in the 04-18-08 fertilizer, avoiding possible imbalances caused by the supplementary addition of K, which could induce an increase in the levels of phenolic compounds in the berries [8,31].

For the anthocyanin contents, it was observed that the use of fertilizer 04-18-08 caused higher levels when compared to the application of KCl, which did not differ from the control. Fugalli et al. [5] and Mostafa et al. [20] reported that the addition of K caused an increase in anthocyanin levels in the berries.

Although anthocyanins are a class of phenolic compounds, the metabolic pathways that generate different phenolic compounds are distinct and can be stimulated or inhibited by various factors [34]. In this sense, the presence of additional N and P in the 04-18-08 fertilizer can favor the production of anthocyanins, increasing their content to the detriment of other phenolic compounds.

Conclusions

According to the results, adding both fertilizers increased the K content in the leaf petioles compared to the control. None of the fertilizers used increased the yield nor soluble solids content, probably due to the high levels in the soil. The application of KCl caused a reduction in the titratable acidity of the must, with a consequent increase in the SS/TA ratio. The application of fertilizer 04-18-08 promoted a growth in the total anthocyanin content and must pH, with no effect on the titratable acidity regarding the control. Thus, it can be considered that both fertilizers can be used in vineyard fertilization without harming the productivity of the plants or the quality of the berries. However, considering that the grapes may be a feedstock for wine and juice production, higher contents of anthocyanins are desirable due to nutraceutical and aesthetic effects. Thus, the composite NPK fertilizer may be a tool to produce grapes with better fitting as a feedstock for the food industry.

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