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"Gheorghe Asachi" Technical University of Iasi, Romania

EVALUATION OF THE NUTRITIONAL STATUS OF STRAWBERRY DURING THE PRODUCTION SEASON

Antonio Domínguez[1], Fátima Martínez[1], Gonzalo Allendes[2], Pedro Palencia[3*]

[1]Agroforestry Department, E.T.S.I. 'La Rábida', Huelva University, 21819, Palos de la Frontera, Huelva, Spain
[2]AGQ Labs & Technological Services, Carretera A-8002, Kilómetro 20.8, 41220 Burguillos, Sevilla, Spain
[3]Plant Production Area, Department of Organisms and System Biology,
Polytechnic School of Mieres, Oviedo University, Mieres, 33600 Asturias, Spain

Abstract

The mineral contents of leaf, leaf petiole, fruit and fruit peduncle during the early and late stages of the production cycle may explain differences in response to fertilization in several strawberry genotypes. The aim of this study was to evaluate the nutritional status of two strawberry cultivars grown in soil. The nutritional status was determined as the amounts of nutrients taken up by the strawberry plants and the nutrient distribution within various parts of the plants during the production season. Uptake and partitioning of nutrients were determined by successive destructive harvesting of plants and mineral analysis of plant organs at two stages of growth (early and late season). The trial was conducted using a randomized complete block design with three replicates per treatment. The data were examined by analysis of variance (three-way ANOVA), with cultivar ('Camarosa' and 'Candonga'), type of sap (leaf petiole sap, fruit peduncle sap), plant organ (leaf and fruit) and growing season included as factors. The macronutrient contents were influenced by the production season, organ and type of sap, and strawberry cultivar. However, the macronutrient contents were more strongly influenced by the production season than by the strawberry cultivar. In addition, the micronutrient contents of leaf petiole sap and the fruit peduncle sap varied widely, whereas the micronutrient content of the whole organ was higher in leaf than in fruit. The results thus suggested that fruit nutrient concentrations decreased over time. The results also revealed a significant effect of production season on the composition of all macronutrients.

Key words: 'Camarosa'; 'Candonga', plant organ, sap

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1. Introduction

The European Network for Strawberry Cultivar Evaluation (COST ACTION, EU, 836) has shown that yield capacity and fruit quality can be affected by interactions between factors such as altitude, latitude, soil characteristics, type of cultivation system, day length and temperature (Krüger et al., 2004). Strawberry cultivation requires direct light and adequate water to achieve high yields as the plants have a relatively shallow root system as well as fruiting and maturation of the fruit occurs shortly about 20-40 days after pollination. Therefore, to guarantee high yields with quality fruit, precision in nutrient applied specific for the cultivar is necessary while taking into account the environmental conditions as it may vary the plant responses. Similar with other horticultural crops and to realize and sustain strawberry production, there is a need then to reduce the amount of fertilizers applied (Shuqin and Fang, 2018). Corollary, farmers must also be informed about the exact quantity of fertilizers required by the crop throughout the production cycle while considering the inherent nutrients from the soil and the environment that may affect the availability of nutrients (water, atmosphere, soil etc.).

A recent development has been made in plant analysis whereby sap is extracted with a hydraulic

* Author to whom all correspondence should be addressed: e-mail: palencia@uniovi.es; Phone: +34985458047; Fax: +34985104777

press allowing determination of nutrients in different plant parts. Use of the hydraulic press provides a quick and easy method of collecting samples for analysis of nutrients in the petioles and peduncles of the leaves and fruits respectively. It can be used to measure the concentration of nutrients in xylem and phloem sap as well as the apoplastic, cytosolic and vacuolic water. However, its efficacy is affected by several factors, such as phenology stage, cultivar, temperature, solar radiation, years and site (Sung et al., 2015). Current diagnostic tools are based on determining nutrient concentrations in plant tissues or in the sap or stem (Doucette et al., 2017).

Internal cycling is one of the main sources of nitrogen (N) for vegetative and reproductive growth of adult trees (Grassi et al., 2002). However, little is known about storage sites, timing and efficiency of remobilised N in strawberry plants (Archbold and Mackown, 1997). Yamasaki et al. (2000) suggested that N metabolism in shoot apex and crown of strawberry plants stimulates flowering, and that shoot apices, crowns and roots need recently absorbed N for initiation of flowering.

Nitrogen application should be based on N uptake rate at each growth stage for the target yield and should be consistent with the environmental need to prevent N leaching (Agostini et al., 2010). The actual nutritional status of the crop should also be monitored during the production cycle in order to correct detected deficiencies or excesses (Westerveld et al., 2003). This is extremely important in vegetable production systems, which are generally characterized by high N inputs but low recovery of applied N. Moreover, as vegetables are usually fertirrigated, assessment of the N content of crops allows for corrective fertilization when deficiencies or excesses are detected (Thompson et al., 2009). Some studies have reported that petiole sap (NO^{3-}) is a good indicator of crop N status for given plant species (Farneselli et al., 2014). Sap (NO^{3-}) values can be affected by factors such as cultivar, crop cycle, amount of N previously applied and crop water status (Goffart et al., 2008).

Calcium (Ca) differs from other elements by being imported into fleshy fruit in only small amounts (i.e. much smaller amounts than in leaves). Although sufficient Ca is usually available in the soil in orchards, localized Ca deficiency may become a problem in many fruit and vegetable crops, with the risk of large economic losses. The strong demand of Ca for the rapid growth of the tissues depletes the Ca in leaves and young fruits, alongside the effect of environmental conditions causes incapacity of the plants to mobilize sufficient Ca during the fast growth resulting to low Ca concentrations in the young tissues (Gonzales-Fontes et al., 2017).

Magnesium (Mg) is essential for plant growth as chlorophyll molecules contain magnesium ions, and chlorophyll is a key component in the photosynthesis reaction, which produces energy for growth. Magnesium also plays a substantial role in phosphorus transport in the plant; it assists in phosphate metabolism, plant respiration, protein synthesis and the activation of several enzyme systems.

Phosphorus (P) is important in the energy administration (ADP-ATP) in plants and it also plays a role in fruit development. Available phosphorus plays an important role in the establishment of plantlets after transplantation, for the formation of new root systems. The phosphorus content is usually sufficient to promote strawberry growth, but most of it is not readily available to plants because it is strongly associated with both the mineral and organic fractions of the soil. Availability is further reduced when the soil pH is very low (<5.5), or in the range 8.0 to 8.5, or if calcium, magnesium or zinc are present in excess. Although strawberries do not demand high levels of phosphorus, suboptimal levels may limit fruit production. Maintaining the pH close to 6.5 will help to maintain the optimal uptake of phosphorus. Soil pH is a key factor to support a favourable root environment and enhance the availability of many nutrients and the growth of plants. Soil with a pH of 6.0 to 6.2 is generally considered ideal for strawberries.

Potassium (K) stands out as the highest concentration cation in strawberry plants, helping them absorb water through the roots and controlling water loss through transpiration. Potassium assists in relevant physiological and metabolic functions such as enzymatic autoactivation, translocation of assimilates, sugar accumulation in the fruit, protects against fungal and microbial diseases and insect damage, and plays an important part to improvements in water use. Potassium is easily percolated from sandy soil, which is the best type of soil for growing strawberries.

All major cations, i.e. calcium, magnesium, potassium and sodium, compete with each other for absorption by root cells. They should therefore be applied to the soil in correct proportions. Over-liming can induce a magnesium deficiency, while supply of excess K^+ can also reduce magnesium uptake or can replace calcium in the plant. Excessive sodium can replace potassium, leading to further problems. Some studies have considered strawberry N requirements (Hochmuth et al., 1996); however, research on the importance of other nutrients in strawberry production is very limited.

This study was carried out to evaluate the nutritional status of two strawberry cultivars (‘Camarosa’ and ‘Candonga’) grown in soil, by monitoring nutritional status via the amounts of nutrients taken up by strawberry plants and by nutrient distribution within various parts of strawberry plants during early and late production seasons.

2. Material and methods

2. 1. Plant material and growth conditions

The study was carried out in commercial strawberry fruit production systems (in high tunnels) close to the village of Moguer (37º17’N, 6º51’W, altitude 35 m) on the southwestern coast of Spain,

during the 2010-2011 season. This experimental site is a major strawberry producing area in Spain. The soil is characterized as loamy sand with an organic matter content of 0.4%, and a pH of 6.51 (Table 1). Beds of dimensions 30 cm (wide) by 60 cm (high) were constructed with a tractor-mounted bed presser. The beds were separated by a distance of 60 cm. Simultaneously with bed pressing, a single drip line (flow rate of 1.56 L m^{-1} per hour and emitters every 30 cm) was placed at a depth of 5 cm in the centre of each bed. The beds were covered with polyethylene mulch, and fumigant (1,3-dichloropropene + chloropicrin, 65:35, v/v) was injected at a depth of 20 cm with four chisels per bed. The fumigant was applied on 16 September 2010.

The mean soil temperatures during fumigation was between 25 and 29ºC. The beds were mulched with a black, virtually impermeable film (1.4 m wide), which increases retention of volatile fumigants and exposure of soil pests to lethal fumes. High tunnels were built using semi-circular steel bars of height 3.3 m (at the tunnel apex) and width 8.3 m. The bars were mounted on side support bars of length 1.8 m. Each high tunnel enclosed six beds and was covered with translucent polyethylene plastic, which allowed 60% of the photosynthetic active radiation to pass through. The tunnels were covered with the plastic on 26 November 2010 without temperature or light control (Oliveira et al., 2020). Bare-root 'Camarosa' and 'Candonga' strawberry plants from commercial nurseries were transplanted on 14 October 2010. Transplants were placed in double rows per mulched bed with spaces of 27 cm x 22 cm between rows and plants, respectively.

Transplanting was combined with intermittent drip application and micro sprinkler irrigation during the first 10 days to cool the strawberry crowns. Conventional crop management techniques were used, as recommended for strawberry production under plastic tunnels in the area (Palencia et al. 2013).

In this area, there are two different production seasons: an early, cold crop production season (low temperatures and high relative humidity) between January and March (early season) and a late, warmer crop production season (high temperatures and low relative humidity) between April and May (late season).

2.2. Laboratory measurements

The harvest levels were determined 121, 126, 132, 139, 146, 154 and 160 days after planting for the early production season and after 204, 210, 217 and 223 days for the late production season. The number of samples of each cultivar was 60 (20 plants per replicate). The absorption and distribution of nutrients is determined through continuous destructive plant harvest and mineral analysis of plant organs in two production seasons (early and late season) from two cultivars ('Camarosa' and 'Candonga'). Plant organs (leaf, leaf petiole, fruit and fruit peduncle) were harvested at different phenological growth stages.

The sampling technique is very important in providing reliable results. Plants were analyzed systematically to monitor the nutritional status of leaf petiole sap and fruit peduncle sap of strawberry plants. Leaf analysis was performed on young mature leaves. Approximately 30 leaves or fruits were collected across the rows of a field or sampling block. The samples were then sent to the Plant Analysis laboratory (Labs and Technological Services AGQ, S.L). Plant material was dried at 60ºC. Total N was analyzed by the Duma method. Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), Iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (Bo) were determined by ICP-AES.

The mineral contents of leaf, fruit, leaf petiole sap and fruit peduncle sap throughout the early and late crop cycle may explain differences in response to fertilization in strawberry cultivars.

Table 1. Main chemical properties of fertirrigated solution and soil solution (15 and 30 cm) measured during the production season

Parameter	***Unit***	***SFR***	***SS15***	***SS30***
pH		6.21 ± 1.18	6.82 ± 047	6.62 ± 0.62
EC 20 ºC	µS/cm	771.85 ± 154.03	838.64 ± 139.35	837.20 ± 169.23
NO_3	mg/L	188.26 ± 59.37	208.10 ± 78.88	219.04 ± 69.38
NH_4	mg/L	5.52 ± 2.48	5.36 ± 0.72	5.34 ± 0.87
H_2PO_4	mg/L	8.58 ± 5.89	10.79 ± 4.73	10.86 ± 3.63
K	mg/L	25.79 ± 14.21	14.05 ± 7.72	18.49 ± 5.77
Ca	mg/L	38.07 ± 7.67	62.32 ± 15.83	59.02 ± 14.58
Mg	mg/L	27.43 ± 4.76	29.40 ± 6.12	29.47 ± 7.72
SO4	mg/L	27.95 ± 35.50	34.00 ± 41.30	24.95 ± 29.70
Fe	mg/L	0.11 ± 0.17	0.07 ± 0.08	0.08 ± 0.06
Mn	mg/L	0.05 ± 0.01	0.15 ± 0.19	0.06 ± 0.04
Cu	mg/L	0.25 ± 0.42	0.07 ± 0.04	0.05 ± 0.00
Zn	mg/L	0.05 ± 0.02	0.11 ± 0.09	0.08 ± 0.07
B	mg/L	0.43 ± 1.16	0.13 ± 0.20	0.12 ± 0.17
Cl	mg/L	72.32 ± 23.70	73.45 ± 14.68	72.43 ± 23.70
Na	mg/L	41.30 ± 12.45	46.92 ± 5.75	42.97 ± 6.68

SFR, Fertilizer solution; SS15, Soil solution at depth 15 cm; SS30, Soil solution at depth 30 cm, EC, electrical conductivity

Two lysimeters were positioned in each high tunnel at depths of 30 cm and 15 cm. For this purpose, a vertical hole of diameter similar to that of the probe was made in the ground with an Edelman auger. The composition of nutrients solutions applied to strawberry plant (fertirrigation solutions) and to soil solutions (30 and 15 cm) were measured during the assay in accordance with standard crop cultivation practices (Table 1). During the experiment, the mean temperature was 23 ºC and mean relative humidity, 69 %. Meteorological data were acquired from the Andalucía Institute of Agrometeorological Research recorded at the Moguer weather station (37º 08' 52'' N, 6º 47' 28'' W and 87 m above sea level) located about 3 km from the strawberry fields. Temperatures were measured daily every 2 seconds and the average recorded every 24 hours.

The trial was performed using a randomized complete block design with three replicates per treatment. The data were analyzed by a three-way ANOVA in which cultivar ('Camarosa' and 'Candonga'), type of sap (leaf petiole sap and fruit peduncle sap) plant organ (leaf and fruit) and growing season were included as factors. When the interactions were significant, they were included in the ANOVA, and a least significant differences test was performed to compare cultivar, type of sap, plant organ and growing season. SPSS-24 was used for all statistical calculations and graphics. Differences were considered significant at $P \leq 0.01$.

3. Results and discussion

3.1. Results

Macronutrient concentrations were measured in the leaf petiole sap, fruit peduncle sap and in the whole organs (leaf and fruit) during the early and late production seasons in 'Camarosa' and 'Candonga' cultivars. The results showed a significant effect of the sap (leaf petiole and fruit peduncle) and of the production season (early and late) on all macronutrients. The ANOVA revealed a significant interaction between the production season and cultivar for the phosphate and Mg contents, and there was a significant interaction between production season and sap for nitrates, phosphates, Ca and Mg content. There was also a significant interaction between cultivar and sap for phosphate content (Table 2).

The nitrate content was significantly lower in the leaf petiole sap than in the fruit peduncle sap and there were significant differences in the nitrate content between the late and early production season (Table 2). During the strawberry growth cycle, nitrate content was significantly higher in the early production season (2219.26 mg L^{-1}) than in the late production season (970.86 mg L^{-1}).

Table 2. Macronutrient content measured in the leaf petiole sap and fruit peduncle sap (mean ± standard deviation) recorded during the early and late production season in 'Camarosa' and 'Candonga' cultivars

Experimental Factor	***NO_3^-***	***NH_4^+***	***N Organic***	***$H_2PO_4^-$***	***K^+***	***Ca^{2+}***	***Mg^{2+}***
	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})
Cultivar (V)							
Camarosa	1812.58± 1314.01	88.75± 39.80	2279.55± 2366.38	398.43± 247.74b	3471.62± 1587.64	359.42± 231.63	294.28± 188.51a
Candonga	1730.77± 1312.55	99.86± 48.79	2492.76± 2568.38	612.02± 500.53a	2959.91± 1433.24	347.79± 211.28	228.52± 124.25b
Significance	NS	NS	NS	**	NS	NS	*
Sap (S)							
Leaf Petiole	1273.38± 548.02b	77.81± 32.20b	2021.62± 2109.30	261.08± 156.52b	2896.11± 1310.51b	474.95± 229.13a	347.51± 172.79a
Fruit Peduncle	2261.79± 1624.29a	110.64± 47.03a	2746.78± 2736.32	747.29± 436.72a	3526.69± 1666.30a	234.01± 128.82b	176.10± 91.69b
Significance	**	**	NS	**	**	**	**
Crop production season (C)							
Early	2219.26± 1346.04a	97.78± 44.53	1490.12± 1530.18b	592.71± 446.56a	3739.59± 1431.64a	409.23± 244.47a	311.96± 175.91a
Late	970.86± 742.43b	88.23± 41.20	3989.84± 2970.85a	351.13± 271.72b	2247.34± 1144.64b	254.06± 119.21b	170.32± 73.19b
Significance	**	NS	**	**	**	**	**
Interaction							
VxC	NS	NS	NS	*	NS	NS	*
SxC	**	NS	NS	*	NS	**	**
VxS	NS	NS	NS	**	NS	NS	NS
VxSxC	NS	NS	NS	NS	NS	NS	NS

*Different letters indicate significant differences in mean values (Tukey's test, P<0.05). Values in each column with no letter in common are significantly different, as determined by Tukey's test ($p < 0.05$). Asterisks indicate significances at * $p < 0.05$; ** $p < 0.01$; NS: non-significant*

The phosphate content was significantly lower in the 'Camarosa' cultivar (398.43 mg L^{-1}) than in the 'Candonga' cultivar (612.02 mg L^{-1}), and the phosphate content was significantly lower in the leaf petiole than in the fruit peduncle. Furthermore, the phosphate content was significantly higher during the early production season than during the late production season (Table 2).

The Ca content was higher in the leaf petiole than in fruit peduncle (474.95 mg L^{-1} and 234.01 mg L^{-1} respectively) and the Ca content was significantly higher in the early than in late production season (Table 2). There was no significant difference in the Ca content between cultivars. However, there were significant differences in the Mg content, which was higher in the 'Camarosa' cultivar (294.28 mg L^{-1}) than in the 'Candonga' cultivar (228.52 mg L^{-1}). The Mg content was also significantly different in the leaf petiole and fruit peduncle. The same trend was also observed in the Ca content. The Mg content was significantly higher in leaf petiole than in fruit peduncle (347.51 mgL^{-1} and 176.10 mgL^{-1} respectively) (Table 2). Regarding the production season, the Mg content was lower in the late season (170.32 mg L^{-1}) than in the early season (311.96 mgL^{-1}) (Table 2).

There were no significant differences in the ammoniacal nitrogen, Kjeldahl nitrogen, organic nitrogen or potassium contents between cultivars. However, there were significant differences in the ammoniacal nitrogen, Kjeldahl nitrogen and potassium content between the two types of sap. The ammoniacal nitrogen, Kjeldahl nitrogen and potassium contents were significantly higher in fruit peduncle sap than in the leaf petiole sap. In relation to production season, the potassium content was significantly higher in early season than in the late season. However, Kjeldahl nitrogen and organic nitrogen contents were significantly higher in the late production season than in the early production season (Table 2).

Concentrations of all macronutrients were higher in leaf petiole sap than in fruit peduncle sap, except for Ca and Mg, the concentrations of which were higher in the fruit peduncle sap. The production season had a significant effect on the composition for all macronutrients. In general, the macronutrient contents were higher in the early than in the late production season, except Kjeldahl nitrogen and organic nitrogen, the concentrations of which were higher in the late production season. The cultivar affected the phosphate and Mg contents. The phosphate content was highest in the 'Candonga' cultivar (612.02 mg L^{-1}) and the Mg content was highest in the 'Camarosa' cultivar (294.28 mg L^{-1}). The results also suggested that plant organ and production season had significant effects on the macronutrient contents. The ANOVA revealed a significant interaction between the production season and plant organ for total N, P, K, Mg and S content (Table 3).

The K content was higher in the early production season (1.94 %) than in the late production season (1.40 %). However, there were no significant differences in K content between organs (Table 3). The macronutrient partitioning between plant organs differed for the different nutrients, and the contents were higher in leaf than in fruit (Table 3).

There were also significant differences in both the Ca and Mg contents between leaf and fruit (Table 3). This may be related to the higher concentrations in leaf petiole sap and fruit peduncle sap respectively (Table 2).

Furthermore, variations in Ca content in fruit peduncle sap may be related to the Ca content in the soil solution (Table 1), so the calcium status in fruit appears to be strongly correlated with Ca concentration in the soil solution. The K, P and total N contents were higher during the early than the late production season. By contrast, the S content was higher in the late than in the early season (0.233 % and 0.125 % respectively).

However, there were no significant differences in the Ca and Mg contents between early and late seasons (Table 3). The results thus suggested that fruit nutrient concentrations decreased over time (from early to late season). In the same way, Domínguez et al. (2009) reported seasonal changes in most leaf mineral contents during the annual cycle. In general, the macronutrient contents were higher in the leaf than in fruit and were higher in the early than in late production season.

Table 3. Macronutrient content measured in organ (leaf and fruit) (mean ± standard deviation) recorded during the early and late production seaon in 'Camarosa' and 'Candonga' cultivars

Experimental Factor	***Total N***	***P***	***K***	***Ca***	***Mg***	***S***
	(%)	***(%)***	***(%)***	***(%)***	***(%)***	***(%)***
Organ (O)						
Leaf	3.14±0.46a	0.50±0.22a	1.81±0.44	1.02±0.20a	0.49 ± 0.08 a	0.197±0.121a
Fruit	1.93±0.44b	0.42±0.13b	1.68±0.27	0.44±0.24b	0.25 ± 0.08 b	0.131±0.503b
Significance	**	**	NS	**	**	**
Crop production season (C)						
Early	2.74±0.78a	0.55±0.16a	1.94±0.30a	0.71±0.34	0.36±0.13	0.125±0.038b
Late	2.17±0.54b	0.30±0.06b	1.40±0.23b	0.75±0.40	0.39±0.17	0.233±0.130a
Significance	**	**	**	NS	NS	**
Interaction						
OxC	**	**	**	NS	**	**

*Different letters indicate significant differences in mean values (Tukey's test, P<0.05). Values in each column with no letter in common are significantly different, as determined by Tukey's test (p < 0.05). Asterisks indicate significance at *p < 0.05; ** p < 0.01; NS: non-significant*

Micronutrient concentrations were measured in the leaf petiole sap and fruit peduncle sap and in plant organs (leaf and fruit) during the early and late production season in the 'Camarosa' and 'Candonga' cultivars. Regarding the micronutrient content of the leaf petiole sap and fruit peduncle sap, the results showed a significant interaction between crop cycle and cultivar for Mn content and between production season and sap for Zn content (Table 4).

Regarding the Mn content, significant differences between cultivars were observed, and the Mn content of the 'Camarosa' cultivar was significantly higher than that of the 'Candonga' cultivar. Furthermore, significant differences in the Mn content were observed between early and late seasons (Table 4). The Mn content was significantly higher in the early than in the late season (5.793 mg kg^{-1} and 4.27 mg kg^{-1} respectively).

The Zn content was significantly lower in the 'Candonga' cultivar than in the 'Camarosa' cultivar (1.55 mg kg^{-1} and 1.96 mg kg^{-1}), and the Zn content was significantly lower in the late season than in the early season (Table 4). Regarding the micronutrient content of the plant organs (leaf and fruit), the results showed a significant interaction between the crop cycle and plant organ for S, B and Cl contents (Table 4). The Cl and Fe contents were higher in late than in early season (1509.27 and 651 relatives to 128 and 92, respectively). Furthermore, there were significant differences in the Cl and Fe contents between leaves and fruits (Table 4). The B, Cl, Fe and Mn contents were higher in leaf than in fruit (Table 4).

3.2. Discussions

Macronutrient content was measured in the leaf petiole sap and fruit peduncle sap and the plant organs (leaf and fruit) during the early and late production season in the 'Camarosa' and 'Candonga' cultivars. The significantly lower nitrate content in the leaf petiole than in fruit peduncle is consistent with the findings of Tagliavini et al (2005), who estimated that fruit peduncle was the major sink for N and K, and of Archbold and Mackown (1997), who demonstrated that recently absorbed N accumulated in leaflets, while the N already present in those leaflets was remobilized and relocated to other tissues, such as roots. Bottoms et al (2013) suggested that decreasing N, P, and K concentrations were observed in the leaf blade during fruiting as fruit constitute a substantial nutrient sink. Furthermore, during the strawberry production cycle, nitrate content was significantly higher in the early season. These results are consistent with those reported by Hochmuth (1994), who found that nitrate content of vegetables tends to decrease with the age of the plant. Hochmuth et al. (1996) reported that the nitrate content of the leaf petiole sap varied from 760 and 970 mg L-1 during the vegetative period and 600 and 740 mg L^{-1} during the fruiting period. Lieten and Missotten (1993) indicated that nitrate content uptake decreased during the green fruit stage and harvest period.

The phosphate content was significantly lower in the 'Camarosa' cultivar and in the leaf petiole. Furthermore, the phosphate content was significantly higher during the early than the late season. The same trend was also observed in nitrate content. Cadahía (2008) suggested that the phosphate content decreased between the vegetative and the fruiting period and the phosphate content in the leaf petiole sap varied from 250 and 380 mg L^{-1} and 300 and 200 mg L^{-1} respectively. Opstad (2008) indicated that phosphate content of the leaf petiole sap varied during the phenological growth stages.

The Ca and Mg contents were higher in leaf petiole than in fruit peduncle, and these values decreased during the late season. The same trend was also observed in phosphate and nitrate contents.

Table 4. Micronutrient content measured in organ (leaf and fruit) (mean ± standard deviation) recorded during the early and late production season in 'Camarosa' and 'Candonga' cultivars)

Experimental Factor	*Boron (mg kg^{-1})*	*Chloride (mg kg^{-1})*	*Copper (mg kg^{-1})*	*Iron (mg kg^{-1})*	*Manganese (mg kg^{-1})*	*Zinc (mg kg^{-1})*	*Sodium (mg kg^{-1})*
Organ (O)							
Leaf	36.42± 10.02a	1526.42± 983.95a	6.01± 2.22	135.43± 41.51a	225.64± 69.71a	35.36± 10.35	251.60± 8.50
Fruit	19.25± 10.22b	400.24± 149.16b	8.43± 0.21	75.71± 33.29b	110.22± 64.40b	33.03± 23.08	253.34± 26.69
Significance	**	**	NS	**	**	NS	NS
Crop production season (C)							
Early	28.49± 15.31	651.36± 414.98b	7.38± 0.68	92.46± 35.68b	148.00± 78.24b	31.87± 9.54	253.60± 22.20
Late	26.69± 8.61	1509.27± 1215.63a	7.08± 4.96	128.50± 57.69a	202.80± 95.13a	38.27± 26.72	250.42± 2.79
Significance	NS	**	NS	**	**	NS	NS
Interaction							
CxO	*	**	NS	NS	NS	NS	NS

*Different letters indicate significant differences in mean values (Tukey's test, P<0.05). Values in each column with no letter in common are significantly different, as determined by Tukey's test (p < 0.05). Asterisks indicate significance at * p < 0.05; ** p < 0.01; NS: non-significant*

Likewise, Cadahía (2008) suggested that Ca content decreased between the vegetative and the fruiting period, and the Ca content of the leaf petiole sap varied from 700 and 1200 mg L^{-1} and 500 and 700 mg L^{-1} respectively.

The highest concentrations of Mg were observed during the early production season. As already mentioned, chlorophyll molecules contain magnesium ions, and as chlorophyll is a key component in photosynthesis, which produces energy for growth, Mg ions are therefore essential during the early season. Cadahía (2008) found that Mg content decreased between the vegetative period and the fruiting period and the Mg content in the leaf petiole sap varied from 300 and 600 mg L^{-1} and 200 and 400 mg L^{-1}, respectively.

Regarding the cultivar, the Mg concentrations were highest in the 'Camarosa' cultivar, whereas the phosphate contents were significantly lower in the 'Camarosa' cultivar. There were significant differences in the ammoniacal nitrogen, Kjeldahl nitrogen and potassium contents between the two types of sap, and they were significantly higher in fruit peduncle than in leaf petiole. Furthermore, the potassium content was significantly higher in the early season than in the late season. The same trend was also observed in phosphate, nitrate, Ca and Mg contents. Cadahía (2008) suggested that potassium content varied between the vegetative period and the fruiting period, and Bibi et al (2016) indicated that K content of plant generally increased with flowering and then decreased with ripening.

Our results revealed that the concentrations of all macronutrients were higher in leaf petiole sap than in fruit peduncle sap, with the exception of the Ca and Mg contents, which were higher in fruit peduncle sap. The results also revealed a significant effect of production season (early and late) on the composition of all macronutrients; these results are consistent with those reported by Domínguez et al. (2009). In general, the macronutrient contents were higher in the early than in the late season, except Kjeldahl nitrogen and organic nitrogen contents, which were higher in the late season. In addition, the cultivar affected the phosphate and Mg contents, which were highest in the 'Candonga' and 'Camarosa' cultivar, respectively. Domínguez et al. (2007) suggested that the effects of cultivar were due to differences in mineral contents.

Regarding macronutrient contents of the leaves and fruit, our results suggested that the K content was higher in early than in late season, but there were no significant differences in K content between organs. Seasonal changes in leaf mineral elements have been found in many agricultural species (Domínguez et al. 2007). On the other hand, Demirsoy et al. (2010) reported that leaf K content varied from 1.05 % to 1.87 % during the production cycle and leaf K increased as soil temperature increased.

Our results showed that macronutrients partitioning between plant organs differed depending on the nutrient considered. There were significant differences in Ca, Mg, P, S and total N contents between organs and the higher values were obtained in leaf than in fruit. These results are consistent with those reported by Tagliavini et al. (2005), who found that most of the Ca was recovered from the leaves. Demirsoy et al. (2010) reported that leaf Ca content varied from 0.22 % to 1.50 % and Almaliotis et al. (2002) reported that leaf Ca varied from 0.77% to 1.48% in 'Tudla' strawberry.

The P content was higher in leaf than fruit (0.50 % compared to 0.42 %). Almaliotis et al. (2002) found that leaf P varied from 0.20% to 0.38% in the cultivar 'Tudla'. Ersoy and Demirsoy (2006) reported that during the fruiting period N moved from leaves to fruit. In addition, the decrease in foliar N may result from dilution in leaves because of increased leaf area. Foliar N content has been found to vary from 1.29 % to 2.5% (Demirsoy et al., 2010) and from 2.0% to 2.8% (May and Pritts, 1990). There were also significant differences in the concentrations of Ca and Mg between leaf and fruit, which may be due to the higher Ca and Mg contents in leaf petiole and fruit peduncle respectively. Furthermore, variations in Ca content of the fruit peduncle may be related to the Ca content in both soil and soil solution, and the Ca content of fruit may be lower due to a dilution effect. During the production cycle, the Ca and Mg content of soil was adequate. In general, a large variation in concentration of macronutrients in the plant organs was observed during the strawberry production season, and the Ca content in strawberry plants may be the result of accumulation in the leaf throughout the entire cycle.

Regarding the strawberry production season, during the early season the K, P and total N contents were higher than in late season. The K content was higher in early season (1.94 %) than in the late season (1.40 %). Demirsoy et al. (2010) suggested that the foliar K content decreased during vegetative period and early fruit ripening, possibly due to a much higher yield. The P content was higher in the early season (0.55 %) than in the late season (0.30 %). Demirsoy et al. (2010) reported that foliar P varied from 0.21 % to 0.46 % during the trial, and May and Pritts (1990) indicated that foliar P varied from 0.40 % to 0.25 % in strawberry.

Although the Ca and Mg contents tended to increase during the late production season, there were no significant differences in the Ca and Mg contents between early and late crop cycle. Daugaard (2001) reported that Ca content increased gradually during summer. The increase probably resulted from an increase in Ca uptake during warm periods due to increased transpiration, as reported by May and Pritts (1990). However, Tagliavini et al. (2005) estimated that the N content was higher in the early season than in the late season. Our results showed that fruit nutrient concentrations decreased over time (from early to late season). These findings are consistent with those of Niskanen and Dris (2002), who reported that whole leaf N, P, Ca, and Mg contents were lower

in the late season than in the early season. Furthermore, Daugaard (2001) observed a general increase in N content during spring, followed by a decline at harvest. The increase during spring is explained by a gradual increase in temperature, followed by an increase in mineralization, and the strawberry plants later used the soil N reserve. Our results showed that the macronutrient contents were higher in leaf and in the early season than in fruit and late season respectively.

Micronutrient contents were measured in the leaf petiole sap of and fruit peduncle sap and in the plant organs (leaf and fruit) during the early and late production season in 'Camarosa' and 'Candonga' cultivars. Regarding micronutrient concentrations in the leaf petiole sap and fruit peduncle sap, our results showed significant differences in the Mn and Zn concentrations between cultivars and between early and late seasons. These results are consistent with those found by Bottoms et al. (2013), who reported statistically significant correlations in the strawberry Mn contents between all stages.

In general, the micronutrient concentrations in the leaf petiole sap and fruit peduncle sap varied widely, with B, Mn, Zn and Na increasing and Cl decreasing during the early season (Table 4). Opstad (2008) suggested that large variations in concentrations of mineral elements in petiole sap are due to the production season and plant development, among others factors. Regarding micronutrients contents of the plant organs (leaf and fruit), our results showed a significant interaction between the crop cycle and organ for the B and Cl contents and the B, Cl, Fe and Mn contents were higher in leaf petiole than in fruit.

4. Conclusions

In conclusion, this study demonstrates that the role for the macronutrients content of the leaf petiole sap and fruit peduncle sap and plant organs (leaf and fruit) during the early and late production season in 'Camarosa' and 'Candonga' cultivars were influenced by the strawberry cultivar, organ and sap, and by production season. However, the macronutrient contents were more strongly influenced by the production season than by the strawberry cultivar.

The results revealed a significant effect of early and late season on the composition of all macronutrients. This will be an important information because strawberry growers must be informed about the exact quantity of fertilizers required by the crop throughout the production cycle. That way, assessing the nutritional status of the strawberry during the growing season is important to reduce the amount of fertilizers used.

There were also significant differences in the Ca and Mg content of leaf petiole sap and fruit peduncle sap and between Ca and Mg content in organ (leaf and fruit). Micronutrient contents of sap leaf petiole and in sap fruit peduncle varied widely, whereas the micronutrient content was higher in leaf than in fruit.

We believe that further research must be carried out with different cultivars to enable general conclusions to be reached regarding the influence of the production season on macronutrient and micronutrient contents of strawberry plants.

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