Factors affecting citrus fruit quality: Emphasis on mineral nutrition

Fatores que afetam a qualidade das frutas dos citros: Ênfase na nutrição mineral

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Abstract
There are some reviews, available in the literature that considers mineral elements effects on fruit quality. However, most studies refer to temperate fruits, such as apple, or to some tropical fruits, such as mango, guava, banana, pineapple and passion fruit. In the case of citrus fruits, it is necessary to compile the information that has been generated recently. The objective of this review was to present and comment some information about the influence of mineral elements on citrus fruit characteristics. It emphasized that potassium has been the most evaluated macronutrient, whereas calcium and magnesium were the least. Potassium was the element with the largest influence on fruit characteristics, followed by nitrogen and phosphorus. The most consistent result related to potassium was the positive effect on fruit fresh mass. Zinc was the most evaluated micronutrient, followed by boron, which was the most influential micronutrient on quality, especially due to its positive effect on fruit fresh mass and juice percentage. Lack of information regarding mineral nutrition effect on citrus fruit quality was confirmed and was more evident for macronutrients.

Additional keywords: Citrus; fruit production, nutrients.

Resumo
Alguns revisões que considerem os efeitos dos elementos minerais na qualidade de frutas estão disponíveis na literatura; no entanto, a maioria faz referência às frutíferas de clima temperado, como a maçã ou algumas tropicais como manga, goiaba, banana, abacaxi e maracujá. No caso das frutas cítricas ou citros, pode-se argumentar que é necessário recopilar as informações que têm sido geradas recentemente. O objetivo desta revisão foi apresentar e comentar algumas informações sobre a influência de elementos minerais sobre as características da fruta, seguido do nitrogênio e do fósforo. O potássio tem sido o macronutriente mais avaliado, enquanto que o cálcio e o magnésio foram os menos pesquisados. O potássio foi o elemento com maior influência nas características da fruta, seguido do nitrogênio e do fósforo. O resultado mais consistente do potássio foi o efeito positivo sobre a massa fresca da fruta. O zinco foi o micronutriente mais avaliado nos experimentos, seguido do boro que foi o micronutriente mais influente na qualidade, especialmente pelo seu efeito positivo sobre a massa fresca e a porcentagem de suco das frutas. Foi confirmada a carência de informações referentes ao efeito da nutrição mineral sobre a qualidade das frutas dos citros, sendo mais evidente para os macronutrientes.

Palavras-chave adicionais: Citrus; fruticultura; nutrientes.

Citrus, or citrus fruits (CTF), belong to the Rutaceae family, Aurantioideae subfamily, which have oil glands, ovary is raised on a floral (nectary) disc and fruit whit an axilar placentation. Citrus fruit trees have hesperidium-type fruits, which are elongated ovaries covered by the rind and containing the juice vesicles (Davies & Albrigo, 1994).

According to Cabezas-Gutierrez & Rodríguez (2010), CTF production is determined by genetic, climatic and horticultural factors, which in interaction will result in yields with quantity and quality variability. The main factor that determines citrus flavor and organoleptic characteristics are the genes located in the chloroplasts, mitochondria and, mainly, in the nucleus, where the main genetic information for sugar, organic acid and carotenoid biosynthesis is contained (Bassene et al., 2008). In CTF, fruit quality is evaluated mainly by fresh size and mass, rind and juice percentage, soluble solids content (SS), titratable acidity (TA), SS/TA ratio and industrial yield, expressed in kg of sugar per 100 kg of processed fruit or SS per box (40.8 kg).

There are some reviews that consider mineral elements effect on fruit quality available in the literature. As examples, there is the study made by Fallahi et al. (2010) on apple; or the study conducted about some tropical fruits, such as banana, mango, guava and papaya, by Aular & Natale (2013); or the study conducted about passion fruit and pineapple by Aular et al. (2014). In the study on apple, it was shown how some mineral elements can affect fruit quality, what cannot be fully affirmed for tropical fruits.
for which further research is recommended. For CTF, reviews on mineral nutrition can be cited, such as that performed by Chapman (1968), which is quite old, in addition to that elaborated by Mattos Júnior et al. (2010). In both cases, information provides only an overview, lacking depth regarding fruit quality.

Association between mineral element concentrations in the soil, mineral contents in the leaves and citrus fruit physicochemical characteristics has been observed. Hammami et al. (2010) found that nitrogen and potassium leaf contents are determinant for “Clémentine” tangerine fruits production and quality. A similar result was obtained by Khan et al. (2011) in relation to ‘Kinnnow’ tangerine. Pestana et al. (2005) established correlations between ‘Valencia’ orange blossom mineral composition and fresh fruit mass and SS/TA ratio. In their research, it was determined that magnesium (Mg), calcium (Ca) and zinc (Zn) were associated with fresh mass estimation, whereas nitrogen (N), phosphorus (P), magnesium (Mg) and iron (Fe) were correlated with SS/TA ratio. Mattos Júnior et al. (2010) found that N was positively associated with the green color of ‘Tahiti’ lime and Ca was negatively correlated with water loss, whereas potassium (K) was positively correlated with water loss, meaning that the higher foliar K content, higher was the water loss and fruit wilting.

In horticultural studies, evaluation of fertilization effects on fruit quality is often relegated to the background. In addition, there are experiments with contrasting results. Thus, the objective of this review was to present and comment some information about the influence of mineral elements on CTF quality characteristics.

Factors affecting citrus fruits quality

Among factors that determine fruit quality (FQ) climate, harvest period, cultivar or rootstock, fruit thinning, hormones, irrigation and mineral nutrition can be highlighted.

Climate

Climate effect on citrus FQ is basically product of rainfall and accumulation of heat (AH) from flowering to harvest. Volpe et al. (2002) evaluated the effect of AH on ‘Valência’ and ‘Natal’ orange trees FQ and concluded that the highest AH were associated with the lowest TA, SS and SS/TA ratio values. In addition, Chelong & Sdoodee (2013), while evaluating FQ of ‘Shogun’ tangerine produced in Yala & Pattani, India, observed that higher mean temperatures, lower precipitation and low soil moisture where negatively affected to fruit development and quality.

Harvest period

Year and harvest period may affect CTF quality. Aular & Rodríguez (2007), while analyzing production year effect on ‘Valencia’ orange tree FQ in Nirgua, Venezuela, detected effect of this factor on juice percentage, TA and SS/TA ratio. In addition, it was also reported in their study that, as harvest advanced, juice percentage, SS and SS/TA ratio increase, while TA decreased. Similar results were obtained by Aular & Aular-Rodríguez (2007) while describing characteristics evolution of ‘Valencia’ orange fruit produced in Yumare, Yaracuy, Venezuela, during the industrial receiving period. Authors indicated that the juice had low TA, high SS/TA ratio, and that the best FQ corresponded to the fruits received in the months of April and May, which coincides with the beginning of the rainy season in that country.

Cultivar

Within each citrus group, there are specific fruit characteristics that can be expressed depending on other quality determinants. Roussos et al. (2013) characterized 22 cultivars of orange tree (Citrus sinensis L. Osbeck), tangerine (Citrus reticulata Blanco) and lemon (Citrus limon Burm. f.), and it was found that tangerine had the highest SS and carotenoid values, oranges had the highest total phenol content, and lemons had the highest TA and the lowest pH. In addition, these authors indicated that, among cultivars of each citrus group, there was FQ variation. Similar results were found by Domínguez et al. (2003), Cavalcante et al. (2006) and Tazima et al. (2009), while evaluating fruits of several orange tree cultivars.

Rootstock

Rootstock influences CTF quality and, in order to prove this, experiments have been carried out to evaluate different rootstocks and cultivars. In this sense, Castle (1995) indicated that rootstock action on FQ is based on its influence on precocity and yield, besides its control over the tree cycle and its phenology. Wagner et al. (2002), while studying “Valencia” orange tree FQ grafted on C. reshni Hort. Ex Tan., C. volkameriana Ten. & Pasq. and C. sinensis (L.) Osb. x Poncirus trifoliata (L.) Raf., found rootstock effect on fruit size, SS, TA, SS/TA ratio and juice volume. The highest SS were determined in the ‘Carrizo’ citrange (Citrus sinensis (L.) Osb. X Poncirus trifoliata (L.) Raf.), while the largest fruit sizes and juice volumes were determined in C. volkameriana Ten. & Pasq.

Stuchi et al. (2009), while determining the FQ of ‘Tahiti’ lime (Citrus latifolia Tanaka) grafted on 12 rootstocks, verified differences in fresh mass, juice percentage, rind thickness, SS and SS/TA ratio, and the best option, according to the authors, was the ‘Rangpur’ lime. Hifny et al. (2012) found that characteristics of ‘Washington Navel’ orange were different when it was grafted on bitter orange (Citrus aurantium L.) or ‘Volkamer’ lemon. According to the authors, SS, TA and vitamin C values were higher when the rootstock was bitter orange tree. Cantuarias-Aviles et al. (2010), when comparing ‘Okitsu’ tangerine fruits grafted on 12 rootstocks, found that ‘Flying Dragon’ induced higher TA and SS values, whereas ‘Cravo Limeira’ and ‘Cravo FCAV’ limes induced higher precocity and lower FQ.
Yildiz et al. (2013), while evaluating rootstock effect on ‘Valencia Late’ and ‘Rhode Red Valencia’ orange tree fruit quality in Dörtyol-Hatay, Turkey, obtained higher fresh fruit mass for ‘Valencia Late’ when it was grafted on ‘Carrizo’, and there were no fresh fruit mass differences for ‘Rhode Red Valencia’. On the other hand, according to the authors, there was no rootstock effect on juice percentage, number of seeds per fruit, TA and SS/TA ratio. Forner-Giner et al. (2011), while analyzing ‘Navalate’ orange tree FQ grafted on ‘Carrizo’ citrange, ‘Cleopatra’ tangerine, ‘Volkamer’ lemon, and C-13 (C. depressa Hay. x P. trifoliata) and 020326 [Troyer citrange (C. sinensis x P. trifoliata) x ‘Cleopatra’ tangerine] hybrids, observed that the largest fruit corresponded to the Volkamer lemon, the highest SS corresponded to the C-13 hybrid, and the smallest fruit size and lowest mass corresponded to Cleopatra.

**Fruit thinning and hormone application**

Among horticultural practices that affect CTF quality, fruit thinning and hormone application are also included. Ouma (2012) pointed out that thinning improves quality, as it provides better fruit size, shape, color and higher SS content. Fruit size can be improved by increasing carbohydrate availability from the source or by increasing sink capacity. When auxins are used during the physiological fall, carbohydrate availability is increased from the source. If auxins are applied during fruit linear growth stage, sink capacity is increased. Ripening can be accelerated through ethylene application, or retarded by gibberelllic acid application (Agusti et al., 2002). According to Galván-Luna et al. (2009), use of growth regulators (auxins, gibberellins and cytokinins) in citrus fruits can increase fruit set and, consequently, yield. Baghdady et al. (2014) verified positive effect of gibberelllic acid (GA₃) leaf application on juice percentage, SS and SS/TA ratio of ‘Valencia’ orange.

**Irrigation**

Irrigation can be considered one of the most significant horticultural practices in CTF quality. In this regard, Vélez et al. (2012) indicated that proper and homogeneous soil moisture can ensure good FQ. However, Alves Júnior et al. (2011), when considering different water supply levels, according to the potential evapotranspiration of ‘Tahiti’ lime produced in Piracicaba, São Paulo, Brazil, did not detect any irrigation effects on quality. In addition, Duenhas et al. (2005) did not observe fertilizer application effect via fertirrigation or conventional application in ‘Valencia’ orange FQ.

On the other hand, ineffective irrigation could be associated with water deficiency, which would have a negative influence on FQ. Thus, Kallsen et al. (2011), while studying water stress effect on “Beck-Earl” orange FQ in California, USA, determined water potential values between -1.4 MPa and -2.5 MPa during the cycle. The latter value was obtained in the harvest period and was considered a soil water deficit (WD) indicator. The authors noted that WD decreased fruit size and increased SS and TA. In addition, there was no WD effect on juice content and SS/TA ratio. Previously, García-Tejero et al. (2010) had evaluated regulated deficit irrigation (RDI) effect on “Salustiana” orange quality, and RDI effects on FQ were observed, increasing SS and TA.

**Mineral nutrition**

Inadequate mineral nutrition, whether due to deficiency or excess, may generate poor FQ. Therefore, it is necessary to achieve nutritional balance, in order to allow plants to grow vigorously and better tolerate biotic and abiotic stresses. Among the mineral elements that affect CTF quality, perhaps the most important ones, in descending order, are, as follows: nitrogen, potassium, phosphorus, magnesium, copper and boron (Zekri et al., 2012).

CTF require high mineral nutrient amounts in order to express their full growth, yield and FQ potential. In some cases, soil mineral concentrations are at sufficiency levels. However, it is necessary to apply acidity correctives for nutrients to become available and be used by the plant. Thus, Molina & Rojas (2005) evaluated liming effect on “Valencia” orange yield, FQ and soil fertility in northern Costa Rica. Three corrective materials were used: coarse-grained CaCO₃, fine-grained CaCO₃ and a physical mixture of 85% CaCO₃ and 15% magnesium oxide, each at doses of 1, 2 e 3 t ha⁻¹, in addition to the control, without liming. Limestone application significantly affected soil fertility, as increasing doses increased exchangeable Ca and reduced acidity and aluminum saturation in the soil. There was no limestone source effect on other soil variables, as well as on yield. However, the CaCO₃ + MgO mixture caused lower TA and higher SS values.

Plant mineral element requirements are specific and may vary according to soil type and its fertility. According to Papadakis et al. (2004), balance between minerals is very important. Thus, foliar content fluctuations of N, P, K, Ca, Mg, Fe, Mn and Zn were evaluated on “Encore” tangerine fruit quality, and the following antagonisms were verified: K–Mg, K–Ca, and K–Mn. Through the information mentioned, it can be inferred that excess K may delay Mg, Ca and Mn absorption, evidencing adverse effects on FQ. The relationship between FQ variables and foliar contents of a mineral element may vary depending on other element contents in the plant tissue. Thus, quality improvement through fertilization without considering all macro and micronutrients is unlikely (Torres et al. 2009b). In order to achieve the aim of this literature review, information was organized for macronutrients and then micronutrients.

**Macronutrients**

According to Zekri et al. (2012), among the main macronutrient effects on CTF quality, increased juice color intensity, SS and TA and increased rind thickness and color were observed for N; TA reduc-
tion and SS/TA ratio increase were observed for P; SS, SS/TA ratio and juice color decrease were observed for K; and slight SS, SS/TA ratio, fruit fresh mass and size increase, with rind thickness reduction were observed for Mg. However, these statements are not always valid, since CTF quality is the product of complex actions involving several factors, acting individually or together.

Regarding N, Aboutalebi (2013) evaluated the effect of this element in ammonium sulfate form (0, 250 and 500 g/plant⁻¹) and detected effect on fruit size, rind percentage, ascorbic acid content and TA for Citrus limetta, and observed that larger N amounts produced fruits with smaller size and lower TA. On the other hand, Almeida & Baumgartner (2002), while evaluating nitrogen fertilization at doses of 94; 188 and 376 kg ha⁻¹ N, detected SS and TA effect in "Valencia" orange fruits, although it was not possible to definitively establish N effect on the behavior of these variables.

For P, Obreza et al. (2008) indicated that, when P is applied excessively, it may cause P misuse and water pollution (eutrophication). Ashkevari et al. (2013), while evaluating phosphate fertilization (25, 50 and 75 g of triple superphosphate, plant⁻¹, 3 times per cycle) in drought conditions on grapefruit (Citrus paradisi Macf.) and orange (Citrus sinensis L. Osb.), determined 13 mg kg⁻¹ for grapefruit and 31 mg kg⁻¹ for orange as proper values. Authors also observed that P application increases could reduce TA and rind thickness, in addition to increasing SS/TA ratio.

According to Quaggio et al. (2011), in order to achieve good CTF quality, perhaps K may be the most important element, since fruit yield and quality are largely influenced by potassium fertilization. Aular et al. (2010) analyzed the relationship between soil and leaf K content and the characteristics of 'Valencia' orange fruit, and verified that soil K content was associated with rind and juice percentage. In addition, according to the authors, the highest leaf K values were related to fresh mass and juice percentage reduction, besides a higher rind and SS ratio. Hammami et al. (2010) obtained higher yield (43 t ha⁻¹ year⁻¹) and quality of 'Clementina' tangerine fruits with K application of 200 kg ha⁻¹ year⁻¹ under Mediterranean conditions.

The influence of K sources and doses on CFT quality has been considered. Almeida & Baumgartner (2002) evaluated potassium fertilization effect (38, 75 and 150 kg ha⁻¹ of K₂O as potassium chloride) on the FQ of 'Valencia' orange in Adolfo, São Paulo, Brazil and found K effect on TA and SS, although without defined trends. 'Clementine' tangerine is a popular fruit among consumers, although the cultivar tends to produce small or medium-sized fruits. Thus, Hamza et al. (2012) evaluated various K doses and sources (0, 5 and 8 % KNO₃, 2.5 and 4 % de K₂SO₄, applied 3 times) to verify their effect on fruit characteristics. It was concluded that foliar K application, regardless of the source used, increased fruit fresh mass, size, color, firmness and rind thickness. In addition, there was a slight increase in juice percentage, TA and SS associated to K application.

Opazo et al. (2001) evaluated the effect of different K sources (KCl, KNO₃, K₂SO₄ and K-MgSO₄) on "Valencia" orange FQ and determined that the critical K value in leaves in La Rosa, Chile was 7.0 kg ha⁻¹. In addition, regardless of the source used, there was no K effect on yield, although it increased juice percentage and TA. Quaggio et al. (2011) evaluated the effect of two K sources (K₂SO₄ and KCl) at doses of 0, 100, 200 and 300 kg ha⁻¹ K₂O per year on 'Pera' and 'Valencia' orange FQ and found that, with increasing K doses, there was a higher fresh fruit mass and SS decrease.

Plant nutritional status and soil fertility evaluation are very important to plan citrus fertilization, and it may vary if the production is destined for fruit market or industrial processing. There are few studies on NPK interaction effect on growth, yield and CTF quality. Quaggio et al. (2006) evaluated NPK fertilization effect, as well as its interactions on 'Valencia' and 'Pera' orange FQ, and found that Valencia cultivar size was positively affected when more than 225 kg ha⁻¹ K was applied. For both cultivars, SS yield per box of 40.8 kg fruit decreased when foliar K level increased, oscillating between 10 and 12 g kg⁻¹. On the other hand, in Pratânia, São Paulo, Brazil, Duenhas et al. (2002), while evaluating the effect of fertirrigation with different NPK doses on 'Valencia' orange FQ and production, did not verify the effect of different doses on fruit characteristics.

Individual effect of each macronutrient will depend on the concentration of the other elements. In this respect, Torres et al. (2009a) evaluated the relationship between macronutrients and 'Valencia' orange FQ considering the nutritional balance through individual and binary relations, obtaining only two significant individual correlations: K:SS and sulfur:SS/TA ratio. On the other hand, several binary relations were statistically correlated with quality variables. It was concluded that leaf K content was positively correlated with SS and rind percentage. TA decreased and SS/TA ratio increased when foliar P content increased compared to the other macronutrients. Juice percentage increased when foliar Ca content increased in relation to the other elements. In this case, binary relations better explained quality variables performance when compared to macronutrient individual concentrations.

A summary of the main results of several studies evaluating macronutrients influence on CTF quality is shown in Table 1. It was observed that K was the most studied mineral element (8 studies), while Ca and Mg were the least studied (2 studies). K was the element that most affected quality, followed by N and P. The most consistent K effect was the positive influence on fresh fruit mass and the least consistent was the effect on SS, for which there were positive and negative responses, responses without a definite trend, or without effect. With the exception of K, lack of information regarding macronutrient effects on CTF quality was evidenced.
Micronutrients

According to Malavolta et al. (2008), CTF quality may be affected by micronutrient deficiency. For example, when there is copper deficiency (Cu), fruit size is reduced. In the case of boron (B), there is juice vesicle drought. Due to its importance, micronutrient foliar application has been the traditional way of providing these mineral elements to plants. However, several of these micronutrients have low translocation (Quaggio et al., 2003), which may damage the effectiveness of this application type.

Generally, there is presumption of micronutrient deficiency in the soil. Therefore, these elements are considered in fertilization programs. Sometimes, this is not valid nor true, as was demonstrated in the study by Torres et al. (2010), who diagnosed the nutritional status of 'Valencia' orange trees in four locations (Aroa, Durute, Nirgua and Yumare) in Yaracuy, Venezuela. Authors indicated that, among the main nutritional limitations, there were low levels of zinc (Zn), Cu and, to a lesser extent, Mn. Excessive values of iron (Fe) were also detected, verifying that leaf tissue analysis sampling and interpretation are essential to adequately plan application of these elements.

In order to evaluate foliar fertilization with B and Zn in the ‘Pera’ orange, Quaggio et al. (2003) applied 0, 2, 4 e 6 kg ha⁻¹ of boric acid and zinc sulfate annually, observing that B application did not improve yield, while Zn was efficient. Regarding FQ, B positively affected fresh mass, while inconsistently affecting SS per 40.8 kg box. Rodriguez et al. (2005), in order to evaluate Zn influence on 'Valencia' orange fruit size in Corrientes, Argentina, concluded that Zn application (13.3 g plant⁻¹) increased the percentage of medium and large-sized fruits. Thus, foliar Zn content is correlated negatively with the small fruit percentage. Godoy et al. (2013) indicated that Zn and Mn limited CTF production. In addition, they also indicated that Zn and Mn foliar application efficiency will depend on the type of fertilizer used. These authors recommend the use of Zn oxide or sulfate, as well as Mn carbonate or sulfate.

Razzaq et al. (2013) evaluated the effect of foliar Zn application (0, 0.2, 0.6, 0.8 % Zn sulfate) on ‘Kinnow’ tangerine yield and FQ in Pakistan. Authors verified that there were higher fresh fruit mass and rind thickness. In addition, SS, TA and ascorbic acid were affected, with no clearly defined trend. Moreover, when the concentration of 0.6 % was used, larger diameter, fresh fruit mass, ascorbic acid and total phenols were obtained.

Fe deficiency in citrus fruits results in yield and FQ reduction, which is why it is a priority to develop methods for Fe deficiency diagnosis and correction, as it negatively affects the synthesis of compounds related to fruit flavor and post-harvest that can persist in the orchard for several years (Pestana et al., 2009). Abolutelebi (2013) evaluated the effect of foliar Fe application (0, 5 and 10 mg L⁻¹ of Fe as iron sulphate) on sweet lemon (Citrus limnetta) FQ and observed positive effects on skin percentage and ascorbic acid content, although no definite trend was found for juice TA.

Micronutrient application, in combination with other horticultural practices, such as hormone application, has also been evaluated. Ashraf et al. (2013) demonstrated that foliar application of 2,4-D auxin in combination with K and Zn in ‘Kinnow’ tangerine improved fruit retention and FQ, since a higher number of fruits and increased fresh fruit mass was obtained, as well as higher juice percentage, SS, ascorbic acid, TA and SS/TA ratio. In addition, Baghdady et al. (2014) found that, when foliar gibberellic acid (AG₃) was applied in ‘Valencia’ orange, combined with Zn and B chelates, there was fruit retention and FQ increase, besides higher fruit fresh mass and juice percentage. In relation to TA and SS, there was statistical effect, although with no definite trend.

Similar to what was investigated for macronutrients, Torres et al. (2009b) analyzed the correlations between foliar micronutrient levels and the FQ of ‘Valencia’ orange, considering the balance between nutrients through individual and binary relations. It was observed 37 binary relations, statistically correlated with quality variables. Authors stated that Mn content was positively correlated with SS and ATT, and negatively with SS/TA ratio. Mn increase in relation to other elements decreased fruit size. Elements B, Cu, Fe and Zn had indirect effects on fruit quality, increasing or decreasing the action of other micronutrients.

Table 2 shows the summary view of micronutrients effect on CTF quality characteristics. It can be observed in Table 2 that Zn was the most researched element, followed by B. Zn influenced all the considered variables, having the most consistent answers on fruit fresh mass and juice percentage. For SS and TA, it was noted that there was statistical significance, although with no defined trend in response to Zn and B application. Lack of information regarding micronutrient effects on citrus fruit quality variables is evident, although to a lesser degree than what was evidenced for macronutrients.

General Considerations

Potassium was the most studied macronutrient, whereas calcium and magnesium were the least evaluated.

Potassium was the element that most affected fruit quality variables, followed by nitrogen and phosphorus.

The most consistent potassium effect was the positive influence on fresh fruit mass.

Zinc was the most studied micronutrient, followed by boron.

Zinc influenced all variables considered, having a positive effect on fruit fresh mass and juice percentage.

Lack of information on mineral element effects on citrus fruit quality was evident, and further research is necessary.
Table 1 - Summary of the main mineral macronutrient effects on citrus fruit quality.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Firmness</th>
<th>Color</th>
<th>Fruit mass</th>
<th>Fruit size</th>
<th>Juice percentage</th>
<th>Rind percentage or thickness</th>
<th>Soluble Solids (SS)</th>
<th>Titratable Acidity (TA)</th>
<th>SS/TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(-) 1</td>
<td>(+) 1</td>
<td>(±) 3</td>
<td>(±) 3</td>
<td>(-) 1</td>
<td>(/)</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(-) 10</td>
<td>(±) 3</td>
<td>(±) 3</td>
<td>(-) 1</td>
<td>(+) 11</td>
</tr>
<tr>
<td>Potassium</td>
<td>(+) 7</td>
<td>(+) 7</td>
<td>(-) 2</td>
<td>(+) 6,7,9</td>
<td>(0) 4</td>
<td>(+) 7</td>
<td>(±) 3</td>
<td>(±) 3</td>
<td>(/)</td>
</tr>
<tr>
<td>Calcium</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(+) 11</td>
<td>(±) 3</td>
<td>(±) 3</td>
<td>(-) 8</td>
<td>(/)</td>
</tr>
<tr>
<td>Magnesium</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
<td>(0) 4,7</td>
<td>(+) 9</td>
<td>(±) 3</td>
<td>(0) 4,7</td>
<td>(+) 11</td>
</tr>
</tbody>
</table>

(+) Increase; (-) Decrease; (±) Statistical differences, with uncertain conclusions; (0) No effect; (/) No information.

1Aboutalebi (2013); 2Ashraf et al. (2013); 3Almeida & Baumgartner (2002); 4Duenhas et al. (2002); 5Quaggio et al. (2006); 6Quaggio et al. (2011); 7Hamza et al. (2012); 8Molina & Rojas (2005); 9Opazo et al. (2001); 10Obreza et al. (2008); 11Torres et al. (2009a)

Table 2 - Summary of the main mineral micronutrient effects on citrus fruit quality.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Fruit set</th>
<th>Fruit mass</th>
<th>Fruit size</th>
<th>Juice percentage</th>
<th>Rind percentage or thickness</th>
<th>Soluble Solids (SS)</th>
<th>Titratable Acidity (TA)</th>
<th>SS/TA</th>
<th>Ascorbic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>(+) 3</td>
<td>(+) 3,4</td>
<td>(/)</td>
<td>(+) 3</td>
<td>(±) 3,4</td>
<td>(±) 3</td>
<td>(/)</td>
<td>(/)</td>
<td>(/)</td>
</tr>
<tr>
<td>Zinc</td>
<td>(+) 2</td>
<td>(+) 2,3,5,6</td>
<td>(+) 5</td>
<td>(+) 2,3</td>
<td>(+) 2,3</td>
<td>(±) 3,5</td>
<td>(±) 3,5</td>
<td>(+) 2</td>
<td>(±) 2,5</td>
</tr>
<tr>
<td>Manganese</td>
<td>(/)</td>
<td>(-) 7</td>
<td>(/)</td>
<td>(±) 7</td>
<td>(+) 7</td>
<td>(±) 7</td>
<td>(±) 7</td>
<td>(-) 7</td>
<td>(/)</td>
</tr>
<tr>
<td>Iron</td>
<td>(/)</td>
<td>(0) 1</td>
<td>(0) 1</td>
<td>(+) 1</td>
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(+) Increase; (-) Decrease; (±) Statistical differences, with uncertain conclusions; (0) No effect; (/) No information.

1Aboutalebi (2013); 2Ashraf et al. (2013); 3Baghdady et al. (2014); 4Quaggio et al. (2003); 5Razzaq et al. (2013); 6Rodríguez et al. (2005); 7Torres et al. (2009b).
References


