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Yield and fruit quality of Melon plants grown under saline conditions in relation to phosphate nutrition

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Abstract: Cultivation in arid and semi-arid regions is severely impacted by soil salinity, leading to an imbalance in plant mineral nutrition and reduced yields. One approach to mitigating these constraints involves investigating the interaction between salinity and phosphorus, aiming to understand the role of phosphorus in reducing the detrimental effects of salinity. This study was conducted in a greenhouse using sandy soil and followed a split-plot randomized block design with six replicates. The factors included three levels of irrigation water salinity (S1=2.0, S2=4.0, S3=6.0 dS.m^{-1}) and three levels of phosphorus (P1=0 Kg P_2O_5.ha^{-1} as the control treatment, P2=100 Kg P_2O_5.ha^{-1} corresponding to 100% of crop needs, and P3=120 Kg P_2O_5.ha-1 with 120% of crop needs). The results revealed the impact of the salinity-phosphorus interaction on morphological parameters, crop yield, quality, and proline accumulation. It was evident that the addition of phosphorus significantly improved melon tolerance to salinity. High salinity levels in the irrigation water resulted in a notable reduction of 17% and 36% in melon growth and fruit yield, respectively, under 4 and 6 dS.m^{-1} compared to the control. However, phosphorus applications tended to increase marketable fruit yield, sugar content, and leaf stomatal conductance. Based on our findings, it is not recommended to irrigate melons with saline water above 4 dS.m^{-1}, as it significantly affects yield. These results suggest that supplemental phosphorus can mitigate the adverse effects of high salinity on plant growth and physiological development.

1. Introduction

Melons, which belong to the Cucurbitaceae family, are cultivated in tropical and temperate regions worldwide. With a wide range of varieties, melons are considered economically important vegetable crops (Giwa & Akanbi, 2020). These fruits are highly nutritious, containing antioxidants like phenolic compounds, ascorbic acid, and carotenoids (Menon & Rao, 2012). They are also a good source of vitamin C, flavonoids, vitamin B, fiber, low in fat and sodium, and provide essential nutrients, particularly potassium (Manchali et al., 2021). Additionally, melons used as vegetables offer health benefits due to their flavonoids, alkaloids, and bitter elements (Gómez-García et al., 2020). In 2020, melon production in the Souss Massa region exceeded 5.9 thousand tons.

Soil salinity poses a significant challenge in arid and semi-arid parts of Africa, affecting approximately 24 percent of the continent (FAO, 2015). The Souss-Massa Basin (SMB) is the second most economically important province in Morocco, primarily due to its high-value agricultural production, tourism industry, and fishery development. The agricultural sector in this region is a major contributor to water demand. The Massa perimeter focuses on cultivating seasonal vegetable crops and citrus production in the Souss Plain, which account for 85% and 55% of the country's exports in these sectors, respectively (Choukr-allah et al., 2016). Studies have shown that 25% of the arable soil in the Souss Massa Region exhibits moderate to strong salinity, primarily resulting from irrigation with saline waters (El Oumlouki et al., 2018). It has been reported that under salinity conditions, three main physiological mechanisms induce stress: reduced water potential in the root medium, toxic effects of sodium and chloride, and nutrient imbalance due to decreased uptake and shoot transport (Yarsi et al., 2017). There is evidence that salinity can lead to an excessive accumulation of phosphorus, reaching toxic levels and causing phosphorus deficiency in plant tissues (Uygur & Yetisir, 2009). In most cases, the application of phosphates in saline areas is likely to increase yields, demonstrating a positive interaction between phosphorus and salinity (Belouchrani et al., 2020).

Therefore, the aim of this study was to investigate the effect of different phosphorus applications in mitigating the negative impact of NaCl on the growth and nutrient content of melon seedlings exposed to moderate and high salt stress, addressing a significant environmental concern.

2. Methodology

2.1. Location and Experimental Materials

This experiment was conducted on the experimental farm of the National Institute of Agronomic Research (INRA), 45 km south of Agadir city in the Souss Massa region, from March 2020 to September 2020. The site was characterized by a semi-arid climate, dry and hot summer, and relatively cold winter. Temperatures are moderate, with an annual average of 18.7 °C, while the daily maximum temperature can reach 40 °C in summer and the minimum temperature 5 °C in winter. The experiment was conducted on sandy soil with low calcium carbonate and slightly alkaline pH. The planting materials used in this study were Galia-type melons (*Cucumis melo L.*), ideal variety, grown on a single arm with a planting density of 10,000 plants/ha (2*0.5m), planted on March 28.

2.2. Treatments and Experimental Design

The experimental design and layout consist of a split-plot design using 6 spaced crop lines (50 m length and 0.9 m width). The plot size was equal to 5.5 x 0.8 m (4.4 m^2) with a total plant per plot unit of 12 plants.

Three P fertilization rates were tested, 0 (P1), 100 (P2), and 120 kg P_2O_5 ha-1 (P3), in combination with three different levels of irrigation water salinity (Electrical Conductivity, ECiw). (S1): The control was the commonly used nutrient solution with an ECiw equal to 2 $dS.m^{-1}$, (S2): which corresponds to the medium level of salinity 4 $dS.m^{-1}$, and (S3) which correspond to the highest-level 6 dS.m-1. Salinity treatments were applied in the main plots in six complete blocks, and phosphorus fertilization was in the sub-plots. Each crop line is divided into 9 plots. The trial includes 54 experimental units (3 P-doses x 3 salinity levels x 6 Replicates). The salinity levels in the investigated treatments were obtained continuously and gradually over 3 days of sodium chloride (NaCl) in freshwater with continuous EC measurements until the required EC values were obtained. Nine tanks with 500 liters each was used, corresponding to the combination of the 3 levels of salinity and the 3 doses of phosphorus fertilization.

Melon seeds were germinated, and seedlings were raised in trays containing peat. Similar-sized (third actual leaf stage) melon seedlings were transplanted in the greenhouse in early April under natural light conditions. Each planting row was supplied with pipelines and a dripper for each plant. Each dripper was spaced at 0.4 m and released water @ 2 $L.h^{-1}$ dripper-1.

2.3. Data Collection

2.3.1. Growth and yield Measurements

The measurement of plant growth was carried out by measuring plant height every 15 days. Peppers were usually harvested weekly, the fruits were counted and weighted, and the yield t h-1 was expressed in a fresh weight basis. After the last harvest, we uprooted the melon plants and separated the aerial part of the roots; then, we weighed each part to obtain the fresh shoot and root biomass.

2.3.2. Physiological Process

The physiological measurements were taken at dawn on fully expanded mature leaves (5th leaf from the apex) on five plants of each experimental unit using LCI-SD equipment (UK). This equipment is a portable measuring system of photosynthesis and stomatal conductance where all the measurements are recorded due to an RAM CARD mechanism. The leaf tissue proline content was measured following the method described by (TROLL & LINDSLEY, 1955), improved by Dreier and Göring (1974), and modified by (MONNEVEUX & NEMMAR, 1986).

2.3.3. Fruit Quality Components

Fruit quality refers to fruit firmness, diameter, and sugar content in the fruit's apical, middle, and basal parts. Harvested fruit was then cut, the juice was extracted and transferred into a refractometer, and the reading was taken in degrees Brix (° Bx). A cylinder probe of 5 mm diameter size was forced onto the pulp surface, and the reading was expressed in (kg/cm). The unmarketable fruits indicate fruits presenting apical necrosis, which was weighed separately.

2.4. Statistical Analyses

Statistical analysis was performed using Minitab 16 software. A two-way analysis of variance (ANOVA) was performed to assess the effects of irrigation water salinity, P fertilizer rates, and their interaction on growth, fruit yield, stomatal conductance, and fruit quality. The significant parameters from ANOVA were subjected to Tukey's multiple comparison tests ($p \leq 0.05$). Correlation among the measured parameters was assessed using Pearson's coefficient.

3. **Results and Discussion**

3.1 Effect of Salinity Sources on Growth and yield

The impacts of salinity and phosphorus fertilization treatments on melon yield and growth are presented in Table 1. The influence of salinity on fresh weight yield was found to be highly significant. A salinity level of 4 dS.m-1led to a 17% reduction in yield, while an increase in salinity levels to 6 dS.m-1 resulted in a 36% reduction. When applying phosphate fertilization at a rate of 100 Kg P2O5.ha-1, an increase of 6% and 3% in yield was observed for salinity levels of 4 and 6 dS.m-1, respectively. Moreover, optimizing phosphorus by 20% enhanced melon production by 25% in a medium salinity level and 6% at a high salinity level.

Table 1. The main effect of salinity and phosphorus fertilization combinations on yield (T/Ha), Plant height, Shoot fresh biomass (g) and Root fresh biomass (g) of melon.

Salinity (dS.m-1)	Phosphorus (Kg P_2O_5.ha-1)	Yield (T/Ha)	Plant height	Shoot fresh biomass (g)	Root fresh biomass (g)
2	0	23.23 ± 5.10bc	194.37 ± 12.27cd	0.81± 0.25abc	0.07± 0.03bc
	100	26.67 ± 10.70b	250.71 ± 23.45ab	0.86± 0.31b	0.09± 0.04b
	120	38.33 ± 8.92a	273.42 ± 23.61a	0.99± 0.45a	0.15± 0.07a
4	0	19.24 ± 4.77bc	173.70 ± 10.62d	0.63± 0.11bc	0.04± 0.02bc
	100	20.31 ± 6.93bc	224.53 ± 30.13bc	0.73± 0 07abc	0.06± 0.02bc
	120	24.00 ± 8.18bc	242.27 ± 50.05ab	0.77± 0.08abc	0.08± 0.03bc
6	0	14.84 ± 3.34c	159.93 ± 13.43d	0.53± 0 08c	0.03± 0.02bc
	100	15.22 ± 3.03c	178.60 ± 25.14d	0.55± 0.11c	0.04± 0.02bc
	120	15.70 ± 6.44c	193.80 ± 13.46cd	0.64± 0.16bc	0.05± 0.04bc
P value	Salinity	0.000	0.000	0.000	0.000
	Phosphorus	0.001	0.000	0.023	0.000
	S*P	0.015	0.038	0.933	0.023

Melon growth was adversely affected by salinity, leading to a slowdown in growth. There was a positive correlation between salinity levels and reductions in plant height, shoot fresh biomass, and root fresh biomass. Under medium salinity (4 dS.m-1), the reductions were 11%, 22%, and 43% respectively. At high salinity (6 dS.m-1) treatments, the reductions were even more pronounced, with decreases of 18%, 35%, and 57% of plant height, shoot fresh biomass, and root fresh biomass, respectively.

3.2. Stomatal conductance

In young, fully expanded leaves, stomatal conductance showed a reduction of 27% under moderate salinity and 36% under high salinity. However, with P fertilization at a rate of 100 Kg P2O5.ha-1, stomatal conductance was significantly enhanced ($p < 0.05$). There was an increase of 47% under 4 dS.m-1salinity and 19% under 6 dS/m salinity (Figure 1).

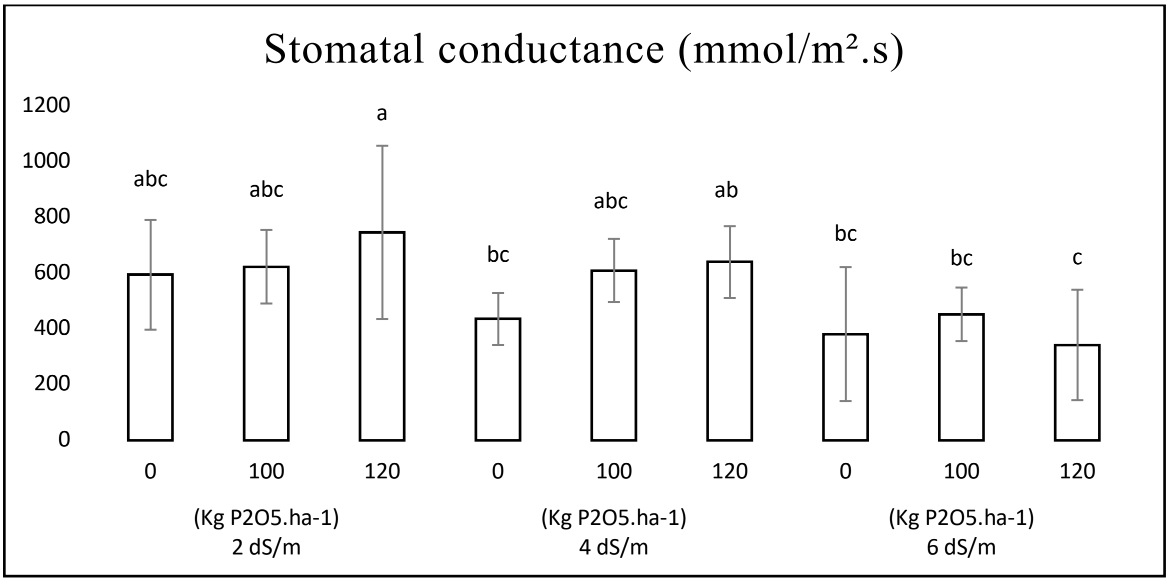

Figure 1. The main effect of salinity and phosphorus fertilization combination of Stomatal conductance (mmol/m².s).

3.3. Fruit quality

In the present study, the focus was on the aspects of melon fruit quality that are crucial for marketability and consumer satisfaction, namely appearance (firmness) and taste. The results indicate that a salinity level of 4 dS.m-1had a positive effect on melon sugar content (Table 2). Regarding fruit quality, the findings suggest that increasing salinity levels have a detrimental impact, leading to higher production of necrotic fruits and decreased fruit diameter and firmness. Increasing salinity levels to 4 dS.m-1and 6 dS.m-1result in a significant increase in the occurrence of necrotic fruits, with a rise of 110% and 240% respectively. However, the application of an additional 100 Kg P_2O_5.ha-1 of phosphorus helps alleviate the incidence of Blossom End Rot by 46% and 58% respectively. Furthermore, a higher dose of 120 Kg P_2O_5.ha-1 leads to a substantial reduction of 80% and 76% in the occurrence of necrotic fruits under 4 dS.m-1and 6 dS.m-1salinity levels respectively.

These results suggest that phosphorus fertilization can mitigate the negative effects of salinity on the incidence of Blossom End Rot and reduce the occurrence of necrotic fruits. However, it's important to consider other factors such as specific melon cultivars, application timing, and environmental conditions when implementing phosphorus fertilization strategies under saline conditions. Both salinity level and phosphorus fertilization had significant effects on fruit quality parameters. Salinity stress resulted in a decrease in the quality of melon fruit, including Blossom in the rot incident, fruit diameter, Fermness and Brix. Specifically, a salinity level of 6 dS.m-1reduced the TSS content by 11% and the acidity content by 23% compared to the control. However, under phosphate fertilization (100 Kg P_2O_5.ha-1), the TSS content showed improvements of 13% and 5% for salinity levels of 4 and 6 dS.m-1, respectively.

Table 2. The main effect of salinity and phosphorus fertilization combinations on Necrotic fruits (Kg/10 plants), Diameter (Cm), Fermness (Kg/cm) and Brix of melon.

Salinity (dS.m-1)	**Phosphorus (Kg P_2O_5.ha-1)**	**Necrotic fruits (Kg/10 plants)**	**Diameter (Cm)**	**Fermness (Kg/cm)**	**Brix**
2	0	1.49 ± 0.87bcd	24.87 ±1.33c	6.31 ± 0.95ab	8.30±0.50e
	100	1 ± 1.09cd	26.67 ± 1.37b	5.43 ± 1.24a	9.77±0.14d
	120	0.14 ± 0.33d	29.53 ± 0.83a	7.52 ± 0.2bc	10.47±0.37cd
4	0	3.14 ±0.87 b	21.33 ± 0.93ef	6.02 ± 2.05abc	10.60±0.47cd
	100	1.69 ± 0.78bcd	23.23 ± 1.35cd	6.29 ± 1.79ab	11.13±0.31bc
	120	0.61 ± 0.96cd	24.93 ± 1.71bc	5.69 ± 1.46bc	11.47±0.45b
6	0	5.06 ± 1.78a	19.6 ± 0.59f	4.5 ± 0.1c	12.57±0.67a
	100	2.14 ± 1.45bc	21 ± 0.77ef	5.04 ± 0.04bc	10.30±0.15cd
	120	1.19 ± 1cd	22.5 ± 0.45de	6.06 ± 1.33abc	10.53±0.41cd
P value	Salinity	0.000	0.000	0.001	0.000
	Phosphorus	0.000	0.000	0.015	0.000
	S*P	0.011	0.005	0.009	0.005

3.4. Principal Component Analysis (PCA)

Figure 2 illustrates the correlation circle of the variables examined. The PC1 axis was primarily influenced by the plant height, shoot fresh biomass, root fresh biomass, stomatal conductance, necrotic fruits, fruit diameter, fruit firmness, and fruit sugar content. The projection of additional dependent variables indicated that salinity exhibited a negative correlation with all PC1 variables. Furthermore, fruit sugar content, root fresh biomass showed a positive correlation with the applied phosphorus rate.

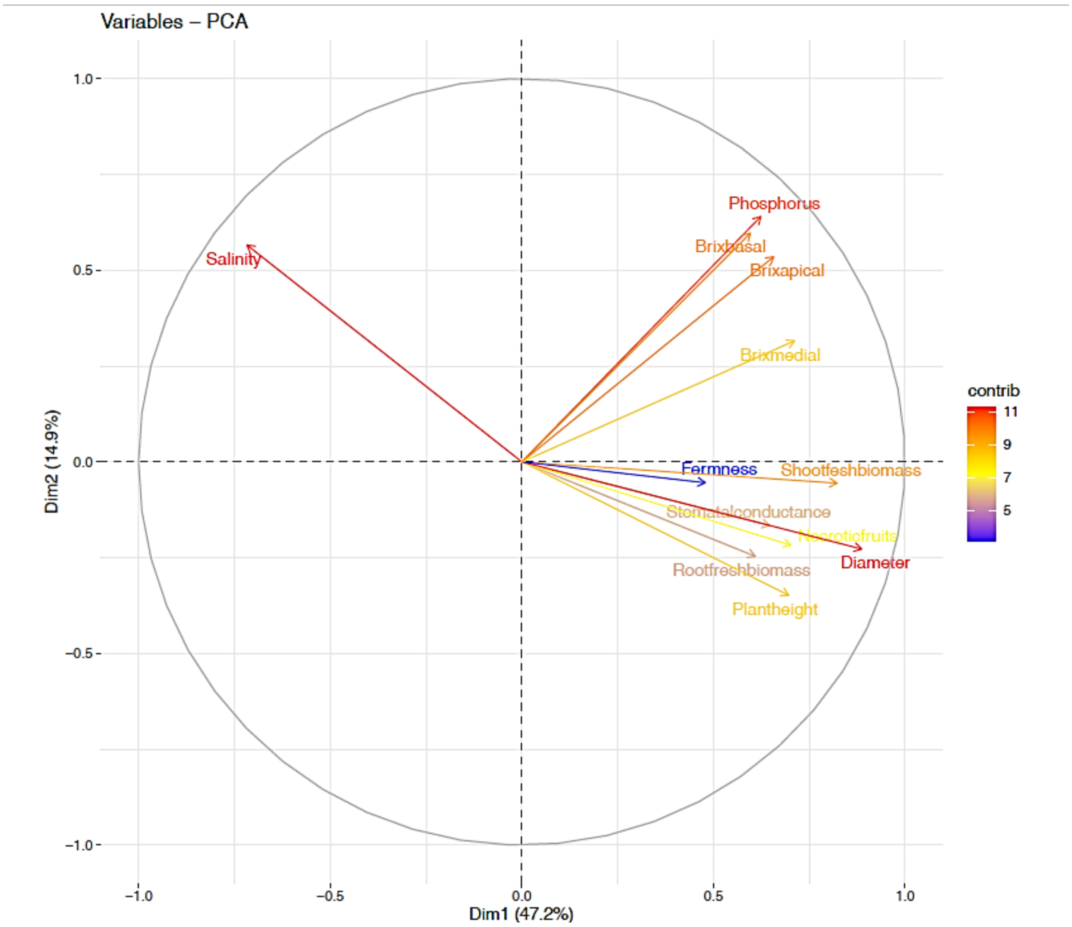

Figure 2. Correlation circle of variables on the two principal components for all investigated parameters. Color gradient corresponds the quality of representation of the contribution of each parameter.

Discussion

The growth, yield, and fruit quality parameters of melons were influenced to different extents by the level of salinity and the rate of applied phosphorus. The primary reason for yield reduction in the presence of salinity is the decrease in photosynthetic activity. In this study, it was observed that melon plants consistently exhibited a decline in stomatal conductance when exposed to elevated salinity levels (table 1). Soil salinity has been found to decrease plants' stomatal conductance (Betzen et al., 2019). This reduction in stomatal conductance leads to a decrease in photosynthetic rate and water uptake (Stepien & Johnson, 2009), ultimately affecting photochemical and carbon metabolism (Maia et al., 2016). Salinity also has detrimental effects on chloroplasts and stomatal structure (Huang et al., 2009) and results in a decrease in chlorophyll and carotenoid content (Hessini et al., 2019).

The decrease in yield observed under saline conditions can be attributed to multiple factors, including reduced plant height. Salinity stress has a detrimental effect on fruit weight and number by disrupting osmotic processes and causing ion or Na^+ toxicity (Isayenkov & Maathuis, 2019). The decrease in the number of fruits per plant is recognized as the primary cause of yield loss in melon cultivars sensitive to salinity (Pereira et al., 2017). Moreover, salinity stress hampers root development by impairing nutrient and water uptake, which is attributed to a disturbance in osmotic adjustment, which limits water and nutrient absorption (Khosh Kholgh Sima et al., 2012). This further contributes to the overall reduction in yield under saline conditions.

Phosphorus fertilization had a significant positive impact on fresh shoot and root biomass, as well as fruit yield, under both saline and non-saline conditions. However, the beneficial effect of phosphorus was more prominent under saline conditions (Table 1), highlighting the potential of P applications as a risk-reduction strategy in moderate salinity conditions. These findings are consistent with previous studies that demonstrated how P fertilization enhances above and below-ground dry weight and yield of melon, thereby increasing the crop's tolerance to salinity (Botía et al., 2005). Furthermore, the application of phosphorus has been shown to alleviate the adverse effects of salinity on other crops such as tomatoes (Kaya et al., 2001), wheat (Ding et al., 2020), sorghum (Belouchrani et al., 2020), Black Cumin (Khalid & Ahmed, 2017), melon (Gopalakrishnan et al., 2022; Guzmán & Olave, 2006) and pepper (Çimrin et al., 2010). It is worth noting that salinity-induced P deficiency can limit crop production, and therefore, supplementary P fertilizer application is generally recommended to manage P deficits in saline soils (Dey et al., 2021).

The application of phosphorus resulted in increased growth and yield parameters of melon. This effect was particularly pronounced at higher phosphorus levels (140 kg P_2O_5•ha^{-1}) under moderate salinity (4 $dS.m^{-1}$) and at phosphorus levels of 120-140 kg P_2O_5•ha^{-1} under high salinity (6 $dS.m^{-1}$) conditions (Table 1). This improvement in crop tolerance to salinity can be attributed to the increased availability of phosphorus in the soil, which indirectly enhances nutrient absorption from the soil (Fahad et al., 2015). Additionally, phosphorus application enhances the synergistic relationship between phosphorus and other beneficial elements such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), while also helping to maintain osmotic equilibrium and enhancing salt tolerance to a certain extent (Malik et al., 1999).

The quality of fruit is a crucial factor that influences the market value of crops. The impact of salinity and phosphorus fertilization treatments on the quality of melon fruit is presented in Table 2. This study revealed that salinity stress generally led to a reduction in fruit quality parameters, with the exception of brix, which showed a positive impact with increased salinity. Similar findings were reported by Pereira et al. (2017). It is hypothesized that the decrease in fruit quality parameters may be attributed to the alteration of cell membrane functionality, which affects solute transport and the regulation of enzymes responsible for maintaining fruit quality parameters (Sarabi & Ghashghaie, 2022).

The phosphorus (P) fertilization has been shown to have a significant effect on melon fruit quality when grown under salinity stress. The application of phosphorus can positively influence various fruit quality parameters and enhance the overall market value of melon crops.

One important effect of phosphorus fertilization is its role in improving sugar content (brix) in melon fruit. Studies have demonstrated that higher levels of phosphorus supply can increase sugar accumulation in melon fruits, resulting in sweeter and more flavorful produce (Fahad et al., 2017). Phosphorus is involved in carbohydrate metabolism and plays a crucial role in the synthesis and translocation of sugars within the plant, leading to an enhancement in fruit sweetness.

In addition to sugar content, phosphorus fertilization has also been shown to influence other fruit quality parameters. It can positively affect fruit size, resulting in larger melon fruits (Fahad et al., 2017). Phosphorus application has also been associated with improved fruit firmness, which is an important characteristic of transportability and shelf life (Martuscelli et al., 2016). Furthermore, phosphorus can contribute to the accumulation of beneficial compounds such as antioxidants and vitamins, enhancing the nutritional value of melon fruits (Fahad et al., 2017).

Conclusions

Given the increasing issue of soil salinization worldwide, including in Morocco, implementing fertilization practices can be a wise solution to mitigate the adverse effects of salinity on crop productivity. Our study's findings demonstrate that providing phosphorus has a positive impact on the growth parameters and yield and fruit quality of melon, particularly under saline conditions, thereby enhancing salinity tolerance. Based on the results obtained, to achieve satisfactory yields, it is recommended to apply a phosphorus rate of 120 kg of P2O5 ha−1 under moderate salinity (4 dS.m-1) and 100 kg of P2O5 ha−1 under high salinity conditions (6 dS.m-1).

Authors' Contributions

Conceptualization: SA and RC; Data curation: SA; Formal analysis: SA; Funding acquisition: RC; Investigation: SA; Methodology: RC; Project administration: RE; Resources: KA; Software: SA and KA; Supervision: RE, MF, KA and RC; Validation: RE, KA, RC; Visualization: KA and RE; Writing - original draft: SA; Writing - review and editing: KA and RE. All authors read and approved the final manuscript.

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