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Fruit Yield and Quality of Fig (*Ficus carica* L.) are Affected by Foliar Sprays of Potassium Sulfate

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ABSTRACT

Fruit yield and quality in fig (*Ficus carica* L.) are highly influenced by mineral nutrition, especially Calcium (Ca) and potassium (K). In this study, the impact of soluble potassium sulfate (K_2SO_4) foliar application on yield, fruit quality, and leaf nutrient content was assessed during three consecutive years (2017- 2019) on fig cv. 'Bouhouli' grown in Northwest Tunisia. Potassium sulfate was sprayed at 2% concentration on leaves of 'Bouhouli' trees twice each year during fruit development. This improved fruit weight by 29.5% and 34.9% in the first and second years, respectively, while yield and fruit quality were improved in 2018 only. The fruit ostiole-end cracking, which is one of the fruit quality criteria, was reduced under potassium treatment by 3-fold (17%) compared to the control (53%), in 2018. Also, potassium treatment increased significantly the content of total soluble solids in the fruits during the first two seasons. Besides, K leaf concentration significantly increased after the 2% K_2SO_4 treatment in 2018 and 2019. These results suggest that potassium sulfate foliar sprays could be used as part of an efficient and sustainable fertilizer program to improve fig tree yield and fruit quality.

Keywords*:* Fig cracking, Fig quality traits, Fig yield, Ostiole-end splitting.

INTRODUCTION

The common fig (*Ficus carica* L.), a deciduous tree belonging to the Moraceae family, is one of the earliest cultivated fruit tree and an important crop worldwide for both fresh and dry consumption (Solomon *et al*., 2006). Figs are a source of vitamins, minerals, dietary fibers and amino acids (Veberic *et al*., 2008). Furthermore, they are also one of the most abundant fruits in the Mediterranean diet, and have been reported to promote human health and quality of life (Caliskan and Polat, 2011). Fig tree is widespread in the Mediterranean region where it is adapted to different edapho-climatic conditions (Hssaini *et al*., 2020). In Tunisia, fig trees are grown all over the country, occupying about 30,000 ha (MARHP, 2019). Djebba Area, located in the northwest of Tunisia, is well known for its fig culture with many specific fig genotypes. 'Bouhouli' is the main fig cultivar grown commercially and represents 86% of the total fig plantations in this area. Since 2012, this cultivar has been designated as protected denomination of origin (AOC Label) "Djebba figs". However, in Djebba Area, fig growers often face difficulties in obtaining sufficient yield and high fruit quality (Gaaliche *et al*., 2012). One of the major drawback of figs, affecting their commercial quality, is the ostiole-end splitting (Trad *et al*., 2014). Fruit cracking or splitting is a disorder limiting the

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commercial value of figs observed in most producing areas (Kong *et al*., 2013; Aydin and Kaptan, 2015). This physiological disorder not only reduces the marketability and consumer acceptance of the fruit, but also allows its contamination by insects and fungi and make it more susceptible to other environmental stresses (Crisosto *et al*., 2011). This may affect the fruit taste, flavor/aroma, texture and health-promoting properties, which are the quality traits expected by consumers (Crisosto *et al*., 2006; Crisosto *et al*., 2010). These quality parameters are strongly influenced by genotype and environmental factors, with a major role of mineral nutrition during fruit set and development (Lester, 2006). Mineral nutrition is an effective management tool to increase yield and profits in fruit trees (Brunetto *et al.,* 2015). However, literature on mineral nutrition of fig tree remains scarce. The fertilization requirements of fig trees have been reported to depend on soil type, organic matter content, and pH (Aksoy and Anac, 1993). Foliar applications of nutrients have been shown to be able to fulfill plant requirements and to be highly efficient (Eichert, 2013). It is an attractive solution, especially in arid locations under low rainfall conditions where the lack of water in summer drastically restricts nutrient absorption by trees (Ben Mimoun *et al*., 2018). Potassium (K) is well known as an essential plant nutrient with the strongest influence on fruit and vegetable quality parameters (Zörb *et al.*, 2014). K sprayed on leaves is an efficient fertilization as it is quickly translocated to other plant parts (Tagliavini and Scandellari, 2013). K is involved in several biochemical and physiological processes that are vital for plant growth, yield, and quality (Marcelle, 1995). In addition to stomatal regulation of transpiration and photosynthesis, K is involved in photophosphorylation, transport of photo-assimilates from source tissues via the phloem to sink tissues (Römheld and Kirkby, 2010). Several studies on K nutrition underlined its effect on yield and fruit quality of various fruit species such as citrus (Ben Mimoun *et al*., 2018), olive (Zivdar *et al*., 2016; Saykhul *et al*., 2016), apricot (Ben Mimoun and Marchand, 2016), peach (Dbara *et al*., 2018) and pear (Dbara *et al*., 2019). In fig, K nutrition is considered as an efficient management tool to improve fruit quality, by enhancing the antioxidant activity, mineral status, and reducing the percentage of fruit ostiole-end cracking (İrget *et al*., 2008; Holstein *et al*., 2017; Gaaliche *et al*., 2019; Krapac *et al*., 2021). However, K-uptake efficiency depends on soil conditions that affect the mobility of the supplied nutrients (Mengel, 2002).

In this study, we aimed to test K foliar spray as an alternative that could favor potassium uptake (Zörb *et al*., 2014). To our knowledge, few researches is currently available regarding the impact of K fertilization on the productivity and quality attributes of fig. To this end, this study aimed to understand the effectiveness of potassium sprayed as potassium sulfate in improving the yield and fruit quality of fig cv. 'Bouhouli'.

MATERIALS AND METHODS

Plant Material, Experimental Design and Treatments

Field trial was conducted during three consecutive seasons (2017–2019) in a fig orchard located at the northwest of Tunisia (Djebba: Altitude, 700 m; latitude, 36°40' N; longitude 9°0' E). The climate of this region is sub-humid characterized by mild winter and hot summer with an annual mean temperature around 20°C. Thermal amplitude is about 16.5°C in summer and 8°C in winter. Average annual rainfall is about 600 mm. The experimental orchard has typical alluvial and clay soil with high water retention capacity. The physical and chemical soil properties of the experimental site are given in Table 1. Agricultural practices including caprification, pruning, soil fertilization and irrigation were done according to standard practices in the area

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Table 1. Physiochemical properties of the soil of the experimental site.

Properties	Depth (cm)		
	0-20	20-40	40-60
Clay (%)	39.38	49.12	44.57
Loam (%)	33.28	20.18	24.78
Sand (%)	27.33	27.40	28.49
pH	8.37	8.35	8.40
EC (mS cm^{-1} at 25°C)	0.16	0.17	0.21
Total calcium (%)	37.07	38.38	42.09
Active calcium (%)	14.56	13.17	15.77
Organic matter (%)	4.98	3.78	3.16
Total N (%)	2.06	1.84	1.18
C/N	14.07	13.76	15.87
Exchangeable calcium (Ca ppm)	10111.26	9118.43	9614.85
Exchangeable magnesium (Mg ppm)	292.44	153.98	127.55
Exchangeable sodium (Na ppm)	50.61	69.55	52.89
Exchangeable potassium (K_2O ppm)	364.18	408.71	235.52
Available phosphorus (P_2O_5 ppm)	47.11	52.22	28.40

for commercial fig production. The mineral nutrition program was applied yearly, which consisted of 1 kg Di-Ammonium Phosphate (DAP) (18-46-0) per tree at the end of February, 0.25 kg of ammonium nitrate (33-0-0) per tree before leaf fall, and 0.5 kg of potassium sulfate (0-0-50) per tree divided into two times in mid-June and end of July.

Twenty-year-old fig trees cv. 'Bouhouli' planted at 8×8 m spacing were selected for the current field trial. The foliar potassium treatments were applied twice each year during fruit development. The first foliar spray was done on the 3rd week of July (about 45 days after fruiting stage), and the second spray 15 days before the commercial harvest on the 1st week of August (Gaaliche *et al*., 2019; Ben Mimoun *et al*., 2018; Ghanem and Ben Mimoun, 2010). The experimental design was completely randomized with two blocks and two treatments. Each block consisted of ten trees per treatment: ten trees were sprayed with a solution of 2% soluble potassium sulfate (K_2SO_4) (Gaaliche *et al*., 2019; Dbara *et al*., 2018; Ben Mimoun and Marchand, 2013) and ten others were left as control (untreated).

Measured Parameters

Yield and Fruit Characteristics

In the three years of the experiment, fruit samples were harvested at the commercial stage of maturity and were immediately transferred to the laboratory for analysis. Morphological measurements and biochemical analyses were carried out on samples of 30 mature fruits per treatment. Fruit weight (g) was determined using a digital balance (A&D FX-5000i, Japan) with 0.01 g accuracy. A digital caliper (LINEAR, 49–923) was used to measure fruit length (mm) and diameter (mm). The number of fruits affected by cracking for each treatment was counted and the data were expressed as the percentage of fruit ostiole-end cracking. Total soluble solids (°Brix) were determined with a digital refractometer (PR-101 ATAGO, Norfolk, VA), and titratable acidity (citric acid %) was determined by titrating fig juice with 0.1N NaOH. At harvest, the total yield of each tree (kg) was also recorded in 2018 and 2019.

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Leaf Nutrient Concentrations

For each year of the three-year study, fifty mature leaves from each treatment were collected at the onset of fruit ripening period (Brown, 1994) in July for chemical analyses. The leaves were rinsed with water, oven-dried, and grounded. The leaf mineral composition was determined in three replicates per treatment. The total Nitrogen (N) was determined by micro-Kjeldahl method (Chapman and Pratt, 1973). The leaf samples were prepared for elemental analysis of Phosphorus (P), Potassium (K), Calcium (Ca), Iron (Fe) and Zinc (Zn) through the destruction of organic matter by dry ashing. Then, P leaf content was determined by reduction with molibdo-vanadate (Chapman and Pratt, 1973) and the leaf concentrations of K, Ca, Fe and Zn were determined using atomic absorption spectrometry (model: Thermo Scientific iCE 3500, Thermo Electron Manufacturing Ltd, Cambridge, United Kingdom).

Statistical Analysis

All data were reported as means±Standard Deviation (SD) and analyzed using SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA). Treatment effect was estimated by a one-way Analysis Of Variance (ANOVA) followed by Duncan's Multiple Range Test to determine the significant differences among mean values at the probability level of 0.05.

RESULTS AND DISCUSSION

Yield

Fig yield (kg tree^{-1}) was increased significantly by potassium treatment, especially during 2018 when the highest fruit yield per tree (147 kg) was recorded on the trees with the 2% K_2SO_4 treatment, with the lowest (114.7 kg) in the control. In contrast, no significant differences in yield were found between treatments in 2019, though a slight increase could be observed in treated trees (Figure 1). In 2019, the highest and lowest yields were 126 and 103 kg tree^{-1}, respectively (Figure 1). These results prove that foliar potassium spray can have a positive effect on tree production in Tunisian conditions, at least in some years. They are consistent with previous findings showing that potassium improved the size and yield of fresh figs growing in California (Holstein *et al*., 2017). According to Honar *et al*. (2021), foliar application of potassium at the concentration of 3 kg 1000 L^{-1} is

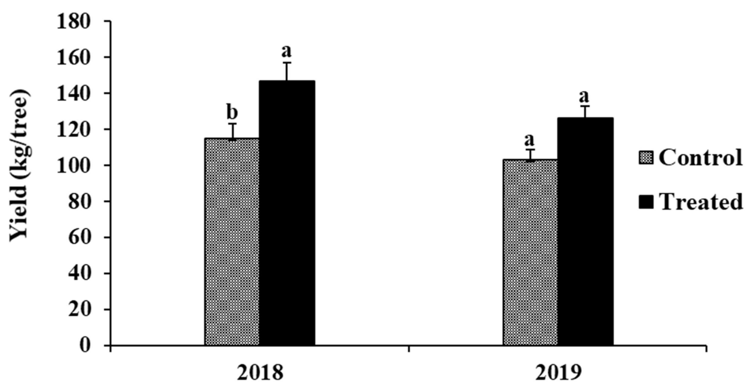

Figure 1. Effect of foliar potassium treatment on total yield of fig cv. 'Bouhouli' in 2018 and 2019. Different letters (a, b) indicate significant differences between treatments in a given year, according to Duncan's multiple range test at P≤ 0.05.

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recommended to achieve the highest fruit production in rain-fed fig orchards under drought conditions. Abd-El-Rhman *et al.* (2017) have also reported that yield per tree of fig cv. 'Sultani' was significantly enhanced compared to the control with increasing rates of supplemental levels of potassium sulfate. Furthermore, increase in tree yield by potassium application has been reported also in other fruit species including apple, pear, peach, olive, citrus and plum (Alva *et al*., 2006; Ben Mimoun and Marchand, 2013; Dbara *et al*., 2018; Ben Mimoun *et al*., 2018). This increase may be due to the main role of potassium in stimulating photosynthesis activity and CO_2 assimilation. Indeed, improvement in leaf photosynthesis is expected to result in yield increase (Engels *et al*., 2012).

Fruit Characteristics

Fruit Weight and Size

The potassium application improved significantly fruit weight in the three-year study (Figure 2-A). By contrast, the potassium treatment had no significant impact on fruit length (Figure 2-B), while it slightly increased fruit diameter even though this effect was significant in 2018 only (Figure 2-C). The highest fruit weight (126 g) was recorded in the second season, 2018, while the lowest value (77.4 g) was noted for the control in the first year, 2017 (Figure 2-A). Fruit size is considered as one of the important external factors determining fig quality, since it greatly influences consumer's appeal (Crisosto *et al*., 2006). The greatest mean fruit diameter (61.9 mm) was recorded under potassium treatment during 2018 (Figure 2C). Soliman *et al.* (2018) had previously shown on fig fruit cv. 'Brown Turkey' that foliar application of potassium sulfate increased the fruit weight, volume and dimensions compared to the control. Irget *et al*. (1999) revealed that the foliar potassium application at 3% concentration improved the fruit size of figs cv. 'Sarilop' such as the shape and width of the ostiole opening. Moreover, foliar spray of potassium sulfate at 1% increased the fruit weight and volume of figs cv. 'Sultani' compared to control fruits (Yousef *et al*., 2017). Therefore, our results are consistent with these previous finding despite no, or few, increase in fruit dimensions. In our results, fruit weight increase may be attributed to the highest uptake of nutrients and carbohydrates by the fruit after photosynthetic improvement with a possible acceleration of metabolic processes. Indeed, adequate potassium application has been shown to increase fruit weight by increasing translocation of photosynthates to the fruits and water use efficiency (Römheld and Kirkby, 2010; Mendoza-Castillo *et al*., 2019). This suggests that high organic matter and favorable water status conditions might have translocated to fruit, thus leading to a higher quantity of carbohydrates and an increased fruit weight (Zörb *et al*., 2014). Furthermore, previous studies have shown that foliar potassium application on different fruit species such as olive (Hegazi *et al*., 2011), citrus (Ben Mimoun *et al*., 2018) and apricot (Moradinezhad and Dorostkar, 2021) increased fruit weight and size. Fig fruits in K_2SO_4-treated trees with a larger weight compared to the control may result from potassium involvement in several physiological, biological, and biochemical processes, such as stimulating cell division, cell elongation, as well as biosynthesis and the transport of organic nutrients and carbohydrate accumulation in the plant, as previously shown by Zörb *et al*. (2014).

Fruit Ostiole-End Cracking

The foliar potassium application reduced significantly the incidence of fruit cracking in 2018 and had no significant effect in 2017 and 2019 (Figure 3). In 2018, fruit ostiole-end cracking was reduced under potassium treatment by 3-fold (17%) compared to the control (53%). This result can be attributed to the role of potassium on the stability and

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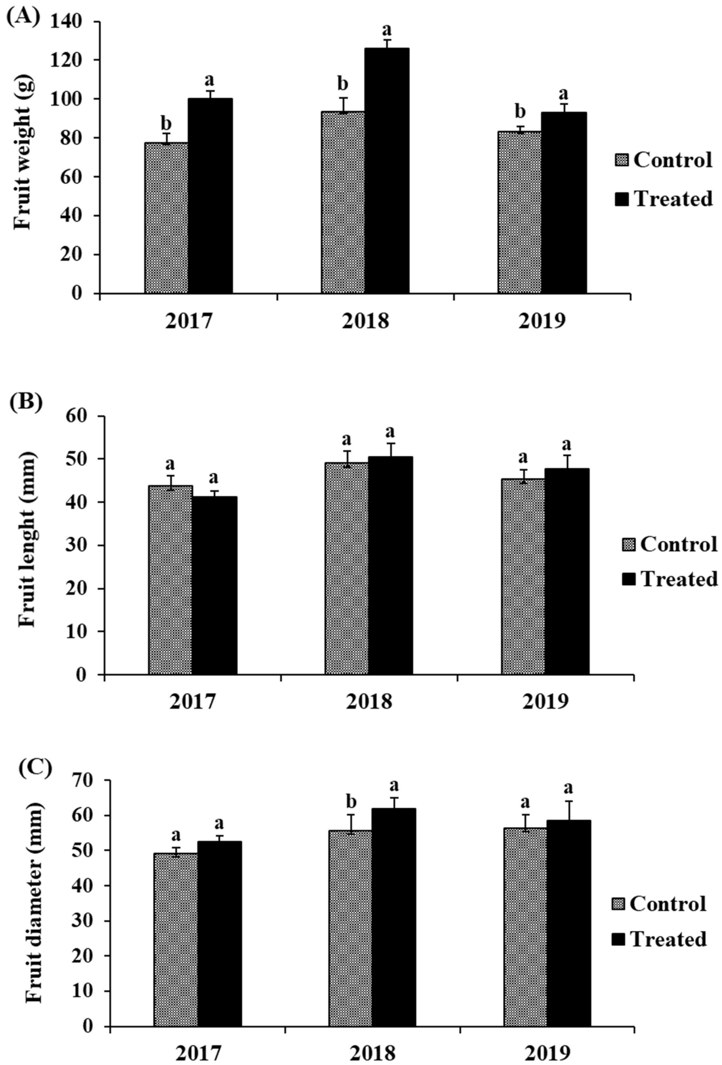

Figure 2. Effect of foliar potassium treatment on fruit weight (A), length (B), and diameter (C) of fig cv. 'Bouhouli' in the three years of study (2017-2019). Different letters (a, b) indicate significant differences between treatment and the control in a given year according to Duncan's multiple range test at P≤ 0.05.

integrity of the cell wall and cell expansion to accelerate cell growth (Li and Chen, 2017). However, additional application of K fertilizer during the late fruit development period has been shown to have little effect on the reduction of pre-harvest fruit cracking (Ali *et al*., 2000). In fact, fruit internal factors, i.e. genetic, skin abnormalities, and external i.e. environmental, biotic or cultural factors are known to affect fruit cracking (Opara *et al*., 1997). Cracking is not yet fully investigated in fig fruits, but previous studies based on observations and surveys have suggested that ostiole-end cracking of fig fruit is linked with variety, climatic conditions, soil properties and nutritional status (Aksoy and Anaç, 1994; Aksoy *et al*., 2003). In particular, the positive effects of some

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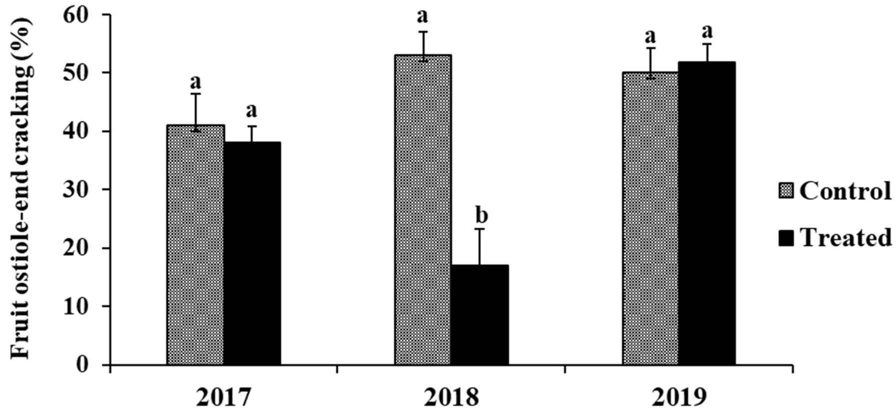

Figure 3. Percentage of figs with ostiole-end cracking in cv. 'Bouhouli' after foliar potassium treatment at 2% K_2SO_4 in the three years of study (2017-2019). Different letters (a, b) indicate significant differences between treatment and the control in each year according to Duncan's multiple range test at P≤ 0.05.

nutriments on fruit cracking reduction could be attributed to their important role in the cell wall and on the mechanical properties of plant tissues (Korkmaz *et al*., 2016; Hosein-Beigi *et al*., 2019). Mitra (1997) found that calcium has an important role in reducing fruit cracking. Consistently, several researchers have shown that the proportion of cracked figs was decreased by Ca applications. However, calcium movement into the fruit is known to decrease as the season progresses, whereas Mg, K, P and N increase along with the translocation of photosynthesis. This reduces the ratio of Ca with respect to other elements, particularly Mg and K that may result in the physiological disorders (Tadesse *et al*., 2001). In our study, the fact that the potassium foliar spray did not have a constant effect on fruit cracking in the three-year study could be due to this equilibrium with other nutrients.

Total Soluble Solids and Titratable Acidity

The potassium treatment increased significantly the Total Soluble Solids (TSS) in 2017 and 2018, and had no significant impact on the titratable acidity (Figure 4). The highest mean TSS (20.3 °Brix) was recorded in the first year of 2% K_2SO_4 treatment compared to the control (18.5 °Brix) (Figure 4-A). The increase in TSS content after foliar application of K is related to its role in the translocation of sugars from leaves to fruits (Römheld and Kirkby, 2010). Soliman *et al*. (2018) reported that application of K_2O at a rate of 400 g per tree followed by a second application of 200 g per tree had led to higher values of TSS and total acidity in figs of cv. 'Brown Turkey'. In general, the Brix values found in our study were higher than those reported by Crisosto *et al*. (2010) who had measured four fresh figs cultivars harvested at two maturity stages. Potassium fertilization has also been effective in enhancing the total soluble solids content and titratable acidity of many fruit trees. In pear trees, foliar application of K fertilizers led to an increase in the concentration of the total soluble solids, titratable acidity and sweetness, along with an elevated K accumulation in leaf and fruit at maturity (Shen *et al*., 2016). Solhjoo *et al*. (2017) have also reported that foliar application of potassium markedly increased the total sugar concentration and titratable acidity of 'Red Delicious' apple fruits compared to the

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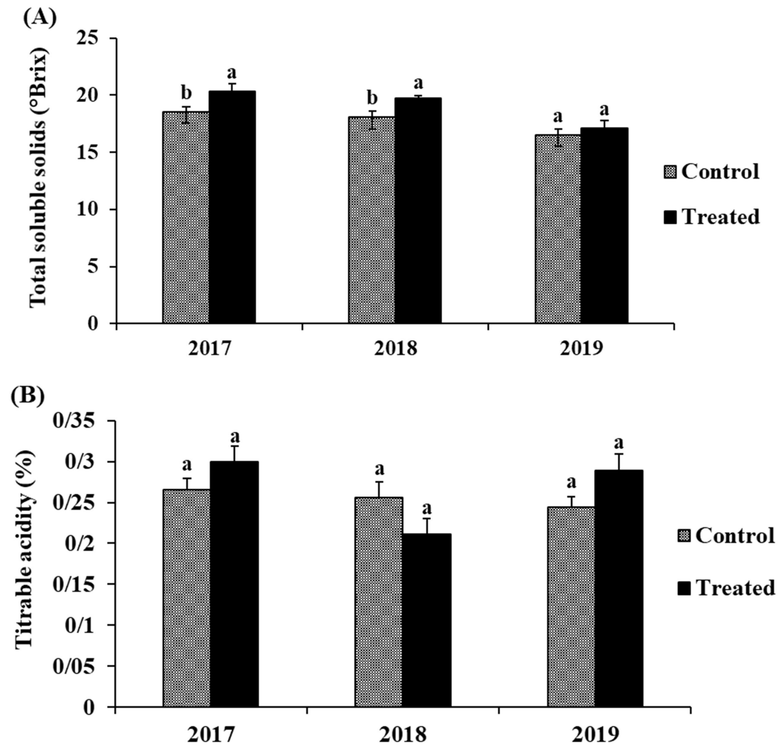

Figure 4. Effect of foliar potassium treatment on total soluble solids (A) and titratable acidity (B) of fig cv. 'Bouhouli' in the three years of study (2017-2019). Different letters (a, b) indicate significant differences between treatment and control in a given year according to Duncan's multiple range test at $P \leq 0.05$.

control. Similarly, in peach, potassium nutrition increased the fruit TSS, which thus enhanced the nutritional properties of the fruit (Dbara *et al.,* 2018). In contrast, in kiwifruit, no effect was found on the TSS and titratable acidity after potassium supplementation, although the thickness of the flesh was less (Pacheco *et al.,* 2008).

Leaf Nutrient Concentrations

The leaf nutrient concentrations of all elements, except K, were similar to the critical values established by Brown (1994) in the Smyrna-type cv. 'Calimyrna' that produce one fig crop per year only. However, leaf K concentrations were found to be higher compared to the critical level. Leaf potassium content is likely to be higher in the San Pedro-type cv. 'Bouhouli' compared to Smyrna-type figs. Such high levels of potassium may be associated with more needs for macronutrients in fig leaves in San Pedro-type figs that produce two fig crops per year (called Breba and Main crop, respectively) than in Smyrna-type figs with only one crop per year. Foliar application of K_2SO_4 increased significantly leaf K content as compared to the control in the three-year study. The leaf K content increased from 1.63 to 2.02% in 2018 and from 0.93 to 1.25% in 2019 (Table 2). Our results suggest that the highest leaf K content observed in 2018 could be the reason of the significant decrease in the percentage of fruit ostiole-end cracking observed in the same year. Foliar application of K_2SO_4 also increased the leaf Fe content in 2018 and 2019 compared to

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Table 2. Effect of foliar potassium treatment on leaf mineral contents of fig cv. 'Bouhouli' in the three years of study (2017-2019).[a]

Year	Treatment	N (%)	P (%)	K (%)	Ca (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})
2017	Control	2.44 b	0.12 a	1.53 b	4.12 b	115.37 a	9.79 b
	Treated	2.70 a	0.13 a	1.69 a	4.27 a	114.40 b	11.03 a
2018	Control	3.03 a	0.15 a	1.63 b	2.95 b	107.71 b	11.99 b
	Treated	2.87 b	0.13 a	2.02 a	3.02 a	117.20 a	14.80 a
2019	Control	2.23 b	0.09 a	0.93 b	3.04 b	115.9 b	10.75 b
	Treated	2.80 a	0.11 a	1.25 a	3.75 a	118.9 a	18.96 a

[a] Mean values in each column followed by the same letters are not significantly different at $P< 0.05$ according to Duncan's multiple range test.

the control, as well as the leaf Zn content, which reached 14.8 and 18.96 mg kg^{-1} in 2018 and 2019, respectively (Table 2). Leaf analyses also showed slight differences in leaf N, P and Ca contents between the treatment and the control in 2018 (Table 2). These results are consistent with those of Soliman *et al*. (2018) who found that the use of potassium in fig cv. 'Brown Turkey' as a fertilizer increased leaf N and K contents while leaf P content decreased significantly with an increasing rate of potassium fertilization. Treatments of K_2O at a rate of 100 g per tree led to the highest P content. In addition, Irget *et al.* (1999) reported that foliar potassium nitrate application at 3% increased K and Ca contents in both leaf lamina and petiole. Recently, leaf potassium content was found higher by about 12 and 19.5%, with potassium EDTA chelate and potassium thiosulphate treatments, respectively (Krapac *et al.*, 2021). Moreover, the effects of potassium treatment on K leaf concentration has been shown in other fruit species such as apple, pear, peach, olive, citrus and apricot (Ben Mimoun and Marchand, 2013, 2016; Dbara *et al*., 2018).

CONCLUSIONS

Our findings revealed that potassium sulfate applied as a foliar spray during fruit development improves yield per tree, fruit weight, and total soluble solids content of fig cv. 'Bouhouli' in field conditions. In addition, foliar fertilization with potassium sulfate reduced the ratio of fruits ostiole-end cracking, which could be related to high K concentrations in leaf. Foliar concentration of some minerals such as K, Fe and Zn also increased after the treatment, suggesting that macronutrients accumulation in fig leaves could be improved, especially for San Pedro-type fig cultivars. The demand for potassium during the growth, development, and ripening phase of fruit is so high that it leads to a limitation of its availability for fig fruits due to the inability of the roots to supply the entire potassium demand even when it is available in the soil. Therefore, foliar application during fruit development allows a quick and direct response to this demand and results in the beneficial effect of this method of supplying this mineral before fruit maturity.

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کمیت و کیفیت عملکرد انجیر (*Ficus carica* L.) زیر تاثیر برگپاشی سولفات پتاسیم

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چکیده

عملکرد و کیفیت میوه در انجیر (*Ficus carica* L.) شدیدا زیر تأثیر تغذیه معدنی به ویژه کلسیم (Ca) و پتاسیم (K) است. در این پژوهش، تأثیر برگ‌پاشی سولفات پتاسیم محلول (K_2SO_4) بر عملکرد، کیفیت میوه و محتوای عناصرغذایی برگ طی سه سال متوالی (۲۰۱۹-۲۰۱۷) بر رقم انجیر "بوهولی" 'Bouhouli'، که در شمال غربی تونس رشد می‌کند، بررسی شد. سولفات پتاسیم با غلظت ۲% هر سال دو بار در طول رشد میوه روی برگ درختان "بوهولی" پاشیده شد. با این کار، وزن میوه در سال اول و دوم به ترتیب ۲۹.۵% و ۳۴.۹% بهبود یافت، در حالی که عملکرد و کیفیت میوه تنها در سال ۲۰۱۸ بهبود یافت.ترک خوردگی انتهای میوه (ostiole-end cracking) که یکی از معیارهای کیفی میوه است، در سال ۲۰۱۸ در تیمار پتاسیم به میزان ۳ برابر (۱۷%) نسبت به شاهد (۵۳%) کاهش یافت. همچنین تیمار پتاسیم باعث افزایش معنی‌دار محتوای کل مواد جامد محلول در میوه ها در دو فصل اول شد.افزون بر این، در سال‌های ۲۰۱۸ و ۲۰۱۹، غلظت پتاسیم برگ پس از تیمار ۲% K_2SO_4 به طور قابل‌توجهی افزایش یافت. این نتایج نشان می‌دهد که برگ‌پاشی سولفات پتاسیم می‌تواند به عنوان بخشی از یک برنامه کودی کارآمد و پایدار برای بهبود عملکرد درخت انجیر و کیفیت میوه استفاده شود.

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