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SCIENTIFIC ARTICLE

Nutrient dynamics of macro and micronutrients in coriander

Dinámica nutrimental de macro y micronutrimentos en cilantro

Enrique González-Pérez[1*], Salvador Villalobos-Reyes[1], Carlos Alberto Nuñez-Colin[2]

[1]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Bajío, km 6,5 Carretera Celaya- San Miguel de Allende, 38110, Celaya, Guanajuato, México.

[2]Programa de Biotecnología, Universidad de Guanajuato. Mutualismo #303, Colonia La Suiza, 38060, Celaya, Guanajuato, México.

*Corresponding author: gonzalez.enrique@inifap.gob.mx

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ABSTRACT

The information about the coriander nutrient management is scarce. This study aims to determine the dynamics of macro and micronutrients in coriander plants during its different phenological stages and growth seasons. The concentration of macro and micronutrients in seven phenological stages and some agronomic components were determined. The most required macronutrients were N (42.1-57.5 g plant^{-1}), followed by K (42.5-53.8 g plant^{-1}) and Ca (7.7-25.9 g plant^{-1}). Mn (105.1-381 mg plant^{-1}) and Fe (49.8-194.4 mg plant^{-1}) were the micronutriments required in the highest amounts. The best plant height (56.4cm), fresh weight (226.7 g pta-1) and dry weight (30.7 g pta-1) was recorded in autumn-winter (A-W) ($P \leq 0.05$), while oil content was from 7.62 to 8.12%.

KEYWORDS

Fertilization doses, fresh biomass, nutriments, phenological stage.

RESUMEN

La información sobre el manejo nutrimental del cilantro es escasa. Así, el objetivo del estudio fue determinar la dinámica de macro y micro-nutrimentos en plantas de cilantro en diferentes etapas fenológicas y épocas de siembra. La concentración de macro y micro nutrimentos en siete etapas fenológicas y algunos componentes agronómicos fueron determinados. El macro-nutrimento más requerido fue N (42.1-57.5 g plant^{-1}), seguido de K (42.5-53.8 g plant^{-1}) y de Ca (7.7-25.9 g plant^{-1}), y los micro-nutrimentos requeridos en altas cantidades fueron Mn (105.1–381 mg plant^{-1}) y Fe (49.8–194.4 mg plant^{-1}). La mayor altura de planta (56.4 cm), peso fresco (226.7 g pta^{-1}) y peso seco (30.7 g pta^{-1}) fue registrada en otoño-invierno (O-I) ($P \leq 0.05$), mientras que el contenido de aceite fue de 7.62 a 8.12%.

PALABRAS CLAVE

Dosis de fertilización, biomasa fresca, nutrimentos, etapa fenológica.

Introduction

Coriander (*Coriandrum sativum* L.) is an aromatic spice of high economic value in the world. The leaves are used in the preparation of an invariable number of culinary dishes, mainly in Indian cuisine, for cooking, flavoring, making beverages, and other; furthermore, its seeds are used to prepare value-added products such as coriander powder, Dhana Dal, curry powder, oleoresin, and essential oil (Patel et al. 2013). Coriander seeds in some European countries are used in the industry for the extraction of essential oil (linalool, geraniol, and so on) and recently have had a boom in the fragrance industry (Dedebas et al. 2021). Coriander in Mexico was introduced in 1519 during colonization, and since then, it has been used in a great variety of dishes and consumed fresh.

The main problem of coriander in fresh production is the low production of fresh biomass and the premature appearance of floral umbels. These problems are associated with the photoperiod, high temperatures, the genetic constitution by genotype and the nutritional content of the plant (González et al. 2017). The nutrient status is perhaps the factor with the greatest influence on the development of the plant and the emergence of the floral umbels due to the nutrients vital role in the function of normal physiological processes during the period of plant growth and development.

Previous studies mention that the coriander plant requires a high content of N during its growth season, which is necessary for the dark green color of the leaves; hence, N is very important to maintain the availability of nitrogen and sulfur in the soil (Carrubba 2015; Sharafzadeh and Ordookhani 2011; Patel et al. 2013). There are no specific fertilization recommendations because it depends on the particular conditions of each soil or nursery substrate.

In this regard, Donega et al. (2013) mention that the order of extraction of nutrients accumulated in coriander over time was K>N>Ca>Mg>P>S. Also, they found that the maximum accumulation was as follows: K 52.2 mg plant^{-1}; N 21.81 to 40.24 mg plant^{-1}; P 10.37 to 40.2 mg plant^{-1}; Ca 4.31 to 5.39 mg plant^{-1}; Mg 2.18 to 3.81 mg plant^{-1} and S 0.94 to 2.57 mg plant^{-1}. Likewise, Grangeiro et al. (2011) reports a similar absorption order, but they mention that after K, Ca is the most required nutrient for coriander (K>Ca>N>Mg>P), and they indicate that the plant accumulates 25.43 K, 20.4 Ca and 11.15 Mg (mg plant^{-1}).

Carrubba (2015) mentions that in healthy plants, a noticeable N uptake (22 to 40 mg plant^{-1}) with large variations according to genotype has been demonstrated. Donega et al. (2013) indicate that accumulation of micronutrients in shoot in descending order was Fe>Zn>B>Mn>Cu and mention that the accumulation of micronutrients was on average 30.2 Fe, 12.6 Mn, 23.8 Zn, 0.6 Cu and 15.8 B μg plant^{-1}. The results of the aforementioned research indicated that, in order to produce higher plants, greater accumulation of dry matter and an increase in seed production, it is necessary to supply the coriander plant with the necessary amount of fertilizer to satisfy its requirements. Likewise, many of these studies have seed yield under fertilization rates ranging from 0 to 80-90 kg N ha^{-1}.

In Guanajuato, Mexico, previous research estimated an average foliage production of 2.0 kg m^2 extracts 180 kg N, 30 kg P_2O_5 and 110 K_2O (González et al. 2017). Therefore, if farmers in the region apply 120 kg ha^{-1} of urea or ammonium sulfate, 50 kg ha^{-1} of diammonium phosphate (DAP) and, in some cases, 100 kg ha^{-1} of potassium chloride, there are insufficient amounts of fertilizers to satisfy the nutritional requirements of the crop (personal communications with farmers). In this regard, Carrubba (2015) mentions that coriander requires 40-90 N, 40-100 P_2O_5 and 40 K kg ha^{-1}. At the same time, Mejía et al. (2008) indicate that coriander requires 70N-60P-78K kg ha^{-1}. Additionally, Lal et al. (2014), recommend the basal application of sulfur 40 kg ha^{-1} along with a foliar application of 0.6% Zn for producing higher yields of coriander.

In different research projects, distinct doses of fertilization were proposed, but this reflects the unlike local conditions and diverse genotypes. Hassan et al. (2012) found that the concentration of N remained constant for three weeks between 2.8 and 2.9%, as did the concentration of P (0.3%) and K (2.8-3.0%) when applying 400 kg of ammonium sulfate (20.5% N), 200 kg of calcium superphosphate (15.5% P_2O_5) and 100 kg of potassium sulfate (48% K_2O). Aishwath (2016) evaluated seven genotypes of coriander and determined that the highest demand for NPK was between 80 and 120 days in genotypes of long-season materials and between 40 and 60 days in short-season materials. Kumar et al. (2015) obtained the best plant and seed production with the application of 60N-30P-30K kg ha^{-1}, 60 and 90 days after sowing.

In other studies, Pawar et al. (2007) obtained higher plant height, more leaves per plant, a greater number of main and secondary branches, and greater fresh weight when applying 100 kg ha^{-1}. Rashed and Darwesh, (2015) found that the highest concentration of N and P was with the dose of 30 N kg in the form of urea, while the highest accumulation of K was with the dose of 60 kg ha^{-1}.

Most of the research has focused on NPK requirements, but coriander requires large amounts of other nutrients, such as S, Ca and micronutrients. Sivakumaran et al. (1996) obtained higher oil production (2.48 kg ha^{-1}), as well as an increase in the S concentration in the leaves when applying 10 kg ha^{-1} of S, while Meena et al. (2016) observed higher plant height, dry matter and seed production, as well as a higher concentration of N, S and Zn in the plant with the application of 40S-5Zn kg ha^{-1}. Said-Al Ahl and Omer (2009) suggested spraying 400 ppm Zn and 200 ppm Fe in the vegetative and flowering stages to increase the yield and provide the highest content of essential oil in both stages. Kerton et al. (2009) indicated that coriander required Ca and that its concentration is a function of the water potential of the plant, but the minimum concentration required is still unknown.

Other authors mentioned that the final concentration of nutrients in seeds or straw, as well as the extraction rate of some nutrients, especially N, P, K, and S, are values used to calculate the amount of nutrients required to produce a ton of product (Mejía et al. 2008; Lal et al. 2014; Carrubba 2015). This index, together with the expected yield value, are used to design open-field fertilization programs.

However, if the nutritional dynamics of the macro and micronutrients were known by the plant's phenological stage during the crop season, a more efficient fertilization program could be developed for the cultivation of coriander, since, along with obtaining higher economic yield, a balanced supply of nutrients is one of the key factors. Unfortunately, knowledge about this nutritional dynamic is lacking. Based on the above, the aim of this study was to determine the dynamics of macro and micronutrients in coriander plants during its different phenological stages and growth seasons.

Materials and methods

The study was carried out in the Bajío Experimental Station of the National Institute of Forestry, Agriculture, and Livestock, (INIFAP) in Celaya, Guanajuato, Mexico, (24°34'44" N; 100°49'11" W; 1750 m) with climate type BS1h (García 2004) in clay and slightly alkaline soil (Table 1).

Crop management and fertilization

In autumn-winter (AW), spring-summer (SS) and summer-fall (SF) season 2017, the INI-17 variety of coriander was growing in a soil with the same characteristics.

In the three seasons, crop management was carried out as instructed by González et al. (2017). The fertilization was applied by drip irrigation. The fertilization dose 120N-40P-70K-20Ca-16.5Mg-46S was estimated from preliminary experiments. The dose

Table 1. Content characteristics of a clay loam and slightly alkaline soil analysis in the Bajío Experimental Station before sowing. Celaya, Guanajuato State, Mexico.

Soil characteristic*	Value	Classification	Soil characteristic[1]	Value	Classification
pH	8.55	High	Ca, mg L^{-1}	4209.39	High
Bulk density, g cm^{-3}	0.99	Medium	Mg, mg L^{-1}	792.65	High
Organic matter, %	1.68	Low	Fe, mg L^{-1}	17.30	High
Electrical conductivity, dS m^{-1}	0.90	Medium	Zn, mg L^{-1}	0.42	Low
N, mg ha^{-1}	10.55	Medium	Mn, mg L^{-1}	7.74	Medium
P, mg L^{-1}	18.42	Medium	Cu, mg L^{-1}	1.04	Low
K, mg L^{-1}	399.56	Medium	B, mg L^{-1}	0.15	Very low

*Analysis performed by Agricultural Laboratories of INIFAP (Celaya, Guanajuato, Mex.), 2017.

application (treatment) was fractioned into four events: (1) 20N-30P-20K; (2) 40N-30K-10Ca-6.5Mg-26S; (3) 40N-20K-10Ca-5Mg; and (4) 20N-5Mg-20S, applied at 0, 30, 50 and 70 days after sowing (DAS). Additionally, a spray foliar of B, Cu, Fe, Mn and Zn chelates (1.5 kg ha^{-1}) (trademark products) was applied at 40 and 60 DAS. Drip water irrigation (8 mm) was applied three times per week, until flowering started.

Accumulation of nutrients

Seven phenological stages were determined: (1) sprouting; (2) tillering; (3) growth; (4) development; (5) ripe commercial; (6) floral umbels emergence; and (7) flowering (Table 2). From each stage, four samples of plant tissue were collected, and they were procesed in a laboratory to determine their nutritional status.

Table 2. Phenological stages of coriander proposed for nutritional monitoring.

Stage	Period Days	Description
Sprouting	0 - 15	Period of sprout of the seedling
Tillering	16 - 20	Period of proliferation of stems
Growth	21 - 40	Stem elongation period
Plant development	41 - 60	Period of accumulation of fresh biomass
Ripe commercial	60 - 70	Maximum accumulation of fresh biomass
Floral umbels emission	71 - 100	Emission of umbels start
Flowering	100 - 120	Start flowering

Plant analysis

The plant samples were collected after the harvest of all the treatments and their replications. Plant samples were successively washed with tap water, 0.1 M HCl, distilled water, and dried at 70 °C. After proper drying, the samples were powdered in a Wiley mill and passed through a 20-mesh steal sieve. Nitrogen concentrations were estimated by the Kjeldahl method (Chapman and Pratt 1973). The samples were digested in nitric and perchloric acid (10:4) for the estimation of P by the vanadate-molybdate-yellow color method (Chapman and Pratt 1973) and K, Ca, Mg, Na, Fe, Cu, Mn, and Zn, by atomic absorption spectrophotometry. S was determined by a colorimetric method and B, by atomic absorption spectrophotometry (AOAC 1990).

Agronomic components

In each season, the number of leaves (NLPP), plant height (PH; g) and the yield per hectare were registered from tillering to ripe commercial stages. Additionally, the fresh biomass per plant (FBPP; g) and dry biomass per plant (DBPP; g) were determined in the ripe commercial stage.

Statistical analysis

A Principal Component Analysis of the nutriment contents was performed in three growth season and in the several phenological stages with NTSYS 2.2 (Rohlf 2005). The analysis of variance and comparison of means (Tukey, $p \leq 0.05$) for some variables were implemented with the Statistical Analysis System software (SAS Institute 2009).

Results and discussion

The principal components analysis showed the importance of variables associated to nutrimental content in coriander in the three growth seasons, and highlighted the macronutrients N, K and Ca, and the micronutrients Mn, Fe and Zn.

The variance values obtained explain each component as a percentage of the total variance. The principal components analysis in the PC-1 explains 50.31% of the total variability of the concentration of nutrients by phenological stage of coriander, while the second one did it at 18.71% (Table 3).

Each of the principal components, the variables that compose them (nutrients) have a weight within each one. According to the results, the six nutrients with the highest eigenvector associated with the main component 1 (PC-1) were N, K, Mg, Zn, Cu and Fe (Fig. 1). The concentration of each nutrient was variable for each phenological stage of the crop and per crop season.

Table 3. Eigenvectors for principal components 1, 2 and 3 for eleven nutriments traits in coriander in three crop seasons.

	PC-1	PC-2	PC-3
Eigenvalue	5.5352	2.0587	1.5799
Proportion of variance	**50.3199**	**18.7154**	**14.3628**
Cumulative variance	50.3199	69.0353	**83.3980**
Ca	0.3486	0.7468*	0.3883
Mg	-0.8441*	0.4718	0.0245
K	-0.7499*	-0.0934	0.3703
Fe	-0.7954*	0.3234	-0.3885
Cu	0.8293*	-0.2701	0.0229
Mn	0.6238	-0.4996	0.5035
Zn	-0.8984*	-0.2517	0.1230
N	-0.7702*	-0.4815	0.1584
S	-0.6693	0.3175	0.2519
P	-0.6704	-0.4373	0.5081

*More correlated trait with the principal component.

Nitrogen, potassium, magnesium, zinc, copper, and iron were selected as representative of PC-1 not only for the value of the eigenvector but also for the importance of these nutrients in the growth and development of the coriander plant (González et al. 2017).

In principal component 2 (PC-2), the variable with the highest magnitude was calcium (Ca) (Table 3), which in A-W and S-S seasons showed an average concentration of 7.7 g plant^{-1} in the commercial ripe stage (Table 4).

In principal component 3 (PC-3) no significant values were presented that could influence the development of the plant in the three seasons evaluated (Table 3).

Nitrogen, potassium, magnesium, zinc, copper, and iron were selected as representative of PC-1, not only for the value of the eigenvector, but also for the importance of these nutrients in the growth and development of the coriander plant (González et al. 2017).

Accumulation of nutrients

Macronutrients

According to the principal components analysis N and K are the macronutrients of greatest demand in the three crop seasons, the order is N>K>Ca>S>P>Mg. In all crop seasons, the order of demand of macronutrients was N>K>Ca>S>P>Mg. These results differ from those mentioned by Donega et al. (2013), whose order of importance is K>N>Ca>Mg>P>S. This contrasts with what Grangeiro et al. (2011) reported, who mentioned that after K, Ca is the most required nutrient by coriander (K>Ca>N>Mg>P).

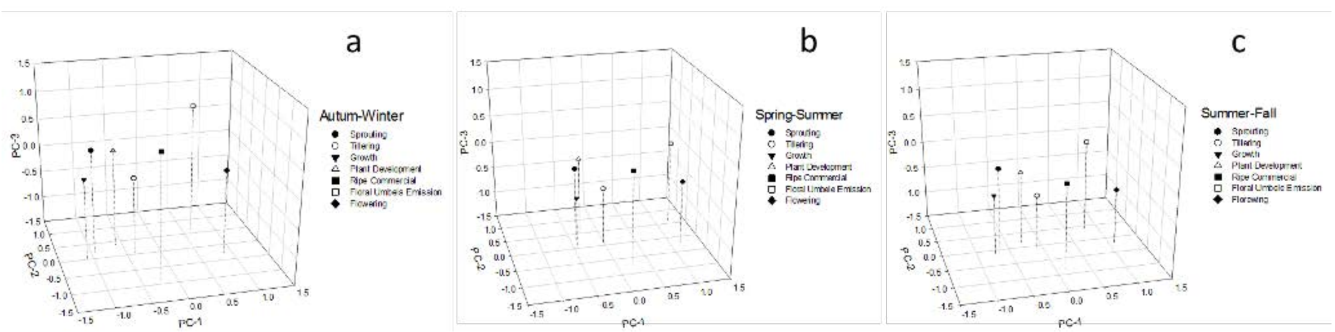

Figure 1. Dispersion diagram of principal components PC1, PC2 and PC3 of the nutrimental content in cilantro in different phenological stages and crop seasons. (a) Autumn-Winter, (b) Spring-Summer, (c) Summer-Fall.

Table 4. Nutrimental concentration of macronutrients (g plant^{-1}) in coriander 70 days after sowing in three growth seasons in 2017.

Season	N	P	K	Ca	Mg	S
Autumn-Winter	57.5a*	5.3a	51.1a	7.7a	3.9a	4.1a
Spring-Summer	52.3b	4.8b	46.5b	7.03a	3.5a	3.8a
Summer-Fall	55.2ab	5.1a	47.1b	6.6b	3.5a	3.1b
Mean	55.0	5.0	48.2	7.11	3.6	3.7

*Different letters in the row indicate significant differences according to Tukey's test ($P \leq 0.05$).

Nitrogen's dynamic in the different phenological stages of coriander was constant in the three seasons. The AW season showed the greater N concentration. However, in AW, in the commercial ripe stage (Figure 1a) a greater N concentration (57.5 mg plant^{-1}) was shown at 60 DAS. After umbel emergence, the N concentration decreased 14% on average (Table 4; Figure 1b).

In this study, it was found that only in the commercial ripe stage did the N concentration decrease slightly. Donega et al. (2013) indicated that the N concentration ranged from 21.8 to 40.2 g plant^{-1}, higher values than the ones obtained in this study. Conversely, Grangeiro et al. (2011) determined that the N concentration ranged from 10.37 to 40.2 g plant^{-1}, values that were lower than the ones obtained in the present study. While Rashed and Darwesh (2015) determined that in plants grown in autumn and fertilized with 60N kg ha^{-1}, there was a final N concentration of 2.33%, which was half of the average value found in this study.

For production of fresh biomass of coriander, the results obtained suggest that the supply of N must be constant from 20 DAS up to 65 DAS due to its association with the photosynthetic activity that determines vigorous vegetative growth and dark green color. Aishwath (2016) indicated that from 8 to 10% of N is extracted by the plants at 40 DAS; from 34 to 35% between 40 and 82 DAS, and from 55 to 56% after 80 DAS (flowering), values which differed from the ones obtained in the present study due to the decrease in the N concentration after the umbel emergence. Cruz et al. (2017) found similar results in the coriander Pakistan variety.

From Potassium, the results indicated that the behavior of K in the three seasons was similar. The highest concentration of K at 20 DAS (54 g plant^{-1}) was recorded in AW. In the Floral Umbels Emission stage (Table 4; Figure 1a), there was a slight increase of 5.8% and a subsequent decrease until flowering stage (100 DAS).

During all growth seasons, the K concentration was in the range of 0.5 to 6%, which agreed with that reported by Havlin et al. (1999) and Fageria (2009). Donega et al. (2013) mentioned that K is the most required nutrient for coriander, with rates of 40.5 to 61.9 g plant^{-1}, which were close to what was obtained in this study (54 g plant^{-1}). Comparatively, Grangeiro et al. (2011) indicated concentrations of 40.2 g plant^{-1}, a concentration higher than that reported by Donega et al. (2013) and lower than what we report in this study (42.5-53.8 g plant^{-1}). Cruz et al. (2017) indicated a concentration of 3.43 g plant^{-1} for K at 30 DAS, while Rashed and Darwesh (2015) mentioned that in coriander grown in autumn, the concentration of K was 2.61%, and that in winter, the concentration of K could increase up to 3.94%. The slight variation in the K concentration during all growth seasons indicated that it was determined from the biomass produced as previously indicated by Aishwath (2016) and Cruz et al. (2017).

In general, the concentration of calcium in coriander in the three seasons decreased during the first 60 DAS with an average of 12 g plant^{-1} (Table 4) and during the emergence of the umbels the concentration increased two-fold (23.4 g plant^{-1}). It is inferred that the increase in the concentration of Ca in the emission of the umbels stage could be due to the plant not generating more leaves; thus, Ca could not translocate to the new leaves as previously mentioned by Kerton et al. (2009) and Konsaeng et al. (2005). Donega et al. (2013) indicated Ca concentrations from 4.31 to 5.339 mg plant^{-1}, values that were lower than those reported in this study and by Grangeiro et al. (2011) in the commercial ripe stage (20.4 g plant^{-1}).

Another factor that could have influenced the greater accumulation of Ca before the appearance of the umbels was the evapotranspiration generated by the irrigation supplied at 55 DAS. Kerton et al. (2009) found that Ca in coriander is accumulated in the mesophyll vacuoles and that the greatest accumulation occurs in old leaves because they have been exposed to evapotranspiration for a longer time, results that can be correlated with the concentration recorded at the beginning of the emission of umbels in this study.

The Sulfur concentration during the development of the crop in the three seasons was similar (Table 4). However, at plant development stage (40 DAS) the maximum S accumulation was registered in AW (5.1 mg plant^{-1}), with a subsequent decrease until the 100 DAS (3.4 g plant^{-1}). Sulfur concentration was within the range of 0.1 and 0.5% for higher plants (Havlin et al. 1999; Fageria 2009). In this regard, Donega et al. (2013) indicated that the S concentration ranged from 0.94 to 2.57 mg plant^{-1}, values lower than the ones determined in our study. Meena et al. (2016) mention that the application of S at doses greater than 40 kg ha^{-1} increased its concentration in the plant due to the crop extracting 6.9 kg ha^{-1} on average.

The behavior of the concentration of P during the development of the crop in the three seasons was like that of N. The greatest P concentration was registered (Table 4) at commercial ripe stage (60 DAS). After 100 DAS the P concentration decreased by 31.6% with respect to the stage with higher concentration. The availability of P was improved when a greater amount of phosphate fertilizer was applied. This favored absorption by the plant in its different development stages; it was observed that as the plant increased its biomass, the P concentration also increased.

The values obtained of phosphorus were consistent with those previously reported by Aishwath (2016), who mentions that the P concentration in the plant is in function of the accumulation of fresh biomass. The values were also consistent with those of Cruz et al. (2017), where, in plants cultivated in hydroponics, a gradual increase in P concentration was registered from 30 (0.3 g plant^{-1}) up to 90 DAS (0.62 g plant^{-1}). Furthermore, Rashed and Darwesh (2015) reported a P concentration of 0.52% in plants grown in autumn, which was a concentration like that found in this study. Conversely, Carrubba (2015) mentioned that the maximum accumulation of P in coriander occurred in the flowering stage, while in our study, the maximum accumulation was at the end of the plant development stage (0.53% P).

For this study, the macronutrient least required by coriander was Magnesium. The highest Mg concentration in the three seasons was registered at 40 DAS (Table 4), decreasing by 22.7% at commercial ripe stage (60 DAS), with a slight increase of 4.6% at 70 DAS (Figure 1a). In general, Mg concentration was in the range of 0.1 to 0.4% established in higher plants (Havlin et al. 1999; Fageria 2009). Donega et al. (2013) reported Mg rates of 2.18 to 3.81 mg plant^{-1}, and Grangeiro et al. (2011) reported 11.15 mg plant^{-1}, concentrations which were lower than the ones found in this study.

Micronutrients

The micronutrients concentration during each crop season had a similar tendency. The highest micronutrients concentration was recorded in the A-W season (Table 5; Figure 1a). The results indicated that the order of nutritional importance was Mn>Fe>Zn>Cu. The results obtained in this study differ from those indicated by Donega et al. (2013), who determined that Fe is the micronutrient most required by coriander and established that the relationship is Fe> Zn> B> Mn> Cu, while the order of required micronutrients in our study was Mn>Fe>Zn>Cu.

According to the results obtained from the principal components analysis and plant nutritional status found in this study, the values suggested that the micronutrient most required by coriander is Mn (Table 5). In AW season, the maximum Mn's concentration was recorded at commercial ripe stage (380 mg plant^{-1}) while in SF, it was 274 mg plant^{-1}. At 70 DAS, the concentration decreased by 22.3% on average. From the flowering stage, the Mn concentration in AW and SS increased, while remaining constant in SF.

The Manganese concentration in plants ranged from 274.3 to 346.7 mg plant^{-1}, which were similar to the values within 200 to 500 mg mentioned in higher plants by Fageria (2009). Values lower than those obtained in this study were indicated by Donega et al. (2013) at 50 DAS (9.11 to 15.71 mg plant^{-1}). The highest concentration recorded in this study could be related to the high production of biomass, promoted by the

Table 5. Nutrimental concentration of micronutrients (mg plant^{-1}) in coriander 70 days after sowing in three growth seasons in 2017.

Season	Fe	Zn	B	Mn	Cu
Autumn-Winter	56.6a*	36.1a	52.7a	380.1a	13.1a
Spring-Summer	51.5b	32.9b	48.3b	346.7b	11.9b
Summer-Fall	49.8b	32.1b	51.6a	274.3c	11.6b
Mean	52.6	33.7	50.9	333.7	12.2

*Different letters in the row indicate significant differences according to Tukey's test ($P \leq 0.05$).

increase in the photosynthetic area from the foliage that the plants showed in the three growth seasons (Havlin et al. 1999).

The principal components analysis indicated that the second most required micronutrient by coriander was Fe (Table 5). At 20 DAS, the highest Fe's concentration was registered during growth stage, with a subsequent decrease of 70.8% at commercial ripe stage (Figure 1b). The highest values in the vegetative and flowering stage were registered (136.3 and 75.1 mg plant^{-1}, resp.) in the AW season. The Iron concentration determined in this study was within the values mentioned by Havlin et al. (1999), and Kobayashi and Nishizawa (2012) (50 to 250 mg plant^{-1}). Donega et al. (2013) reported values from 24.08 to 36.67 mg plant^{-1}. Conversely, Said-Al Ahl and Omer (2009) reported concentrations from 89.3 to 193.6 mg plant^{-1} in the vegetative stage and from 99 to 232 mg plant^{-1} in the flowering stage. Both authors mentioned that the most required micronutrient by the coriander is Fe, while the results found in the present study suggested that the micronutrient most required by coriander is Mn.

In general, Zinc concentration was constant during the three crop seasons. Its concentration was 23.4 to 39.6 mg plant^{-1} (Table 5). The principal components analysis suggests that it is the third micronutrient most required by coriander (Figure 1a). The result obtained in this study corroborate that Zn is the second micronutrient required by coriander and that its concentration in the plant ranges from 17.8 to 29.7 mg plant^{-1}, as previously reported by Donega et al. (2013). Said-Al Ahl and Omer (2009) found that Zn concentration in coriander plants was from 57.3 to 82.0 and from 59.1 to 87 mg plant^{-1} in the vegetative and flowering stages, respectively, values that were higher than those found in this study.

According to the results obtained from the principal components analysis and plant nutritional status in this study, copper (Cu) is the least required micronutrient. The Cu concentration recorded was from 11 to 13 mg plant^{-1} from growth stage (Table 5). Havlin et al. (1999) mentioned that in higher plants, the concentration of Cu ranged from 5 to 20 mg and that concentrations lower than 4 ppm are a symptom of deficiency. Although the maximum concentration (13.1 mg plant^{-1}) found in this study did not cause toxicity symptoms. Donega et al. (2013) did not find symptoms of deficiency in coriander when the Cu concentration was 0.6 mg plant^{-1}, which differed from that found in this study, also indicated by Havlin et al. (1999).

However, coriander requires minimum amounts of copper, so it is deduced that the Cu accumulation in the plant tissue was influenced by the application of copper-based fungicides used to control foliar diseases from 20 DAS to the floral umbels emission stage, and not by the absorption of the plant.

Agronomic components

The highest plant height (PH; 56.4 cm), fresh weight (FW; 226.7 g pta^{-1}) and dry weight (DW; 30.7 g pta^{-1}) were recorded in A-W season (Table 6). The lowest values of PH, FW and DW were recorded in S-S season. Regarding the basal leaf number (BLN), there were no significant differences ($P \leq 0.05$), while fresh biomass yield (FBY) in the three crop seasons was 93.3 t ha^{-1} on average. The oil content in the three seasons was from 7.62 to 8.12%.

The results obtained may be because weather and nutrition are essential in creating the plant dry matter, as well as many energy-rich compounds that regulate photosynthesis and plant biomass production.

Table 6. Biometric analysis of INIFAP-17 variety of coriander cultivated in three growth seasons in 2017.

Season	PH¶	BLN	FW	DW	FBY	Oil
	cm	#	g	G	t ha^{-1}	%
Autumn-Winter (AW)	56.4a*	31a	226.7a	30.7a	98.8a	7.73a
Spring-Summer (SS)	43.7b	29a	196.1b	20.8c	88.6b	8.12a
Summer-Fall (SF)	51.2a	31a	208.3b	26.4ab	92.5b	7.62a
Mean	50.4	30.3	210.4	26.0	93.3	7.82

*Different letters in the row indicate significant differences according to Tukey's test ($P \leq 0.05$). ¶PH = plant height; BLN = basal leaves number; FW = fresh weight; DW = dry weight; FBY = fresh biomass yield.

Hnamte et al. (2013), with the application of biofertilizers + NPK + vermicompost, obtained a PH of 40.5 cm and 7.2 BLN on average, while Patel et al. (2013) reported a PH of 74.5 cm and 5.1 BLN when applying 60N-30S kg ha^{-1}. Donega et al. (2013), in five coriander accessions, showed plants with 7.24 basal leaves that produced a fresh weight of 5.04 to 7.37 g and from 0.33 to 0.61 g of dry weight on average. Meanwhile, Grangeiro et al. (2011) found plants with 0.92 g of DW. The largest FW and DW obtained in this study could be due to the variety used to produce a greater number of basal leaves and the use of taller plants than the varieties used in other studies. Conversely, Rashed and Darwesh (2015) found plants of 134 cm in height with 10.8 BLN, 442.3 g of FW and 158.1 g of DW on average in plants sown in October, values that were higher than those obtained in this study. Regarding oil content in the coriander seed, the oil levels found in this study were greater than the 5% reported by Khodadadi et al. (2016) in seeds without dehulling.

Conclusions

The principal components analysis and plant nutritional status results suggest that the macronutrient most required by coriander is N, followed by K and Ca (N > K > Ca > S > P > Mg), while Mn and Fe were the most demanded micronutrients (Mn > Fe> Zn > Cu). The growth season did not influence the concentration of nutrients, but it did affect the production of biomass. AW was the best season for sowing coriander in Bajío region. The different phenological stages showed variation in nutrient concentration, registering the highest concentration of macro and micronutrients in the floral umbels emission stage.

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