

Research Article

Effects of Foliar Fertilization on Nutrient Uptake, Yield, and Fruit Quality of Pomelo (*Citrus grandis* Osbeck) Grown in the Mekong Delta Soils

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Foliar application is a popular technique to supply mineral nutrients to crops. It also enhances nutrient use efficiencies, especially under limited soil fertility or restricted environmental conditions. This study aimed to evaluate the influence of foliar application of phosphorus (P) with potassium (K), magnesium (Mg), and zinc (Zn) on the nutrient uptake, yield, and fruit quality of pomelo. The experiments were conducted between 2018 and 2021 in three different sites of alluvial soils, including four treatments, namely, control (without foliar fertilization), FF1 (containing P, K, and Mg), FF2 (P, K, Mg, and Zn), and FF3 (Zn). The results indicated that the P, K, and Mg concentrations in leaves and fruits were significantly enhanced after the spraying of solutions FF1 and FF2 compared with the control and FF3. The application of FF1 and FF2 greatly improved the fruit quality, and the fruit yield response was as high as 4.0-5.0 t ha⁻¹. Foliar Zn application (FF3) increased the Zn concentration in leaves, but there was no improvement in fruit Zn content, fruit quality, and yield compared to the control treatment. The results indicate that FF1 or FF2 could be used as a sustainable fertilizer strategy for pomelo trees because of its ability to improve the leaf and fruit nutrient concentration and enhance the fruit quality and productivity of pomelo.

1. Introduction

Pomelo (*Citrus grandis* Osbeck) is a citrus fruit originating in China. It is widely cultivated in the tropical regions of Southeast Asia, such as Thailand, Vietnam, Indonesia, and the Philippines [1]. Pomelo is the largest among the citrus fruits. Its diameter is up to 25 cm, its average weight is 1.0-2.0 kg, and its skin is green to yellow when ripe [2,3]. In the Vietnamese Mekong Delta (VMD), this fruit accounts for about 35% of the total agricultural production [4]. Citrus fruits, especially pomelo, are considered to be of high value in the region for both domestic markets and exports. They are widely cultivated in the Hau Giang province, Vietnam, which is located near the Hau river; thus, making it suitable for horticulture [5]. However, in recent years, pomelo production has been unstable due to soil degradation and poor farming practices. Furthermore, the deficiency in

phosphorus, potassium, magnesium, and zinc concentrations in citrus fruit production reduced fruit yield, which resulted in decreased profits of this commodity [6]. Foliar nutritional spray is a technique of supplementing nutrient to plants to achieve a more efficient fertilization [7]. A previous study indicated that the use of foliar fertilization significantly improved crop productivity and leaf mineral nutrient concentration compared to no foliar application [7].

Foliar feeding is not dependent on root health and soil pH that affect nutrient uptake [8,9]. The use of foliar fertilization reduces fertilizers application amounts, as well as its loss to environment [10], especially under soil degradation or soil compaction [11]. For example, phosphorus easily precipitates under low soil pH; about 20% of phosphorus is available to plants, and the remaining percentage would turn into insoluble compound [12]. Potassium is a mobile nutrient, making it easy to leach out the soil solution

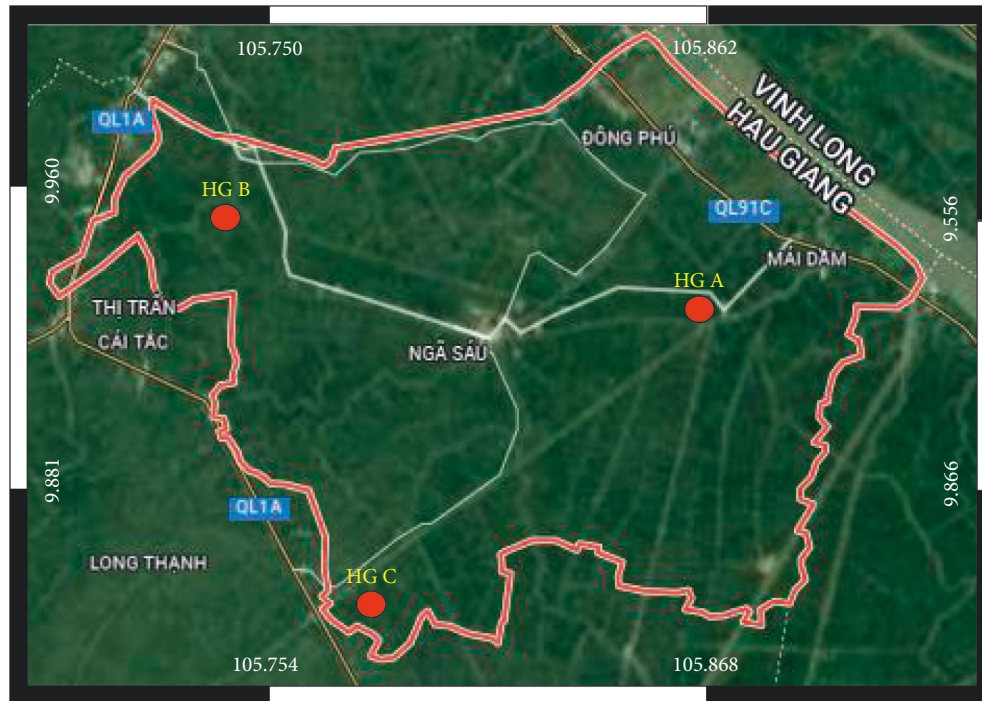


FIGURE 1: Location of the conducted experiments.

[13]. In addition, some essential nutrients in soil, such as magnesium and zinc, that influence the growth and production of citrus fruits are less available under low soil pH [14, 15].

Macroelements (phosphorus, potassium, and magnesium) play a significant role in improving citrus fruit yield and fruit quality [16]. Phosphorus is a key nutrient for citrus and a major limiting factor for plant growth and yield [17]. Phosphorus plays many vital roles in cell division, photosynthesis processes, enzyme activation, metabolism, and movement of sugars [18]. It is also essential for citrus growth, flower development, and increase in fruit set [19]. Likewise, potassium is an essential element and has significant effects on stomatal opening and closing, enzyme activity, cell division, protein synthesis, sugar and starch production, and acid metabolism of citrus juice [20]. The application of potassium on leaves reduces fruit drop, increases the juice volume, total soluble solid (TSS), and improves nutrient uptake [21]. Khalid et al. [22] concluded that foliar application of phosphorus and potassium significantly improved the titratable acidity and ascorbic acid contents of “Kinnow,” which is a mandarin fruit. Magnesium plays an important role in chlorophyll production, stimulates phosphorus uptake, and participates in carbohydrate metabolism and sugar formulation [23]. According to Morton et al. [24], magnesium deficiency reduces citrus fruit yield and quality.

Zinc in small amounts, nevertheless, is vital for various functions in enzyme activation, metabolic processes, auxin and chlorophyll formation, and photosynthesis [25, 26]. Foliar spraying of zinc improves micronutrient deficiencies,

which results in enhanced fruit quality [27, 28]. The fruit quality and yield of pomegranate were improved by the spraying of zinc [29].

Although the role of foliar fertilization has been widely studied worldwide, research on its influence on the nutritional status, yield, and fruit quality of pomelo trees in the alluvial soils of the VMD area is scarce. Thus, this work aimed to evaluate the influence of foliar application of P (phosphorus) with K (potassium), Mg (magnesium), and Zn (zinc) on leaf and fruit mineral nutrient status, pomelo fruit quality, and yield.

2. Materials and Methods

2.1. Site, Plant, and Soil. The field experiment was conducted in three different “5 Roi pomelo” orchards located in Chau Thanh District, Hau Giang province, Vietnam, from November 2018 to May 2021. The research locations are presented in Figure 1, namely, HG A ($9^{\circ}55'40.8''N$, $105^{\circ}50'57.0''E$), HG B ($9^{\circ}56'44.6''N$, $105^{\circ}45'20.7''E$), and HG C ($9^{\circ}51'51.2''N$, $105^{\circ}47'13.4''E$). The study areas have a tropical monsoon climate with an average annual temperature of about $26^{\circ}C$ - $28^{\circ}C$. They have two distinct seasons: dry season from December to April and rainy season between May and November. The annual precipitation ranges from 1,000 to 1,300 mm, and most of the rainfalls are concentrated during the rainy season. To sum up, temperature, sunshine, humidity, and rainfall were favorable for the growth and development of pomelo in this study.

The trial was conducted in a 5-year-old plantation that was planted by rootstock, with a 4.0×4.0 m spacing (625

TABLE 1: Initial physicochemical properties of the experimental soils.

Parameter	Unit	HG A		HG B		HG C	
		0-20 cm	20-50 cm	0-20 cm	20-50 cm	0-20 cm	20-50 cm
pH _{H2O}		5.62	6.15	4.22	4.84	5.27	5.61
EC	mS cm ⁻¹	0.13	0.14	0.19	0.10	0.33	0.15
Available phosphorus	mg kg ⁻¹	20.0	12.2	30.2	12.8	25.0	9.47
Total nitrogen	%	0.10	0.12	0.11	0.13	0.18	0.15
Soil organic matter	%	2.57	3.06	2.70	2.30	3.91	4.25
Exchangeable cations							
Na ⁺	meq 100g ⁻¹	0.23	0.42	0.18	0.41	0.41	0.71
K ⁺		0.60	0.45	0.73	0.39	0.66	0.50
Ca ²⁺		10.2	9.01	6.67	10.0	11.6	12.9
Mg ²⁺		4.66	5.12	2.60	4.61	5.54	5.58
CEC	meq 100g ⁻¹	21.8	20.1	19.1	19.6	21.9	20.7
Bulk density	g cm ⁻³	1.18	1.16	1.25	1.15	1.10	1.18
Soil texture							
Sand	%	0.50	1.00	0.50	1.10	0.20	0.70
Silt		49.5	34.0	43.8	41.9	44.6	45.5
Clay		50.0	65.0	55.7	57.0	55.2	53.8

trees per ha). At the time of the experiment, the pomelo trees were 3.0 to 3.5 m tall, and the canopy diameter was 2.5 to 3.0 m. The trees that were selected for the experiment had the same trunk diameters. Table 1 presents the physical and chemical properties of the soil before the experiment was conducted.

2.2. Experimental Design and Treatments. The experiment was a factorial laid out in a randomized complete block design (RCBD), which included four treatments: control; foliar fertilizer 1, commercial fertilizer YaraVita HYDROPHOS (containing P₂O₅ (29.7% w/w), K₂O (5.0% w/w), and MgO (6.7% w/w)); foliar fertilizer 2, commercial fertilizer YaraVita HYDROPHOS Zn (containing P₂O₅ (29.7% w/w), K₂O (5.0% w/w), MgO (4.5% w/w), and Zn (6.0% w/w)); and foliar fertilizer 3, a commercial fertilizer Senca ZINTrust (containing Zn (35% w/w)). There were 48 pomelo trees per trial per site, and each treatment included 12 trees divided into three replications. The foliar fertilizers were sprayed once every 2 months and stopped spraying foliar fertilizer 2 months before fruit harvest. The volume of water applied was about 2 L per tree per spraying.

The application rates of N, P, and K (700, 450, and 700 g per tree per year, respectively) were in accordance with the recommendation of the Southern Horticultural Research Institute (SOFRI), Vietnam. N, P, and K were applied as urea (46% N), superphosphate (7% P), and potassium chloride (50% K). After a month of the harvest stage, 20% of the total N and 30% of the total P were applied; 15%, 40%, and 30% of the total N, P, and K, respectively, were applied before 2 months of flowering; and 20%, 10%, and 15% of the total N, P, and K, respectively, were applied a month after the fruit set. At 2.5 months after the fruit set, 25% of the total N, 10% of the total P, and 15% of the total K were applied for pomelo

tree; 4 months after the fruit set, pomelo was applied NPK at the rate of 20%, 10%, and 20%, respectively; 20% of total K was applied 2 months before the fruit harvest. All treatments in this research accepted normal horticultural care for pest and disease control.

2.3. Data Recording. Pomelo leaves were collected three times in May in 3 years (2019, 2020, and 2021); each leaf sample included 50 leaves. Leaf samples were picked up from the 3rd or 4th position of 3-5-month-old, newly flushed, and nonfruiting twig on the outer canopy [30]. After the collection, the leaves were washed twice with tap water and then washed again with distilled water. Subsequently, the leaves were oven-dried at 70°C for 72 h and then crushed and stored in the plastic bag to analyze mineral nutrients.

Twelve pomelo fruits from each treatment (four fruit samples per replication) were harvested at the ripening stage (February 2019, 2020, and 2021). After the harvest, the peels and pulps of the fruits were separated. The peels were minced, dried at 70°C for 72 h, grounded, and then stored in a plastic box. The pulps were dried using a freeze dry system (FreeZone 6 Liter; Labconco, USA).

The concentrations of mineral nutrients (P, K, Mg, and Zn) in the leaves and fruits were analyzed according to the standard procedures described by Houba et al. [31] at the Soil Science Department, College of Agriculture, Can Tho University. All samples were digested in condensed H₂SO₄ and 30% of H₂O₂ using the microwave system. The concentration of P was analyzed via UV-Vis spectrophotometry. The concentrations of K, Mg, and Zn were extracted with HCl 1M and determined via atomic absorption spectrophotometry.

The acidity of the juice was determined using the titration method [32]. The titrating reagent used was NaOH

TABLE 2: Concentrations of P, K, Mg, and Zn in leaves (dry weight).

Factor	2019					2020					2021															
	P	K	Mg	Zn	g kg ⁻¹	P	K	Mg	Zn	g kg ⁻¹	P	K	Mg	Zn	g kg ⁻¹	P	K	Mg	Zn	g kg ⁻¹						
(A) Foliar fertilizers	Control	1.22 ^b	17.2 ^b	2.49 ^b	26.1 ^b	1.22 ^b	16.9 ^b	2.49 ^b	27.2 ^b	1.30 ^b	18.0 ^b	2.52 ^b	25.6 ^b	FF1	1.60 ^a	21.4 ^a	2.78 ^a	26.2 ^b	1.66 ^a	21.9 ^a	2.87 ^a	26.7 ^b	1.62 ^a	20.8 ^a	2.88 ^a	25.3 ^b
	FF2	1.58 ^a	21.0 ^a	2.83 ^a	29.5 ^a	1.61 ^a	22.9 ^a	2.75 ^a	29.2 ^a	1.60 ^a	20.8 ^a	2.88 ^a	29.6 ^a	FF3	1.29 ^b	18.4 ^b	2.52 ^b	29.0 ^a	1.23 ^b	17.1 ^b	2.52 ^b	29.6 ^a	1.24 ^b	18.0 ^b	2.41 ^b	28.5 ^a
	HG A	1.41	19.2	2.70	28.1	1.45	19.7	2.72	29.0	1.43	19.1	2.69	26.8	HG B	1.42	19.7	2.62	27.8	1.42	19.8	2.62	28.5	1.47	19.6	2.70	27.8
(B) Experimental sites	HG C	1.44	19.6	2.66	27.2	1.43	19.6	2.63	27.0	1.43	19.5	2.63	27.1	F (A)	***	***	***	***	***	***	***	***	***	***	***	***
F (B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	F (A × B)	*	*	*	*	*	*	*	*	*	*	*	*
F (A × B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns													

Different lowercase letters indicate significant differences at $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***), ns, not significant; FF1: 29.7 P2O5, 5.0 K2O, 6.7 MgO (% w/w); FF2: 29.7 P2O5, 5.0 K2O, 4.5 MgO, 6.0 Zn (% w/w); FF3: 35 Zn (% w/w).

TABLE 3: Concentrations of P, K, Mg, and Zn in whole fruits (dry weight).

Factor		2019				2020				2021			
		P	K mg 100g ⁻¹	Mg 100g ⁻¹	Zn	P	K mg 100g ⁻¹	Mg 100g ⁻¹	Zn	P	K mg 100g ⁻¹	Mg 100g ⁻¹	Zn
(A) Foliar fertilizers	Control	27.3 ^b	167 ^b	5.13 ^b	0.22	27.3 ^b	149 ^b	5.31 ^b	0.19	27.5 ^b	154 ^b	5.37 ^b	0.20
	FF1	30.9 ^a	197 ^a	5.60 ^a	0.22	30.5 ^a	197 ^a	5.73 ^a	0.19	30.4 ^a	228 ^a	5.71 ^a	0.20
	FF2	30.8 ^a	200 ^a	5.44 ^a	0.21	31.3 ^a	205 ^a	5.79 ^a	0.21	30.9 ^a	210 ^a	5.74 ^a	0.22
	FF3	27.6 ^b	165 ^b	5.29 ^b	0.19	27.5 ^b	159 ^b	5.31 ^b	0.22	28.0 ^b	156 ^b	5.35 ^b	0.22
(B) Experimental sites	HG A	28.9	185	5.37	0.21	29.0	174	5.53	0.20	29.3	187	5.59	0.21
	HG B	29.5	178	5.38	0.20	29.6	177	5.55	0.20	29.1	187	5.50	0.21
	HG C	29.0	185	5.36	0.21	28.9	181	5.54	0.21	29.3	186	5.55	0.21
F (A)	*	***	**	ns	**	***	**	ns	**	***	***	ns	
F (B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
F (A × B)	ns	*	**	ns	ns	ns	ns	ns	*	*	***	ns	

Different lowercase letters indicate significant differences at $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***); ns, not significant; FF1: 29.7 P₂O₅, 5.0 K₂O, 1.6 MgO (% w/w); FF2: 29.7 P₂O₅, 5.0 K₂O, 4.5 MgO, 6.0 Zn (% w/w); FF3: 35 Zn (% w/w).

0.1 N. Phenolphthalein was the indicator substance. The TSS of the juice was estimated using an automatic digital refractometer (ATAGO, PAL-1, Japan). The filtered juice was placed on a clean prism, and the results were expressed as °Brix.

2.4. Statistical Analysis. The SPSS software (version 16.0) was used for all data analyses in the study. The data obtained from the field and laboratory were analyzed via one-way analysis of variance (ANOVA). Statistical significance was assessed using Duncan's *post hoc* test at $p < 0.05$. Pearson's correlation was used to determine the relationships between variants.

3. Results

3.1. Effects of Foliar Fertilization on Nutrient Uptake. In 2019, the spraying of solutions FF1 and FF2 significantly increased the concentrations of P, K, and Mg in the leaves compared with the spraying of the control and FF3 solutions (Table 2). Foliar feeding with only Zn (FF3) significantly increased the concentration of Zn. In 2020, the leaf P concentration was about 0.4 g kg⁻¹ greater with FF1 and FF2 than with other treatments, ranging from 1.61 to 1.66 g kg⁻¹. Similarly, the leaf K concentration was significantly higher with FF1 and FF2 by 15%. The leaf Mg concentration with the control and FF3 was lower than with FF1 and FF2. Foliar Zn application did not affect the concentrations of P, K, and Mg in leaves but increased the concentration of Zn. In 2021, the leaf P, K, and Mg concentrations were increased by the application of FF1 and FF2. Foliar application of solution FF3 containing Zn improved their concentrations in leaves. No difference in the P, K, and Mg concentrations was observed between FF3 and the control; the concentrations of P, K, and Mg were approximately 1.24, 18.0, and 2.41 g kg⁻¹, respectively (Table 2). Among the three study sites in 2019, 2020, and 2021, the concentrations of leaf mineral nutrients were not different. To sum up, foliar application of P, K, Mg, and Zn was more effective in increasing the concentrations of leaf mineral nutrients in the 3 years of experiment. The effectiveness of foliar fertilization in three sites was the same.

The use of FF1 and FF2 solutions induced significant differences in the nutrient concentrations of "5 Roi" in the 3 years of trial (Table 3). The application of the FF1 and FF2 solutions significantly increased the fruit P, K, and Mg concentrations compared with the application of FF3 and control. There was no difference between foliar fertilizer treatments and control in terms of the fruit Zn concentration. The mineral nutrients (P, K, Mg, and Zn) in fruits were not different between three sites. The nutrient (P, K, and Mg) concentrations of fruits with FF1 and FF2 were higher than with other treatments in the three consecutive years of research.

3.2. Influence of Foliar Fertilization on Fruit Yield and Quality. The content of TSS was high with the FF1 and FF2 treatments and low with control and FF3 in the 3 years of experiment (Table 4). There was no difference in the TSS between FF1 and FF2. The acidity of the juice was significantly decreased by foliar fertilization, except for FF3. Compared with the FF1 and FF2 treatments, the acidity of the juice was high with the control and FF3. Similar to TSS, the productivity of pomelo was greatly enhanced by the application of FF1 and FF2 foliar fertilizers. The pomelo yield was higher with the FF1 and FF2 treatments by about 15% than with the control. Meanwhile, the spraying of solution FF3 did not improve fruit yield compared with the spraying of the control.

3.3. Relationship between Fruit Quality, Yield, and Leaf Nutrients. The correlation analysis of leaf nutritional parameters (Figure 2) revealed a positive correlation between P and K ($r = 0.69$), P and Mg ($r = 0.84$), P and TSS ($r = 0.72$), and P and yield ($r = 0.54$) and a strong negative correlation between P and acidity ($r = -0.73$). The leaf K concentration was negatively correlated with acidity ($r = -0.57$) and positively correlated with the leaf Mg concentration, TSS, and yield ($r = 0.50$, $r = 0.52$, and $r = 0.46$, respectively). Similar to P and K, the leaf Mg concentration was positively correlated with TSS ($r = 0.63$) and yield ($r = 0.44$) and negatively related with the acidity of the juice ($r = -0.60$). There was no

TABLE 4: Influence of treatments on the pomelo yield and fruit quality.

Factor		2019			2020			2021		
		TSS (°Brix)	Acidity (%)	Fruit yield (t ha ⁻¹)	TSS (°Brix)	Acidity (%)	Fruit yield (t ha ⁻¹)	TSS (°Brix)	Acidity (%)	Fruit yield (t ha ⁻¹)
(A) Foliar fertilizers	Control	8.44 ^b	0.83 ^b	23.5 ^b	8.50 ^b	0.88 ^b	26.8 ^b	8.42 ^b	0.85 ^b	29.0 ^b
	FF1	10.7 ^a	0.55 ^a	28.3 ^a	10.2 ^a	0.61 ^a	30.8 ^a	10.8 ^a	0.65 ^a	32.5 ^a
	FF2	11.1 ^a	0.57 ^a	27.7 ^a	10.2 ^a	0.63 ^a	30.5 ^a	10.7 ^a	0.66 ^a	33.0 ^a
	FF3	8.67 ^b	0.81 ^b	23.2 ^b	8.66 ^b	0.81 ^b	27.5 ^b	8.79 ^b	0.83 ^b	28.5 ^b
(B) Experimental sites	HG A	9.62	0.71	25.2	9.38	0.76	29.0	9.78	0.75	30.7
	HG B	9.84	0.68	25.6	9.43	0.72	28.8	9.68	0.77	30.8
	HG C	9.70	0.69	26.2	9.38	0.73	28.9	9.56	0.73	30.7
F (A)		***	***	***	***	***	***	***	***	***
F (B)		ns	ns	ns	ns	ns	ns	ns	ns	ns
F (A × B)		ns	*	***	*	ns	*	ns	ns	*

Different lowercase letters indicate significant differences at $P < 0.05$ (*), $P < 0.01$ (**), and $P < 0.001$ (***); ns, not significant; FF1: 29.7 P2O5, 5.0 K2O, 6.7 MgO (% w/w); FF2: 29.7 P2O5, 5.0 K2O, 4.5 MgO, 6.0 Zn (% w/w); FF3: 35 Zn (% w/w).

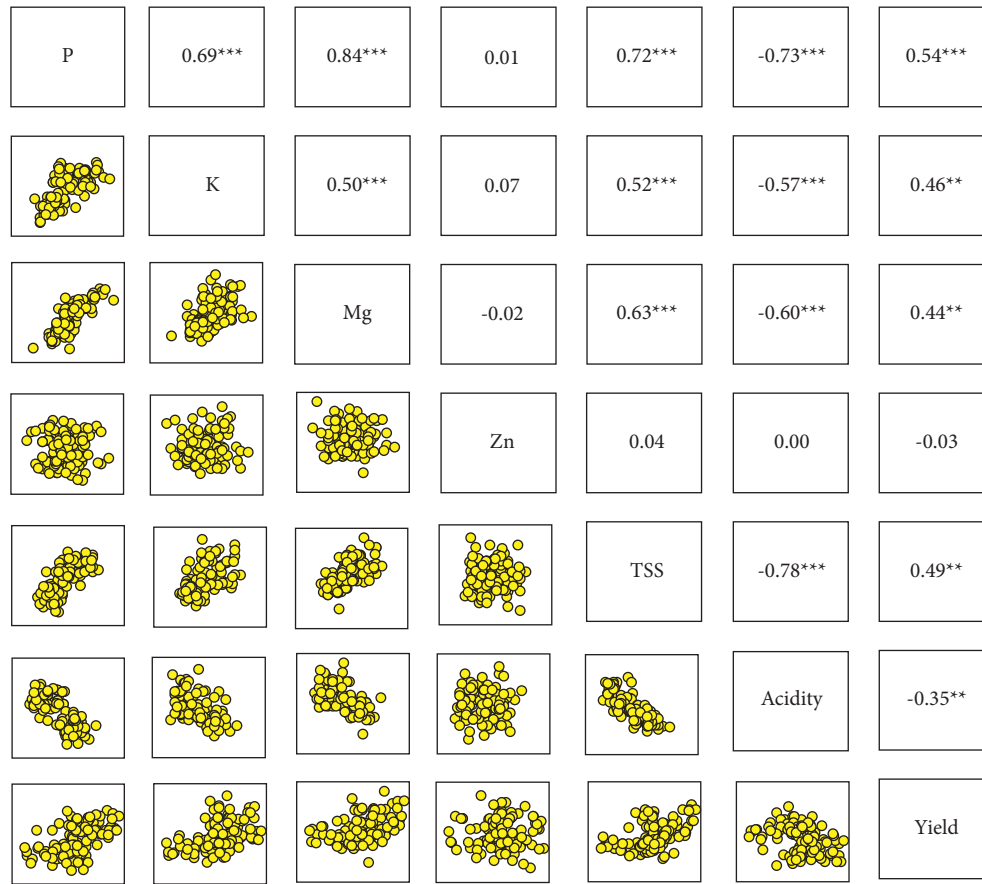


FIGURE 2: Correlation coefficient matrix of the leaf mineral nutrients, fruit quality, and yield.

different correlation between leaf Zn and other mineral nutrients. The content of TSS was negatively correlated with acidity ($r = -0.78$) and positively correlated with yield ($r = 0.49$). The acidity of the fruit was negatively correlated with yield ($r = -0.35$).

3.4. Correlation between Fruit Quality, Yield, and Fruit Nutrients. The result in Figure 3 indicates that the fruit Zn concentration was not significantly related to other

elements. There was a positive correlation between P and K ($r = 0.51$), P and Mg ($r = 0.55$), P and TSS ($r = 0.46$), and P and yield ($r = 0.30$), whereas the concentration of fruit P was negatively correlated with fruit acidity ($r = -0.47$). Likewise, the concentration of K in fruit was positively correlated with Mg, TSS, and yield ($r = 0.59$, $r = 0.61$, and $r = 0.47$, respectively) and negatively correlated with the acidity of the juice ($r = -0.61$). The concentration of Mg in fruit was positively correlated with TSS ($r = 0.53$) and yield ($r = 0.48$) and negatively correlated with acidity ($r = -0.45$). The

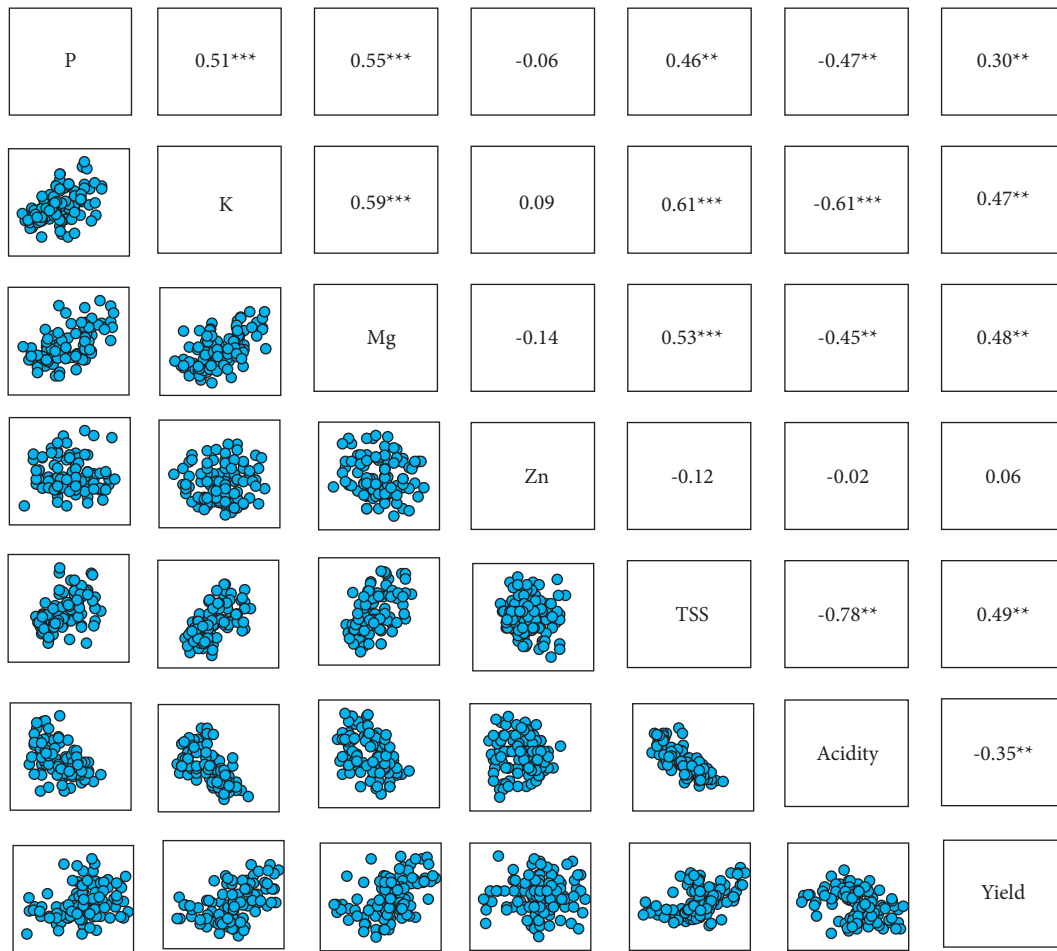


FIGURE 3: Correlation coefficient matrix of fruit nutrients, fruit yield, and fruit quality.

relationship between fruit quality and yield is the same as the result presented in Section 3.3.

3.5. Relationship between Leaf and Fruit Nutrients. Positive correlations were observed between fruit P and leaf P ($y = 6.7x + 19.4$; $r = 0.49$) and leaf K ($y = 0.45x + 20$; $r = 0.45$) and leaf Mg ($y = 4.24x + 17.8$; $r = 0.34$) (Figure 4(a)). The correlation between fruit K and leaf K or leaf Mg was positive, and the equations expressing the relationship are as follows: $y = 101x + 36$ ($r = 0.69$), $y = 5.12x + 81$ ($r = 0.47$), and $y = 78x - 26$ ($r = 0.59$), respectively (Figure 4(b)). The correlation coefficient values (r) were 0.53 between fruit Mg and leaf P, 0.35 between fruit Mg and leaf K, and 0.44 between fruit Mg and leaf Mg (Figure 4(c)). There was no correlation between the concentrations of Zn in fruit and other mineral nutrients in leaf (Figure 4(d)). Similarly, the concentration of Zn in leaves was not correlated with fruit P, K, and Mg concentrations.

4. Discussion

In this study, the application of foliar fertilizer containing P, K, and Mg (FF1) or P, K, Mg, and Zn (FF2) improved the

concentrations of P, K, and Mg in leaves; enhanced the concentrations of P, K, and Mg in fruits; increased TSS; reduced the acidity of the juice; and increased productivity.

P is a key element that directly affects fruit yield and quality [33]. The P concentration in plants affects not only crop growth and yield but also root growth and the uptake of other mineral nutrients [33]. In this research, the P concentration in leaves had a positive correlation with the leaf K and Mg concentrations (Figure 2). The leaf P concentration significantly increased after the application of foliar fertilizers, which ranged from 1.58 to 1.66 g kg^{-1} DW (Table 2). According to Li et al. [34], the optimum content of P in pomelo leaves ranged from 1.4 to 1.8 g kg^{-1} DW. Hence, the leaf P concentration with the control and FF3 treatments was found to be deficient (Table 2). In this study, the fruit P concentration was improved by the application of foliar P fertilizer, and a positive correlation was observed between P and other nutrients (K and Mg) in fruit. The results were not in agreement with that of Vinas et al. [35] that the foliar application of P did not increase fruit P concentration. In this study, P provided via foliar fertilization increased the TSS and fruit yield but decreased the acidity of the juice (Table 4). Sucrose is a key factor that affects the TSS concentration [36]. Sucrose synthesis was controlled by sucrose

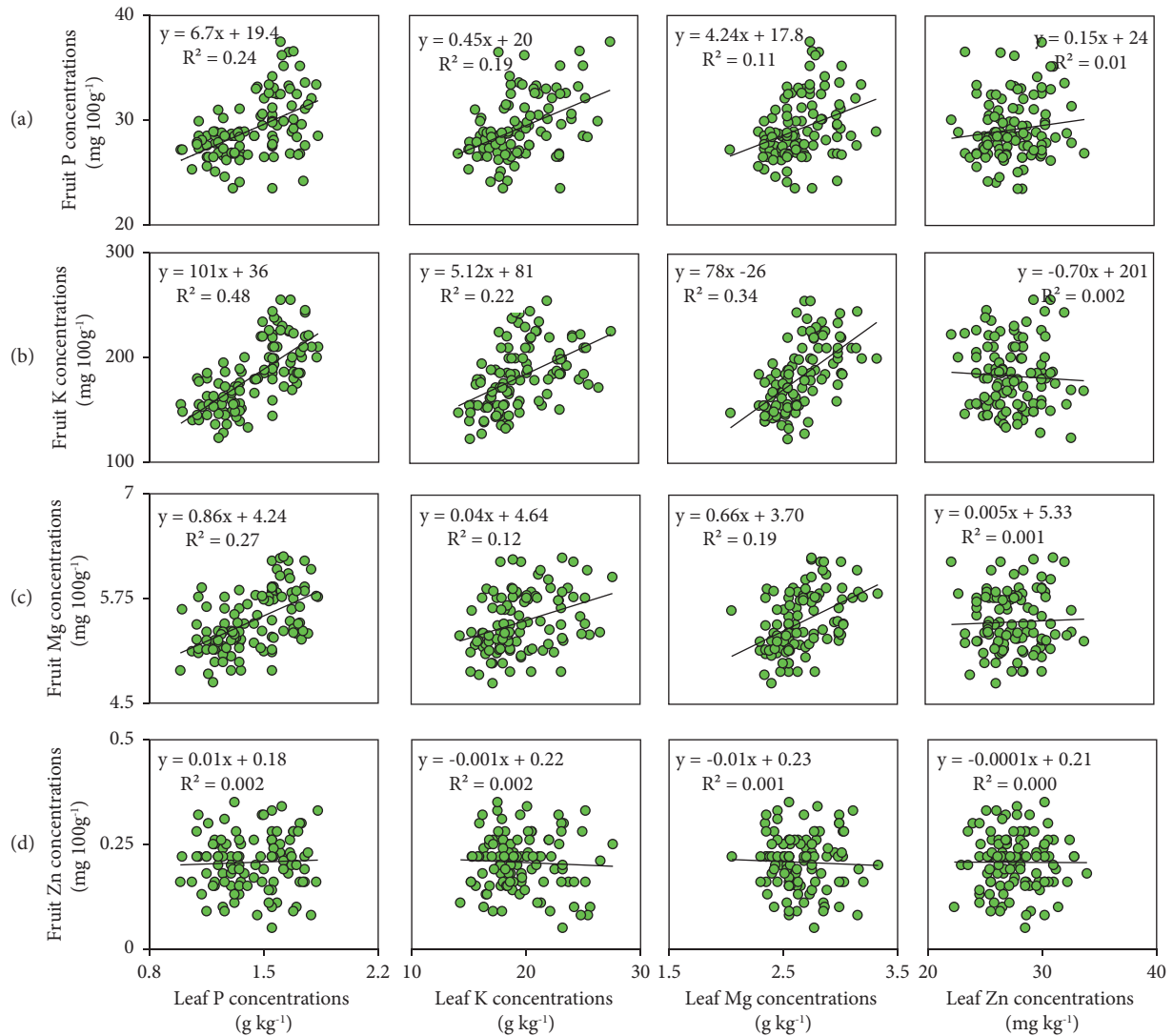


FIGURE 4: Linear correlation coefficient of pairs between fruit and leaf nutrients.

phosphate synthase enzymes. The activity of these enzymes could be affected by P, which enhances the synthesis of sucrose, resulting in an increase in the TSS content [37]. Citric acid is a key substance that influences the concentration of fruit acidity [38]. The acidity of the juice was decreased by the application of P as it affected the enzyme activities that correlated with citric acid synthesis [37]. Previous studies have demonstrated that productivity was increased by the application of foliar P fertilization [39,40]. The P uptake of plants from soil can be limited by soil pH and root activity, whereas the application of P via foliar fertilization is less affected by soil physicochemical properties [9]. The application of P can contribute to the enhancement of photosynthesis, which leads to an increase in carbohydrate concentrations in flower and fruits, resulting in the decrease in pomelo fruit drops [41]. This increases the number of fruits per tree and improves fruit yield.

K is a key nutrient that plays a role in the photosynthetic and metabolic processes in plants and a key role in the taste and flavor of fruits [19]. We found that the content of K in leaves and fruits significantly increased after the spraying of foliar K (Tables 2 and 3). This finding agrees with the result that the spraying of foliar K increased the accumulation of K in leaves [42] and in fruits [43,44]. Similar to foliar P fertilizer, spraying of foliar K enhanced TSS, decreased the juice acidity, and improved fruit yield (Table 4). The application of K increased the enzyme activities of sugar metabolism in fruits [45] and stimulated the transport of nutrients and sugar [46], leading to increased TSS content. According to El-Rahman et al. [47], K applied via foliar fertilization decreased the acid content. K can affect the plants' metabolism and biochemical reactions in sugar production, decreasing the citric and malate acid contents [48]. Meanwhile, both substances mainly influence the acidity of citrus fruit [49].

Previous study concluded that fruit yield was increased by foliar K fertilization [42,47]. K contributes to flower stimulation and flower initiation, resulting in an increased vigorous flowering and enhanced fruit set. So, it has also a potential to improve productivity [48].

Mg is known as a factor that determines fruit quality as it affects photosynthesis, the antioxidant system, and carbohydrate content [50]. In this research, the concentrations of Mg in leaves and fruits were significantly increased by foliar Mg spraying (Tables 2 and 3). Hanafy et al. [51] also concluded that the application of Mg via foliar fertilization increased the concentration of Mg in the leaves and fruits of navel orange compared with the application of control. Foliar Mg fertilizers significantly increased the TSS content and fruit yield and reduced the acidity of the juice in comparison with no use of Mg treatments (Table 4). These findings are not in agreement with the results of Ram and Bose [52], who reported that foliar fertilization with Mg was not effective in increasing the TSS and TA contents of mandarin orange. The increase in the content of TSS by Mg spraying could be due to the increasing enzyme activities, which synthesize sucrose and glucose [23]. Similar to K, Mg has a vital function in flower formation and fruit set. Furthermore, it is closely related with carbohydrate synthesis and transportation in plant tissues [50].

Zn is an important nutrient in crops, and the deficiency of this nutrient may lead to a decline in flowering and fruit set as well as yield losses [53]. According to Kurešová et al. [54], the addition of Zn significantly increased the Zn concentrations both in leaves and fruits. However, the content of Zn in leaves and fruits was not enhanced by foliar spraying of Zn in this study (Table 2 and 3). The content of TSS was not increased by the application of Zn via foliar fertilization compared with the control (Table 4). Our results are not in agreement with that of Ferdosi and Farooq [55] that foliar spraying of Zn increased the TSS content of fruits. In our study, the acidity of the juice was not affected by foliar Zn application. This finding is not in agreement with that of Ahmad et al. [56] that Zn significantly affected fruit acidity. The yield of pomelo did not increase after foliar spraying of Zn, a finding that is in agreement with that of Morgan et al. [57].

The study demonstrated that the leaf P, K, and Mg concentrations were positively correlated with TSS content and yield but negatively correlated with acidity (Figure 2), which agrees with the results of Li et al. [58] who reported that there was a positive correlation between the leaf nutrients (P, K, and Mg) and TSS content of citrus fruits or yield. Similarly, we found that most of the nutrients in citrus fruits were negatively correlated with the acidity of fruits and positively correlated with the TSS content and fruit yield (Figure 3). In this study, we realized that the concentrations of P, K, and Mg in leaves increased the contents of these nutrients in fruits (Figure 4), which enhanced fruit quality and productivity (Figure 3). Similar results have also been reported by Zhang et al. [59] and Xu et al. [60]. In conclusion, spraying of P, K, and Mg is a beneficial way for improving mineral nutrient status and enhancing fruit yield and quality in the pomelo orchard.

In summary, the use of foliar fertilizers (FF1 and FF2) was beneficial to enhance the concentrations of P, K, and Mg in both leaves and fruits compared with the control treatment (Tables 2 and 3). In addition, we found that the application of FF1 and FF2 improved fruit quality and pomelo yield significantly compared with the conventional soil fertilization (Table 4). From the results of this study, we recommend the use of FF1 and FF2 for citrus orchard in the VMD.

5. Conclusions

The application of foliar fertilizers (P, K, and Mg or P, K, Mg, and Zn) increased plant nutrition, resulting in improved fruit quality and productivity of pomelo cultivated in the alluvial soils. The use of foliar fertilization enhanced the concentrations of P, K, and Mg in fruits, which have a strong correlation with fruit quality, leading to enhanced fruit quality. Furthermore, these elements in both leaves and fruits had a positive correlation with fruit yield, thus enhancing pomelo productivity. The strategy of using foliar feeding plays a crucial role in the improvement of the quality of pomelo fruits, increasing the efficiency of fertilizer use and reducing soil chemical contamination.

Data Availability

All data supporting the conclusions of this study are included in this article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

L. V. D. and N. N. H. conceptualized and designed the experiment; L. V. D. and N. P. N. conducted the experiments and collected samples; L. V. D. and N. P. N. performed sample analysis; L. V. D. and N. N. H. analyzed the data and wrote the original draft; L. V. D., N. P. N., and N. N. H. reviewed, edited, and approved the final manuscript. All authors have read and agreed to the published version of the manuscript.

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