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Relationship Between Leaf Nutrient Concentrations with Fruit Yield and Quality of Pummelo (*Citrus maxima* Merr.) in Nghe An Province, Vietnam

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Abstract

Pummelo is a high-value cash crop in Vietnam, where optimizing cultivation practices requires a profound understanding of the correlations between leaf nutrient concentrations and fruit quality. This study investigated the correlations between leaf nutrient levels and the yield and quality of the 'Quang Tien pink' pummelo cultivar. The research was conducted in 2024 across 25 pummelo orchards in Nghe An Province. Leaf samples were analyzed for concentrations of N, P, K, Ca, Mg, Zn, Mn, Cu, and Fe. Fruit characteristics evaluated included fruit weight, circumference, peel thickness, edible portion, juice volume, juice pH, total soluble solids (TSS), titratable acidity (TA), and the TSS/TA ratio. The findings demonstrated that foliar N, P, and K concentrations were significantly and positively correlated with fruit circumference, fruit weight, juice volume, TSS, juice pH, and TA. In contrast, P and K levels were negatively correlated with peel thickness (r = -0.639, -0.906, respectively). Leaf Ca concentration was positively correlated with peel thickness (r = 0.537) but negatively associated with fruit weight (r = -0.406) and TSS (r = -0.404). Additionally, Zn, Cu, Fe, and Mn concentrations showed significant positive correlations with TSS (r = 0.723, 0.660, 0.443, and 0.570, respectively), while Zn and Cu were negatively correlated with peel thickness (r = -0.539, -0.456, respectively). These results establish a robust scientific baseline for precision nutrient management strategies to maximize the yield and fruit quality of pummelo.

Keywords: correlation analysis; fruit quality parameters; orchard nutrient management

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INTRODUCTION

Pummelo (*Citrus maxima* Burm. Merr.) is one of the major fruit crops in Vietnam, with a cultivation area of approximately 89,416 ha and an annual production exceeding 1.2 million tons (FAO, 2024). Among its cultivars, the 'Quang Tien pink' pummelo is widely grown in Nghe An province. It is highly favored by consumers for its plump, juicy segments with a pink hue, crisp texture, and sweet taste. The average fruit weighs from 1.5 to 2.0 kg, and each tree typically yields 100 to 200 fruits, resulting in an estimated total annual yield of 250 to 300 kg per tree (Minh, 2017). Unlike other pummelo varieties, this cultivar is notable for its lack of bitterness or astringency.

Plant nutrition is a determining factor in the growth, yield, and fruit quality of citrus species. Citrus trees exhibit high demand for essential nutrients, particularly during critical phenological stages such as flowering, fruit formation, and fruit development. Macronutrients–especially N, P, and K–are crucial; however, both their excesses and deficiencies can adversely affect fruit yield and quality (Chen et al., 2022). Furthermore,

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Ca and Mg are secondary macronutrients that play crucial roles in the structural stability of cell membranes and photosynthetic efficiency. Deficiencies in these elements often lead to premature fruit drop and significantly reduce post-harvest shelf life. In particular, Mg deficiency has been shown to stunt plant growth and disrupt the Mg and Ca balance in orange trees (Guo et al., 2023).

Furthermore, trace element deficiencies can lead to nutritional imbalances, resulting in reduced fruit set, poor fruit quality, and lower vitamin C content (Khatun et al., 2024). Beyond soil nutrient availability, foliar nutrient content is increasingly recognized as a key indicator influencing both yield and fruit quality due to its important roles in plant metabolic processes. Leaves are the primary sites of metabolic processes, and maintaining optimal nutrient concentrations in leaves is essential for achieving high fruit yield and quality (Reddy et al., 2019). Recent studies have demonstrated that leaf nutrient analysis enables precise identification of excesses or deficiencies of various essential elements in fruit trees (Qurat et al., 2024).

Establishing correlation between leaf nutrient concentrations and fruit outcomes is vital. Because leaf nutrient content reflects real-time nutritional status more effectively than soil analysis, it enables growers to optimize fruit quality (Li et al., 2017). Thamrin et al. (2014) found that the 3rd to 4th leaves of pummelo provide the most reliable assessment of N, P, and K status, showing stronger correlations with early fruit development compared to the 5th to 6th leaves. Similar relationships between leaf nutrient content and productivity have been documented in other fruit crops, such as pear (Dar et al., 2015). The concentrations of N, P, K, Ca, Mg, and Zn in leaves had significant positive correlation with mandarin fruit yield (Rymbai et al., 2024). Specifically, in pummelo, research indicates that the edible portion ratio was negatively correlated with leaf N concentration; total soluble solids (TSS) and titratable acidity (TA) were negatively and positively correlated with leaf Ca, respectively, and TA showed a positive correlation with leaf Cu (Li et al., 2015).

Although considerable research has examined the effect of soil nutrient concentration on fruit yield and quality of pummelo, limited information is available regarding the relationship between leaf nutrient concentrations–covering macronutrients, secondary nutrients, and micronutrients–and fruit yield and quality. This study aimed to investigate the relationships between leaf nutrient status and fruit yield and quality traits of the ‘Quang Tien pink’ pummelo cultivar, identify key nutrients influencing fruit development, and inform optimized nutrient management practices.

MATERIALS AND METHOD

Research locations

This study was conducted across 25 orchards belonging to the cooperative that cultivated ‘Quang Tien pink’ pummelo. The pummelo orchards were located in Thai Hoa and Nghia Dan districts (105°18’ to 105°35’ E, 19°13’ to 19°33’ N) of Nghe An province, Vietnam. The selected trees were of uniform age, ranging from 7 to 12 years. The pummelo trees were grafted onto sour pummelo rootstock and planted at a spacing of 5 m × 6 m. Orchard management practices were consistently applied throughout the study, including irrigation, pruning, weed control, and pest management. Environmental conditions, including mean temperature, rainfall, and humidity in 2024 are presented in Figure 1.

Soil sampling and analysis methods

Soil samples from each orchard were collected and homogenized into 25 representative composite samples. Each composite soil sample (1,000 g) was obtained at a depth of 0 to 20 cm beneath the outer canopy using a soil sampling tube. Soil samples were air-dried, sieved through a 2-mm mesh, and stored in sealed plastic bags. Soil pH was determined in a 1:2.5 soil-to-water suspension using a pH meter (model Total Meter PHS-550). Available P was extracted using Bray II solution (0.03 M NH_4F in 0.10 M HCl), followed by analysis via the molybdenum blue method. Extraction of exchangeable K, Ca, and Mg was performed with 1 M NH_4OAc at pH 7.0. Potassium was determined using a flame photometer, while Ca and Mg concentrations were analyzed using an atomic absorption spectrophotometer (AAS) (model Perkin Elmer Analyst 200). The extraction of Zn, Mn, Cu, and Fe was carried out using diethylenetriaminepentaacetic acid (DTPA) solution, and subsequently quantified by AAS (Jones, 2001; 2003).

Leaf sampling and analysis methods

A composite leaf sample was collected from the same trees used for soil sampling between August and September 2024. A total of 25 composite leaf samples were collected from 25

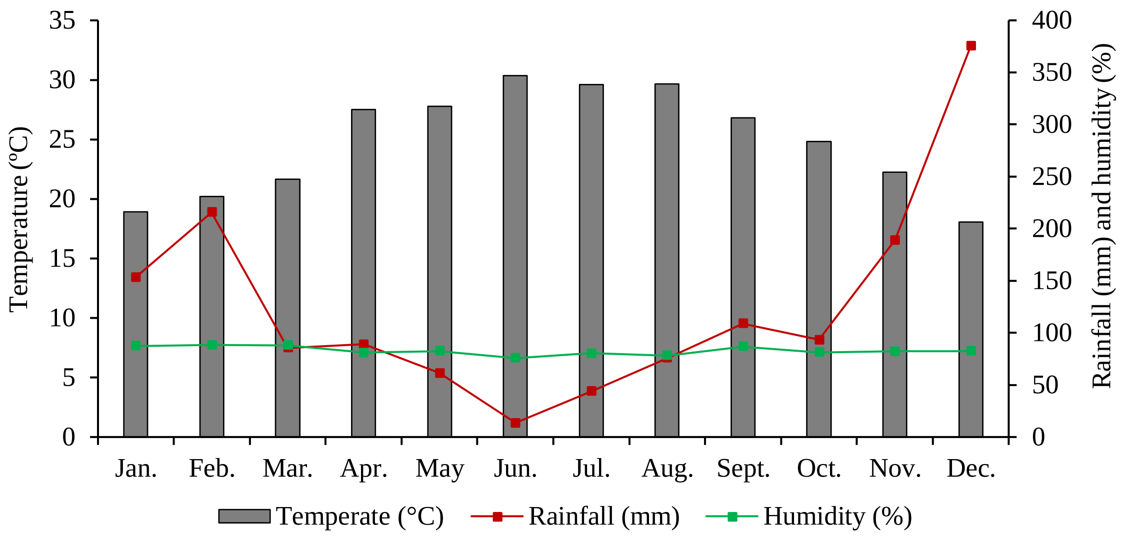

Figure 1. Average temperature, rainfall, and humidity in 2024

pummelo orchards. Each composite sample consisted of 150 fully expanded, non-fruiting leaves (30 leaves from each of 5 trees), aged 3 to 5 months, and harvested from the 3rd or 4th node of recently flushed twigs from all 4 canopy directions.

The leaf samples were washed with deionized water, then oven-dried at 65 °C until a constant weight. The dried tissues were ground into a fine powder. Total N was determined using the Kjeldahl method. For the analysis of P, K, Ca, Mg, Zn, Mn, Cu, and Fe, the samples were digested with 2:1 HNO_3:$HClO_4$ mixture. Potassium was analyzed using a flame photometer, while P was measured via the vanadomolybdate method, and the remaining elements were analyzed using an AAS (SPAC, 2000).

Fruit sampling and analysis methods

Pummelo fruits were harvested at physiological maturity (August to September 2024) from the same representative trees used for soil and leaf sampling. Five medium-sized, fully mature fruits (1 fruit per tree) were harvested from each orchard, resulting in a total of 125 fruits collected from 25 orchards. Fruit samples were weighed using a digital balance (±0.01 g accuracy). Morphological parameters were then calculated as follows: the average fruit weight was calculated as the total fruit weight divided by the number of fruits. The edible portion percentage was determined by the ratio of the pulp (segment) weight to the total fruit weight, multiplied by 100.

The fruit circumference was measured at its widest point (the equatorial region) using a measuring tape. Peel thickness was measured at 4 equidistant points around the equator of each fruit using the same caliper. The average of the 4 readings per fruit was used for analysis. For internal quality assessment, each sampled fruit was manually juiced with a stainless-steel juicer, and the juice-to-fruit ratio was calculated using the juice volume and fruit weight. TSS was measured by applying several drops of freshly extracted juice on the prism of a digital refractometer (ATAGO PAL-1, Japan) and recording the results at 20 °C.

TA, expressed as a percentage of citric acid, was determined following the procedure by Boland (1995). A 10 ml aliquot of filtered juice was diluted with 50 ml of distilled water and titrated against 0.1 N NaOH using phenolphthalein as an indicator. The endpoint was determined by the appearance of a persistent pink color. TA was calculated and expressed as % citric acid using Equation 1.

$$\text{TA (\% citric acid)} = \frac{\text{Volume of NaOH} \times \text{Normality} \times 0.064}{\text{Volume of juice}} \times 100 \quad (1)$$

Where 0.064 is the milliequivalent weight of citric acid. The TSS/TA ratio was calculated from TSS divided by TA.

Data analysis

Prior to analysis, the data were tested for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test. Descriptive statistics, including the range, mean, and standard deviation, were then calculated using Microsoft Excel 2016 for soil composite (n = 25), leaf composite (n = 25), and fruit (n = 125; 5 fruits per orchard) samples. Subsequently, analysis of variance (ANOVA) and Pearson correlation analyses were performed using SPSS version 26.0 to evaluate the relationships between leaf nutrient content and fruit yield and quality parameters. Statistical significance was determined at $p < 0.05$ and $p < 0.01$ (significant at 5% and 1% level, respectively).

RESULTS AND DISCUSSION

Soil properties

The chemical characteristics of the topsoil in the sampled pummelo orchards are summarized in Table 1. The results reveal considerable variation in soil pH and essential nutrients. The soil pH_{H2O} was categorized as acidic, ranging from 4.80 to 6.43, with an average of 5.71. Available P was higher than the recommendation for pummelo, ranging from 77.62 to 181.09 mg kg^{-1}, with an average of 117.26 mg kg^{-1}. Exchangeable K varied from 92.31 to 176.05 mg kg^{-1}, averaging 123.10 mg kg^{-1}. Exchangeable Ca and Mg varied from 602.90 to 869.00 and 140.60 to 199.30 mg kg^{-1}, averaging 728.38 and 167.31 mg kg^{-1}, respectively.

Extractable Zn and Cu ranged from 1.35 to 3.35 and 2.69 to 5.87 mg kg^{-1}, averaging 2.43 and 4.27 mg kg^{-1}, respectively. Extractable Fe and Mn varied from 30.52 to 65.51 and 17.46 to 36.98 mg kg^{-1}, averaging 45.79 and 26.25 mg kg^{-1}, respectively. The pH_{H2O}, exchangeable K, Mg, and Zn were all within the optimal ranges for pummelo, with recommended ranges of 5.50 to 6.50, 100.00 to 150.00 mg kg^{-1}, 120.00 to 240.00 mg kg^{-1}, and 1.10 to 3.00 mg kg^{-1}, respectively (Hien et al., 2016).

Conversely, available P and extractable Cu, Fe, and Mn were found to exceed the optimal thresholds established for pummelo (Li et al., 2015). The excessive levels of available P are particularly concerning. Physiologically, high soil P can induce nutrient antagonism, specifically inhibiting the uptake of Zn and Fe (Xie et al., 2019). Notably, exchangeable Ca was lower than the optimal range for pummelo (Hien et al., 2016). Deficiency of Ca can lead to poor root development and increased susceptibility to physiological disorders, such as fruit cracking or albedo breakdown, due to the compromised structural integrity of the fruit peel (Shi et al., 2024). The results indicate that although the orchards maintain appropriate pH and concentrations of K, Mg, and Zn for pummelo cultivation, a significant nutritional imbalance persists. High levels of P and micronutrients (Cu, Fe, and Mn) pose a risk of nutrient toxicity and may interfere with the uptake of other essential elements. Furthermore, exchangeable Ca remains the primary limiting factor in these soils, as levels fall below the required threshold for pummelo trees.

Nutrient concentration in pummelo leaves

Leaf nutrient content analysis was conducted to evaluate the nutritional status of pummelo trees (Table 2). The concentrations of N, P, and K in pummelo leaves ranged from 2.51 to 3.01, 1.31 to 1.92, and 13.97 to 23.47 g kg^{-1}, respectively, with mean values of 2.75, 1.71, and 19.23 g kg^{-1}. Furthermore, Ca and Mg concentrations in the foliage of the ‘Quang Tien pink’ cultivar ranged from 26.46 to 41.90 and 3.65 to 5.31 g kg^{-1}, with respective mean values of 32.06 and 4.65 g kg^{-1}.

Micronutrient concentrations in the leaf were also documented: Zn ranged from 11.36 to 19.60 mg kg^{-1}, Cu from 6.55 to 10.41 mg kg^{-1}, Fe from 50.02 to 85.25 mg kg^{-1}, and Mn from 15.02 to 37.55 mg kg^{-1}, with mean values of 16.98, 7.44, 64.83, and 27.96 mg kg^{-1}, respectively. According to the nutrient sufficiency ranges proposed by Zhuang et al. (1991)–N: 25.00 to 31.00 g kg^{-1}, P: 1.40 to 1.80 g kg^{-1}, K: 14.00 to 22.00 g kg^{-1}, Ca: 20.00 to 38.00 g kg^{-1}, Mg: 3.20 to 4.70 g kg^{-1}, Fe: 60.00 to 140.00 mg kg^{-1}, Mn: 15.00 to 140.00

Table 1. Topsoil chemical properties (0 to 20 cm) in pummelo orchards

Nutrient	Unit	Range	Mean*	SD
pH_{H2O}		4.80-6.43	5.71	0.35
Available P	mg kg^{-1}	77.62-181.09	117.26	57.44
Exchangeable K	mg kg^{-1}	92.31-176.05	123.10	26.06
Exchangeable Ca	mg kg^{-1}	602.90-869.00	728.38	102.11
Exchangeable Mg	mg kg^{-1}	140.60-199.30	167.31	17.47
Extractable Zn	mg kg^{-1}	1.35-3.35	2.43	0.60
Extractable Cu	mg kg^{-1}	2.69-5.87	4.27	1.20
Extractable Fe	mg kg^{-1}	30.52-65.51	45.79	10.34
Extractable Mn	mg kg^{-1}	17.46-36.98	26.25	12.05

Note: *Mean of 25 composite samples, SD = Standard deviation mg kg^{-1}, Cu: 8.00 to 17.00 mg kg^{-1}, and Zn: 24.00 to 44.00 mg kg^{-1}–all measured nutrient levels in this study were within the optimal range, except for Zn.

In related study, Hien et al. (2016) reported optimal leaf concentrations for N, K, Ca, Mg, and Zn as 26.20 to 28.50, 17.90 to 22.10, 25.40 to 42.00, 4.30 to 5.20 g kg^{-1}, and 14.20 to 53.50 mg kg^{-1}, respectively. Furthermore, Quyen et al. (2024) reported that the leaf nutrient contents of N, P, K, Ca, and Mg in high-yielding ‘Nam Roi’ pummelo orchards in Hau Giang and Vinh Long provinces, Vietnam, were 27.80, 1.63, 20.80, 20.40, and 19.60 g kg^{-1}, respectively. Consequently, the N, P, K, Ca, and Mg contents in that study fall within the optimal range for citrus trees.

Pummelo fruit yield and quality

The yield and quality parameters of ‘Quang Tien pink’ pummelo are summarized in Table 3. Fruit weight exhibited a range of 1,001.37 to 1,581.83 g, with a mean of 1,266.94 g. Fruit circumference and peel thickness ranged from 45.30 to 53.20 cm and 1.44 to 2.11 cm, with respective mean values of 49.21 cm and 1.76 cm. The edible portion varied from 53.80 to 63.17%, and juice volume ranged from 342.22 to 414.53 ml kg^{-1}, with corresponding mean values of 58.52% and 375.14 ml kg^{-1}. Regarding chemical quality, the TSS and TA ranged from 9.10 to 11.08% and 0.50 to 0.58%, respectively, with mean values of 10.03% and 0.55%. Juice pH ranged from 3.82 to 4.23 (mean 4.02), and the TSS/TA ratio ranged from 17.68 to 19.64 (mean 18.37). These results are consistent with Tuyết et al. (2017), who reported fruit weight of ‘Quang Tien pink’ cultivar ranged from 1.22 to 1.31 kg, and TA ranged from 0.51 to 0.54%. Furthermore, the study by Nguyen et al. (2022) on the quality of premium pummelo varieties in Vietnam such as ‘Da Xanh’, ‘Nam Roi’, ‘Long Co Co’, and ‘Thanh Kieu’ reported TSS contents of 11.88±0.26, 10.62±0.53, 10.23±0.53, and 10.43±1.02, respectively. Consequently, the TSS content of the ‘Quang Tien pink’ pummelo is comparable to that of the pummelo varieties currently cultivated in Vietnam.

Relationships between leaf nutrient contents and pummelo fruit yield and quality

This study investigated the relationships between the concentration of essential mineral nutrients in pummelo leaves and various fruit yield and quality parameters (Table 4 and Figure 2). The concentration of N in leaves exhibited significant positive correlations with fruit weight (r = 0.507), edible portion (r = 0.810), fruit

Table 2. Leaf nutrient concentrations in the pummelo ‘Quang Tien pink’ cultivar

Nutrient	Unit	Range	Mean*	SD
N	g kg^{-1}	2.51-3.01	2.75	0.14
P	g kg^{-1}	1.31-1.92	1.71	0.13
K	g kg^{-1}	13.97-23.47	19.23	2.74
Ca	g kg^{-1}	26.46-41.90	32.06	3.91
Mg	g kg^{-1}	3.65-5.31	4.65	0.34
Zn	mg kg^{-1}	11.36-19.60	16.98	1.70
Cu	mg kg^{-1}	6.55-10.41	7.44	0.71
Fe	mg kg^{-1}	50.02-85.25	64.83	6.99
Mn	mg kg^{-1}	15.02-37.55	27.96	4.88

Note: *Mean of 25 composite samples, SD = Standard deviation

Table 3. Pummelo fruit yield and quality

Parameter	Unit	Range	Mean*	SD
Fruit weight	g	1,001.37-1,581.83	1,266.94	152.26
Circumference	cm	45.30-53.20	49.21	2.39
Peel thickness	cm	1.44-2.11	1.76	0.18
Edible portion	%	53.80-63.17	58.52	2.81
Juice volume	ml kg^{-1}	342.22-414.53	375.14	20.07
TSS	%	9.10-11.08	10.03	0.46
Juice pH		3.82-4.23	4.02	0.11
TA	%	0.50-0.58	0.55	0.02
TSS/TA		17.68-19.64	18.37	0.53

Note:*Mean of 25 samples, SD = Standard deviation

Table 4. Correlation coefficients between leaf nutrient content and pummelo fruit yield and quality

Nutrient	Circumference	Fruit weight	Peel thickness	Edible portion	Juice volume	TSS	Juice pH	TA	TSS/TA
N	0.856**	0.507**	-0.377	0.810**	0.906**	0.432*	0.464*	0.496*	-0.088
P	0.565**	0.421*	-0.639**	0.344	0.514**	0.673**	0.668**	0.600**	0.131
K	0.424*	0.490*	-0.906**	0.343	0.483*	0.896**	0.927**	0.851**	0.094
Ca	-0.288	-0.406*	0.537**	-0.390	-0.363	-0.404*	-0.373	-0.312	-0.152
Mg	0.341	0.121	0.025	0.053	0.301	0.089	0.227	0.223	-0.203
Zn	0.336	0.283	-0.593**	0.349	0.400*	0.723**	0.720**	0.696**	0.064
Cu	0.410*	0.337	-0.456*	0.154	0.286	0.660**	0.493*	0.465*	0.307
Fe	0.319	0.480*	-0.320	0.102	0.218	0.443*	0.360	0.391	0.083
Mn	0.479*	0.474*	-0.387	0.357	0.456*	0.570**	0.537**	0.547**	0.040

Note: $^{*}p < 0.05$, $^{**}p < 0.01$ (significant at 5% and 1% level, respectively)

circumference (*r* = 0.856), juice volume (*r* = 0.906), TSS (*r* = 0.432), juice pH (*r* = 0.464), and TA (*r* = 0.496). These correlations may be attributed to the role of N as a fundamental component of chlorophyll, which promotes cell division and elongation, leaf expansion, bud initiation, flowering, fruit set, and the synthesis of sugars and amino acids, thereby influencing fruit flavor (Liao et al., 2019). These findings are consistent with previous reports by Dar et al. (2015), Singh et al. (2022), and Qurat et al. (2024).

Leaf P concentration showed a significant positive correlation with fruit circumference (*r* = 0.565), weight (*r* = 0.421), juice volume (*r* = 0.514), TSS (*r* = 0.673), juice pH (*r* = 0.668), and TA (*r* = 0.600). This association may be attributed to critical functions of P in energy transfer, cellular structure, and metabolic processes (López-Arredondo et al., 2014). Similar correlations were reported by Singh et al. (2022) and Qurat et al. (2024). Notably, P concentration was negatively correlated with peel thickness (*r* = -0.639).

Leaf K content also demonstrated significant positive correlations with circumference (*r* = 0.424), fruit weight (*r* = 0.490), juice volume (*r* = 0.483), TSS (*r* = 0.896), juice pH (*r* = 0.927), TA (*r* = 0.851), and a significant negative correlation with peel thickness (*r* = -0.906). This association may be attributed to the role of K in activating more than 60 enzymes and being essential for sugar and starch formation, protein synthesis, normal cell division and development, neutralization of organic acids, and regulation of carbon dioxide supply through stomatal control, which improves sugar utilization efficiency (Shah, 2024). These observations are consistent with prior studies by Dar et al. (2015), Singh et al. (2022), and Qurat et al. (2024). Increased peel thickness in the absence of K fertilization has been noted by Fernandez and Guzman (2013) and Hien et al. (2016).

Leaf Ca content exhibited a significant positive correlation with peel thickness (*r* = 0.537), likely reflecting its structural role in cell membrane composition as calcium pectate, supporting cell division and membrane integrity (Jaime-Guerrero et al., 2024). This finding aligns with observations by Dar et al. (2015). However, Ca content was negatively correlated with both fruit weight (*r* = -0.406) and TSS (*r* = -0.404), a trend also noted by Li et al. (2015). This inverse relationship may be attributed to the antagonistic effect of Ca on K uptake, which in turn influences

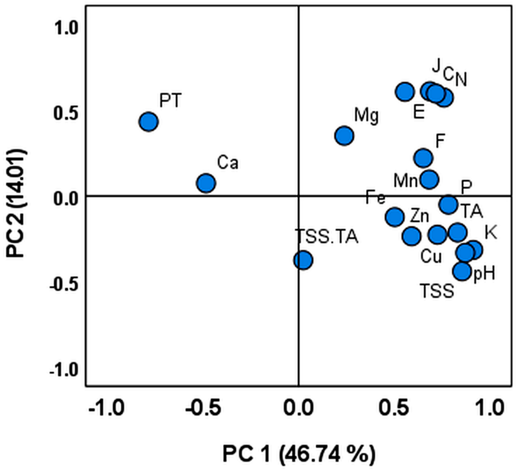

Figure 2. Principal component analysis of leaf nutrient content in relation to pummelo fruit yield and quality

Note: F = Fruit weight; C = Fruit circumference; PT = Peel thickness; E = Edible portion; J = Juice volume; pH = Juice pH; TSS.TA = TSS/TA ratio

fruit weight and TSS (Hien et al., 2017). Leaf Mg content showed no significant correlations with any fruit yield or quality parameters in this study, supporting the finding of Singh et al. (2022). However, Li et al. (2015) reported a positive correlation between Mg and the edible rate of pummelo fruit.

Leaf Zn content exhibited positive correlations with juice volume (*r* = 0.400), TSS (*r* = 0.723), juice pH (*r* = 0.720), and TA (*r* = 0.696). Zn is essential for chlorophyll production, carbohydrate metabolism, starch formation, flowering and fruit set; deficiencies often lead to poor flowering and fruit development (Tahir et al., 2020). These correlations were also reported by Dar et al. (2015) and Singh et al. (2022). Hien et al. (2016) noted that low leaf Zn content affected the TSS and TSS/TA ratio of pummelo fruit. Moreover, zinc and boron foliar application have been shown to increase juice content and TSS in orange fruit (Sajid et al., 2012). Conversely, a significant negative correlation was observed between Zn and peel thickness (*r* = -0.593).

Leaf Cu levels showed a significant positive correlation with fruit circumference (*r* = 0.410), TSS (*r* = 0.660), juice pH (*r* = 0.493), and TA (*r* = 0.465). This is because Cu is an important component of several oxidase enzymes such as cytochrome oxidase, ascorbic acid oxidase, and lactase, and plays a critical role in photosynthesis and metabolism (Yruela, 2009). Similarly, leaf Fe content showed significant positive correlations with fruit weight (*r* = 0.480) and TSS (*r* = 0.443), reflecting the role of Fe in DNA synthesis, respiration, and photosynthesis (Rout and Sahoo, 2015). Leaf Mn levels showed a significant positive correlation with circumference (*r* = 0.479), fruit weight (*r* = 0.474), juice volume (*r* = 0.456), TSS (*r* = 0.570), juice pH (*r* = 0.537), and TA (*r* = 0.547). This is because Mn supports chlorophyll formation, serves as a cofactor for several respiratory enzymes and metabolic pathways, it is also a critical structural component of various metalloproteins (Mousavi et al., 2011). Similar positive correlations with Cu, Fe, and Mn have been reported in pear by Dar et al. (2015).

In summary, N, P, K, Ca, Zn, Cu, Fe, and Mn contents in leaves were positively associated with the majority of fruit yield and quality attributes, including circumference, weight, edible portion, juice volume, TSS, juice pH, and TA. In contrast, K, P, Zn, and Cu were negatively correlated with peel thickness.

CONCLUSIONS

The levels of N, P, K, and most micronutrients in leaves are critical factors determining the quality and yield of pummelo. While N, P, and K are fundamental to increasing fruit weight and TSS content, higher concentrations of K, P, Zn, and Cu contribute to thinner peels and superior quality. In contrast, leaf Ca content increases peel thickness but reduces fruit size and sugar levels. These results emphasize the necessity of targeted nutrient management, particularly for K and Zn, to maximize the commercial value of the ‘Quang Tien pink’ pummelo cultivar. Future studies should focus on determining the appropriate thresholds for foliar K and Zn applications to optimize the balance between juice quality and peel thickness in the 'Quang Tien pink' pummelo cultivar. Furthermore, long-term field trials are required to develop fertilization strategies that mitigate the antagonistic effects of Ca on fruit weight and sugar accumulation while maintaining structural resistance to physiological disorders.

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REFERENCES

Boland, W., Hopke, J., Donath, J., Nüske, J., & Bublitz, F. (1995). Jasmonic acid and coronatin induce odor production in plants. *Angewandte Chemie International Edition in English*, *34*(15), 1600–1602. https://doi.org/10.1002/anie.199516001

Chen, Y., Li, F., Wu, Y., Zhou, T., Chang, Y., Lian, X., ... & Lu, X. (2022). Profiles of citrus orchard nutrition and fruit quality in Hunan Province, China. *International Journal of Fruit Science*, *22*(1), 779–793. https://doi.org/10.1080/15538362.2022.2129548

Dar, M. A., Wani, J. A., Raina, S. K., Bhat, M. Y., & Malik, M. A. (2015). Relationship of leaf nutrient content with fruit yield and quality of pear. *Journal of Environmental Biology*, *36*(3), 649–653. Retrieved from https://jeb.co.in/journal_issues/201505_may15/paper_21.pdf

FAO. (2024). *Crops and livestock products*. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Fernandez, A., & Guzman, C. D. (2013). Quality and nutrition of pummelo as influenced by potassium. *Journal of Environmental Science and Engineering*, *2*, 97–105. Retrieved from https://www.davidpublisher.com/Public/uploads/Contribute/5518fc160f42b.pdf

Guo, J., Jiao, Y., Wang, Y., Hu, W., Jia, Y., Huang, Z., … & Chen, L. S. (2023). Regulation of magnesium and calcium homeostasis in citrus seedlings under varying magnesium supply. *Plant Physiology and Biochemistry*, *204*, 108146. https://doi.org/10.1016/j.plaphy.2023.108146

Hien, H. N., Maneepong, S., & Suraninpong, P. (2017). Effects of potassium, calcium, and magnesium ratios in soil on their uptake and fruit quality of pummelo. *Journal of Agricultural Science*, *9*(12), 110–121. https://doi.org/10.5539/jas.v9n12p110

Hien, H. N., Somsak, M., & Potjamarn, S. (2016). Nutrient uptake and fruit quality of pummelo as influenced by ammonium, potassium, magnesium, zinc application. *Journal of Agricultural Science*, *8*(1), 100–109. http://dx.doi.org/10.5539/jas.v8n1p100

Jaime-Guerrero, M., Álvarez-Herrera, J. G., & Flscher, G. (2024). Effect of calcium on fruit quality: A review. *Agronomía Colombiana*, *42*(1), 1–14. https://doi.org/10.15446/agron.colomb.v42n1.112026

Jones, J. B. (2001). *Laboratory guide for conducting soil tests and plant analysis*. Washington: CRC Press. https://doi.org/10.1201/9781420025293

Jones, J. B. (2003). *Agronomic handbook: Management of crops, soils and their fertility*. New York: CRC Press. https://doi.org/10.1201/9781420041507

Khatun, A., Mukherjee, S., Bullah, M., & Bhattacharya, P. (2024). Effects of micronutrients on crop quality. *International Journal of Research in Agronomy*, *7*, 107–114. https://doi.org/10.33545/2618060X.2024.v7.i4b.537

Li, R., Chang, Y., Hu, T., Jiang, X., Liang, G., Lu, Z., … & Guo, Q. (2017). Effects of different fertilization treatments on soil, leaf nutrient and fruit quality of *Citrus grandis* var. *longanyou*. *World Journal of Engineering and Technology*, *5*, 1–14. https://doi.org/10.4236/wjet.2017.52B001

Li, Y., Han, M. Q., Lin, F., Ten, Y., Lin, J., Zhu, D. H., … & Chen, L. S. (2015). Soil chemical properties, 'Guanximiyou' pummelo leaf mineral nutrient status and fruit quality in the southern region of Fujian Province, China. *Journal of Soil Science and Plant Nutrition*, *15*(3), 615–628. http://doi.org/10.4067/S0718-95162015005000029.

Liao, L., Dong, T., Qiu, X., Rong, Y., Wang, Z., & Zhu, J. (2019). Nitrogen nutrition is a key modulator of the sugar and organic acid content in citrus fruit. *PLoS ONE*, *14*(10), e0223356. https://doi.org/10.1371/journal.pone.0223356

López-Arredondo, D. L., Leyva-González, M. A., González-Morales, S. I., López-Bucio, J., & Herrera-Estrella, L. (2014). Phosphate nutrition: Improving low-phosphate tolerance in crops. *Annual Review of Plant Biology*, *65*(1), 95–123. https://doi.org/10.1146/annurev-arplant-050213-035949

Minh T. (2017). *Quang Tien pink pummelo are a cash crop [Bưởi hồng Quang Tiến "hái ra tiền"]*. Nghe An News. Retrieved from https://baonghean.vn/buoi-hong-quang-tien-hai-ra-tien-10143958.html

Mousavi, S. R., Shahsavari, M., & Rezaei, M. (2011). A general overview on manganese (Mn) importance for crops production. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1799–1803. Retrieved from https://ajbasweb.com/old/ajbas/2011/September-2011/1799-1803.pdf

Nguyen, N. H. K., Tran, M. T., Le, T. D., Nguyen, M. V., & Tran, T. T. (2022). Chemical properties and biological properties of four varieties of pomelo (*Citrus grandis* (L) Osbeck) in the Mekong Delta of Vietnam. *Food Research*, *6*(4), 267–272. https://doi.org/10.26656/fr.2017.6(4).479

Qurat, S., Bisati, I., Rather, G. H., Bhat, M. I., Bhat, S. A., & Murtaza, I. (2024). Relationship of leaf nutrient concentrations on fruit yield and quality of apple. *International Journal of Advanced Biochemistry Research*, *8*(7), 437–441. https://doi.org/10.33545/26174693.2024.v8.i7Sf.1528

Quyen, N. K., Dang, L. V., Ngoc, N. P., Phuong Thao, P. T., & Hung, N. N. (2024). Determination of nutritional sufficiency ranges for pomelo (*Citrus grandis* Osbeck) grown on alluvial soils using DRIS. *PLoS ONE*, *19*(10), e0312231. https://doi.org/10.1371/journal.pone.0312231

Reddy, A. R., Munaswamy, V., Reddy, P. V. M., Reddy, B. R., & Sudhakar, P. (2019). Leaf nutrient status Vis-à-vis fruit yield and quality of sweet orange (*Citrus sinensis* (L.) Osbeck). *International Journal of Plant & Soil Science*, *31*(3), 1–8. https://doi.org/10.9734/IJPSS/2019/v31i330212

Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolim. *Reviews in Agricultural Science*, *3*, 1–24. https://doi.org/10.7831/ras.3.1

Rymbai, H., Deshmukh, N. A., Ramesh, T., Verma, V. K., Baiswar, P., Mawlein, J., ... & Mishra, V. K. (2024). DRIS standards for identifying yield-limiting nutrients in Khasi Mandarin and their relationship with fruit yield on acidic soil of the eastern Himalayas, India. *Journal of Plant Nutrition*, *47*(8), 1331–1346. https://doi.org/10.1080/01904167.2024.2308193

Sajid, M., Rab, A., Jan, I., Haq, I., Shah, S. T., Iqbal, A., … & Shakur, M. (2012). Pre-harvest treatment of Zn & B affects the fruit quality and storability of sweet orange. *Journal of Agricultural Science and Technology*, *2*, 1224–1233. Retrieved from https://www.davidpublisher.com/Public/uploads/Contribute/55d3f60f1ea3c.pdf

Shah, I. H., Jinhui, W., Li, X., Hameed, M. K., Manzoor, M. A., Li, P., … & Chang, L. (2024). Exploring the role of nitrogen and potassium in photosynthesis implications for sugar: Accumulation and translocation in horticultural crops. *Scientia Horticulturae*, *327*, 112832. https://doi.org/10.1016/j.scienta.2023.112832

Shi, G., Zhou, X., Tong, C., & Zhang, D. (2024). The physiological and molecular mechanisms of fruit cracking alleviation by exogenous calcium and GA3 in the Lane Late navel orange. *Horticulturae* *10*(12), 1283. https://doi.org/10.3390/horticulturae10121283

Singh, N. P., Singh, J., Singh, S., & Gill, P. S. (2022). Soil-leaf nutrient relationships with fruit quality and yield of litchi (*Litchi chinensis*) in northern India. *Indian Journal of Agricultural Sciences*, *92*(12), 1453–1457. https://doi.org/10.56093/ijas.v92i12.124134

SPAC. (2000). *Soil analysis handbook of reference methods (1st ed.)*. Soil and Plant Analysis Council. CRC Press. https://doi.org/10.1201/9780203739433

Tahir, R., Adnan, M., Bilal, H. M., Saeed, M. S., Tampubolon, K., Rehman, F. U., & Prince. (2020). Impact of foliar application of Zn on growth yield and quality production of citrus: A review. *Indian Journal of Pure & Applied Biosciences*, *8*(6), 529–534. http://doi.org/10.18782/2582-2845.8496

Thamrin, M., Susanto, S., Susila, A., & Suta, D. A. (2014). Correlation between nitrogen, phosphorus and potassium leaf nutrient with fruit production of pummelo citrus (*Citrus* *maxima*). *Asian Journal of Applied Sciences*, *7*(3), 129–139. http://doi.org/10.3923/ajaps.2014.129.139

Tuyết, V. T., Sâm, P. T., Trâm, N. T., & Trường, L. V. (2017). Ảnh hưởng của phân bón qua lá và GA3 Thiên Nông đến chất lượng quả của giống bưởi hồng Quang Tiến. *Journal of Vietnam Agricultural Science and Technology*, *11*(84), 41–46. Retrieved from https://tapchi.vaas.vn/vi/tap-chi/anh-huong-cua-phan-bon-qua-la-va-ga3-thien-nong-den-chat-luong-qua-cua-giong-buoi-hong

Xie, X., Hu, W., Fan, X., Chen, H., & Tang, M. (2019). Interactions between phosphorus, zinc, and iron homeostasis in nonmycorrhizal and mycorrhizal plants. *Frontiers in Plant Science*, *10*, 1172. https://doi.org/10.3389/fpls.2019.01172

Yruela, I. (2009). Copper in plants: Acquisition, transport and interactions. *Functional Plant Biology*, *36*(5), 409–430. https://doi.org/10.1071/FP08288

Zhuang, Y., Renji, W., Lixuan, C., Zhian, X., Wenbao, X., Yuzong, H., & Zhenlong, Z. (1991). Optimum range of mineral element contents in the leaves of Guanxi honey pomelo (*Citrus grandis*). *Journal of Fujian Academy of Agricultural Sciences*, *6*(2), 52–58. Retrieved from http://fjnyxb.xml-journal.net/en/article/1991/2