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Coriander Essential Oil Composition from Two Genotypes Grown in Different Environmental Conditions

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The objective was to study the essential oil composition of coriander fruits in plants growing in environments differing in soil conditions and weediness level. Factorial field experiments were conducted in two locations from the Rolling Pampas, Argentina, and two coriander landraces (European and Argentinean) were tested under two levels of nitrogen fertilization and weediness. Data were evaluated with uni- and multivariate techniques. The variation in the oil composition was related to the relative proportion of the constituents and not to the presence/absence of a particular component. Weather conditions in 1997 favored linalool and camphor in both landraces. Location, fertilization, and weediness also affected the chemical profile. The European landrace showed a more stable concentration of the major components than the Argentinean landrace. These results, which show the relationships between some environmental conditions and the essential oil composition, are useful in the development of innovative strategies aimed to improve oil composition and to manage crop pests.

KEYWORDS: Coriander; *Coriandrum sativum*; terpenes; soil condition; fertilization; weedines

INTRODUCTION

Genotype is a major determinant of how plants acquire and utilize resources and leads to large differences in secondary metabolite synthesis (*1*). Variations in the environment also influence the production of secondary metabolites, which is frequently increased by both biotic and abiotic stresses (*2*−*6*), and can also influence the essential oil composition (*7*−*9*). Variations in volatile terpene composition have an ecological function, producing a different biological signal related to the complexity of their components (*10*, *11*).

Hornok (*12*) detected strong dependence among temperature, radiance during fruit development, and water supply of crops of coriander (*Coriandrum sativum* L.) and its essential oil contents, but scarce data are published about the relationship between ecological or agronomic variables and essential oil composition in coriander. de la Fuente et al. (*13*) found that the impact of site degradation on coriander essential oil yield was significantly different between coriander landraces and soil degradations. The essential oil yield of two landraces was higher in the most degraded soils. This difference in adjustment of the crop to the ecological conditions can be extended to its tolerance to pest and disease attacks, as well as weed competition (*11*, *14*−*17*). These results have economic implications related to the management strategies adopted in the face of site degradation, that is, adding inputs (water, agrochemicals) could be useless if soil degradation is the main limiting environmental factor (*13*).

Considering ecological implications and applications in agriculture, knowledge of the chemical composition related to site degradation may allow the production of crops with specific quality (*8*) and with their "personal bodyguards" via chemical signals that protect them in a very environmentally friendly manner (*16*). Terpenoids may be produced in defense against herbivores but may also serve as secondary functions attracting the natural enemies of these herbivores (*18*−*21*).

Our objective was to study how site quality affected the composition of coriander essential oil. Changes in site quality were achieved by combining two nitrogen fertilization and two weed infestation levels with two soil conditions created by cropping history.

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Table 1. Meteorological Conditions during the Experiments[a]

month	year	rad (MJ m^{-2})	T_{max} (°C)	T_{min} (°C)	T_{me} (°C)	rain (mm)
August	1996	402.85	21.58	6.39	13.98	28.10
	1997	331.93	18.41	6.43	12.42	38.10
September	1996	418.10	19.94	6.26	13.10	34.50
	1997	456.96	20.11	7.00	13.55	8.60
October	1996	559.37	24.06	11.45	17.75	48.40
	1997	534.05	21.45	10.50	15.97	214.70
November	1996	690.16	28.09	13.25	20.67	67.10
	1997	611.23	25.56	14.25	19.91	188.60
December	1996	671.53	29.30	16.69	23.00	96.00
	1997	598.56	26.78	15.17	20.98	135.40

[a] Monthly values are averages for maximum (T_{max}), minimum (T_{min}), and mean temperature (T_{me}) and cumulative for solar radiation (rad) and rainfall (rain).

MATERIALS AND METHODS

Site and Growing Conditions. During 1996 and 1997, we conducted field experiments in the center of the Rolling Pampas, Argentina (32−35° S and by 58°−62° W), on silty clay loam soils. The Rolling Pampas, an important temperate crop-producing area in Argentina, have been cropped for more than a century (*22*), and since the late 1970s, soybeans [*Glycine max* (L.) Merr.] have increased cropping intensity and the soil degradation rate (*14*, *15*, *23*, *24*). The original abiotic (physical and chemical) and biotic characteristics of the Mollisols dominant in the Rolling Pampas landscape have been changed by soil compaction, nutrient exploitation, and replacement of soil fauna and flora by pest pathogens and weeds (*14*, *15*, *25*−*29*).

We located a set of fields in the highlands within the Arroyo Dulce soil series (*30*) and classified them in relation to their management history and indicators based on soil analysis and weed communities, developed by de la Fuente et al. (*28*), Suárez et al. (*31*), Cárcova et al. (*32*), and Maddonni et al. (*26*, *27*). Two groups with contrasting soil degradations were identified. Fields in the high degradation group presented a large number of agricultural cycles (>10 years), soils with low stability indices (<20%), and the absence of the floristic group indicators of soils with low degradation. Fields in the group with low degradation presented a low number of agricultural cycles (<10 years), high stability index (>20%) expressed as a proportion of pristine soil mean weighted diameter of aggregates (*33*) and the presence of the weed floristic group indicators of low soil degradation.

Data on meteorological conditions of the region (temperature, solar radiation, and rainfall) from the nearest meteorological station (<30 km) were gathered (**Table 1**).

Field Experiment. We designed a complete randomized block design factorial experiment with three replicates, in two locations differing in the level of soil degradation (high and low). Two landraces (called by us Argentinean and European landraces of coriander, as indicated by the genetic origin of their ancestors), two levels of nitrogen fertilization (0 and 135 kg of N/ha), and two levels of weed infestation (with and without weed control) were tested. Soil samples were taken before sowing date, to determine initial soil conditions (**Table 2**).

On August 17,. 1996, and July 25, 1997, we sowed 48 plots of 20 m^2 with a plot sowing machine. Each plot consisted of 21 rows, 17.5 cm apart and 5.5 m long, and sowing density was 450 seeds/m^2.

The two coriander landraces we tested differ significantly with regard to some traits. The Argentinean coriander landrace produces high average fruit weight (∼11 mg per dry fruit) and low essential oil content (∼0.5% v/w) (*34*). It is mainly used for spice production. The European coriander landrace has low average fruit weight (∼5 mg per dry fruit) and high potential of essential oil content (∼2% v/w). It is mainly used for essential oil extraction (*34*). Although coriander essential oil yield has been the subject of several studies (*13*, *34*, *35*), the response of the essential oil composition of both landraces to changes of the environmental quality (physical, chemical, and biological) is unknown.

At the sowing date, we fertilized plots manually with urea, and every 15 days the plots were hand-weeded, according to treatments, simulating traditional crop management techniques normally used in winter crops in this region.

Table 2. Two Year Means for Years from the Last Pasture, Stability Index (SI), Organic Carbon (C), Organic Nitrogen (Nt), and pH in Soils with High and Low Soil Degradation

	soil layer (cm)	location (soil degradation) low	high
years from last pasture		3	20
SI (%)	0–20	31.9	19.2
C (%)	0–20	2.29	2.14
	20–40	1.94	2.04
Nt (%)	0–20	0.25	0.22
	20–40	0.21	0.22
pH	0–20	6.8	6.4
	20–40	7.4	6.4

We visually evaluated weed species cover−abundance (*36*) in plots without weed control.

Determination of Content and Essential Oil Composition. At physiological maturity we harvested ∼200 g of coriander by hand from plants selected randomly from each plot and crushed under identical conditions. We obtained the oils by hydrodistillation of crushed samples (extraction time = 2 h) using a Clevenger-type apparatus according to the European Pharmacopoeia method (*37*). The oil was dried over anhydrous sodium sulfate and stored at −18 °C until analyzed.

We performed GC analysis on a Hewlett-Packard 5890 series II gas chromatograph equipped with two flame ionization detectors (255 °C), two fused capillary columns of different polarities, a methyl silicone and a polyethylene glycol 20000 column (HP-1 and HP-Wax, 50 m × 0.25 mm, film thickness = 0.25 mm), which were used simultaneously, and a split injector at 255 °C (split ratio = 1:150). The temperature was programmed from 90 to 220 °C at a rate of 3 °C/min. Nitrogen was used as gas carrier at a flow rate of 0.8 mL/min.

GC-MS was performed on a Perkin-Elmer Autosystem gas chromatograph Q-mass 910 quadrupole mass spectrometer, equipped with two fused silica columns, a nonpolar J&W DB-1 (30 m × 0.25 mm, 0.25 μm film thickness) and a polar DB-Wax (30 m × 0.25 mm, 0.25 μm film thickness). The GC parameters were the same as abovementioned, but helium was used as carrier gas. Mass units were monitored from 45 to 350 at 70 eV.

We identified the oil components by (1) determination of their retention indexes (RI) in relation to a homologous series of fatty acids methyl esters (C_4−C_{18}) (*38*) and (2) comparison of their mass spectra, which were compared with those in our own library (built with pure standards and reference essential oils of known composition) and with literature data (*39*).

Statistical Analyses. To reveal the relationship among essential oil samples and to identify the possible factors that explain the variation in the essential oil composition, we analyzed the composition data by multivariate statistical procedures: principal component analysis (PCA, indirect gradient analysis) (*40*, *41*).

We tested fixed effects: year, location, fertilization, and weediness with ANOVA using a mixed procedure (SAS), for essential oil content and major components of the essential oil. Blocks within year and location effects were considered to be random. When the location × treatments interaction was significant, we used the test of effect slices (SAS) to compute the simple effect of location.

RESULTS

Meteorological conditions, temperature, and radiation were slightly different between 1996 and 1997. Rainfall was higher in the 1997 growing season than in 1996, especially around fructification (**Tables 1** and **3**). Broad-leaved species accounted for 60−90% of the weeds present in the plots, and their cover-abundance was 1.0−2.5%. Grasses accounted for 10−40% of the weeds, and their cover-abundance ranged from 0.14 to 1.75%. Total cover-abundance did not differ among nonweeded plots ($P < 0.05$), ranging from 0.14 to 2.5%.

Table 3. Phenological Events of the Studied Coriander Landraces

	days from sowing			
	Argentinean		European	
	1996	1997	1996	1997
start of flowering	83	82	91	90
seed filling	98	128	108	138

Analyses of the essential oils (**Table 4**; **Figure 1**) showed 16 main identified constituents. Regardless of the landrace, linalool, α-pinene, γ-terpinene, camphor, geranyl acetate, and geraniol were the major constituents in the essential oil, and camphene, β-pinene, sabinene, myrcene, limonene, *p*-cymene, terpinolene, terpinen-4-ol, (*E*)-2,2-decenal, and α-terpineol were the minor constituents.

Results of principal component analysis (PCA) considering the whole data set showed a suitable projection of samples in the space formed by the two first principal components, because 95.3% of the total variance was retained in this projection (**Figure 2**). Axis 1 (88.9% of variance) showed a contrast between the landraces, whereas axis 2 (6.3% of variance) presented a contrast between years.

The correlation between essential oil constituents and the two principal components indicated that linalool was negatively correlated with axis 1 ($r = -0.99$), whereas α-pinene and myrcene were positively correlated with the same axis ($r = 0.94$ and 0.95, respectively). Camphor was negatively correlated with axis 2 ($r = -0.62$), whereas γ-terpinene was positively correlated with the same axis ($r = 0.82$) (**Table 5**).

We considered both landraces separately for the analysis to identify the main factors and to see their relationship with the different environments. In the Argentinean coriander landrace, results of PCA showed a suitable projection of samples in the space formed by the two first principal components, because 94.7% of the total variance is retained in this projection (**Figure 3**). Axis 1 (88.5% of variance) showed a contrast between years, whereas axis 2 (6.2% of variance) presented a contrast between locations (soil degradation), mainly during 1997, when rainfall was higher than in 1996. The correlation between constituents and the two principal components indicated that linalool was

Table 4. Essential Oil Composition in Fruits of the Two Studied Coriander Landraces

main component	% of total terpenes			
	European		Argentinean	
	1996	1997	1996	1997
α-pinene	5.9 (1.1)	5.1 (0.8)	4.4 (0.7)	2.1 (0.9)
camphene	0.8 (0.1)	0.8 (0.15)	0.3 (0.04)	0.3 (0.1)
β-pinene	0.5 (0.07)	0.4 (0.05)	0.4 (0.07)	0.2 (0.05)
sabinene	0.3 (0.03)	0.3 (0.03)	0.3 (0.03)	0.1 (0.03)
myrcene	0.9 (0.1)	0.8 (0.1)	0.5 (0.04)	0.3 (0.1)
limonene	2.0 (0.2)	1.9 (0.2)	0.9 (0.08)	0.7 (0.2)
γ-terpinene	4.7 (0.6)	3.9 (0.6)	5.6 (0.6)	2.7 (1.1)
p-cymene	0.7 (0.2)	1.2 (0.6)	1.0 (0.1)	1.0 (0.5)
terpinolene	0.3 (0.03)	0.4 (0.2)	1.3 (0.4)	0.2 (0.02)
linalool	72.2 (1.9)	73.1 (2.4)	77.7 (2.0)	82.9 (2.3)
camphor	4.6 (0.2)	4.9 (0.2)	2.4 (0.2)	3.0 (0.6)
terpinen-4-ol	0.2 (0.06)	0.02 (0.04)	0.5 (0.2)	0.4 (0.4)
(*E*)-2,2-decenal	0.2 (0.06)	0.1 (0.07)	0.4 (0.2)	0.3 (0.3)
α-terpineol	0.5 (0.04)	0.4 (0.07)	0.2 (0.02)	0.2 (0.03)
geranyl acetate	1.7 (0.5)	2.3 (0.3)	1.4 (0.4)	1.1 (0.3)
geraniol	3.9 (0.3)	2.7 (0.3)	2.3 (0.3)	1.9 (0.3)

[a] Means over all treatments; values in parentheses are standard deviations.

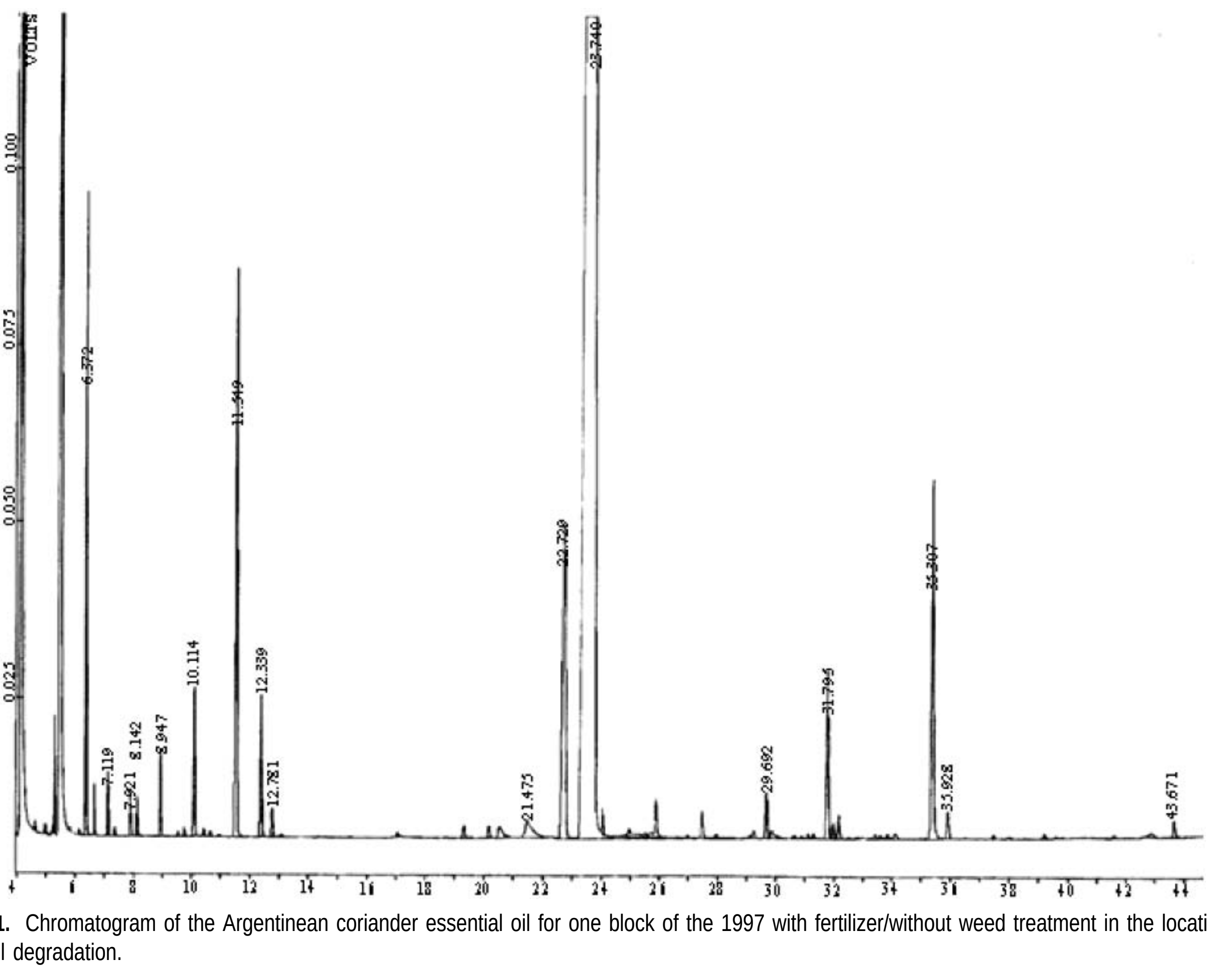

Figure 1. Chromatogram of the Argentinean coriander essential oil for one block of the 1997 with fertilizer/without weed treatment in the location with high soil degradation.

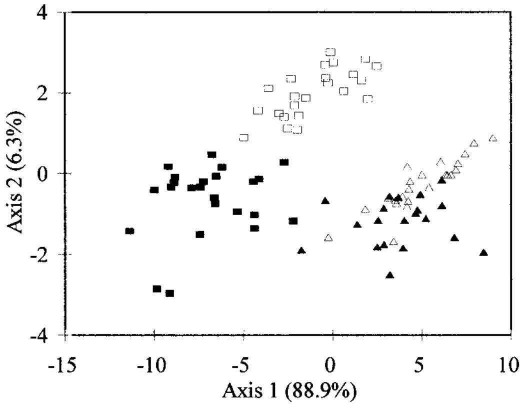

Figure 2. PCA of terpenoid composition from two coriander landraces in 1996 and 1997: (triangles) European landrace; (squares) Argentinean landrace. Open symbols designate 1996 and solid symbols, 1997.

Table 5. Correlation (*r*) of the Essential Oil Components with the Two Main Axes of PCA of the Whole Data Set

	r	
component	axis 1	axis 2
α-pinene	0.94	0.23
camphene	0.83	−0.35
β-pinene	0.81	0.53
sabinene	0.88	0.39
myrcene	0.95	−0.08
limonene	0.90	−0.26
γ-terpinene	0.54	0.82
p-cymene	0.02	−0.15
terpinolene	0.12	0.06
linalool	−0.99	0.03
camphor	0.67	−0.62
terpinen-4-ol	−0.33	0.28
(*E*)-2,2-decenal	−0.33	0.22
α-terpineol	0.88	−0.17
geranyl acetate	0.55	−0.35
geraniol	0.72	−0.13

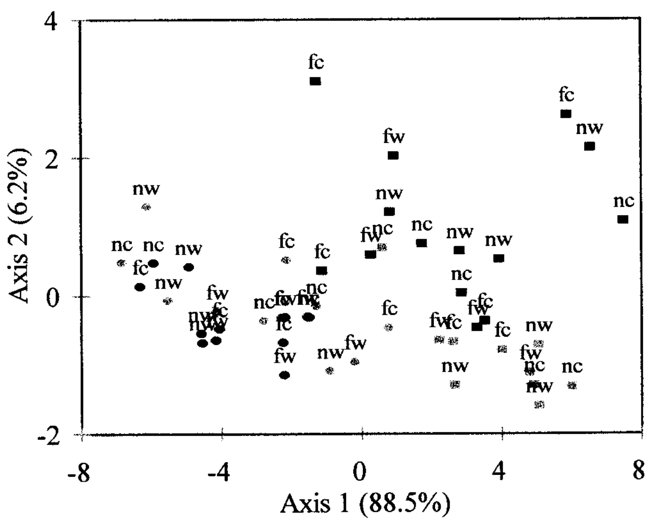

Figure 3. PCA of terpenoid composition from the Argentinean landrace in 1996 and 1997: (circles) 1996; (squares) 1997. Soil degradation is designated by the darkness of the symbol [low (black); high (gray)]. Labels refer to fertilization [(f) fertilizer; (n) no fertilizer] and to weed infestation level [(w) not weeded; (c) weeded].

positively correlated with axis 1 ($r = 0.99$), whereas α-pinene, *β*-pinene, and sabinene were negatively correlated with the same axis ($r = -0.93$, -0.94, and -0.94, respectively). Terpinen-4-ol and (*E*)-2,2-decenal were positively correlated with axis 2 ($r = 0.67$ and 0.65, respectively), and *γ*-terpinene was negatively correlated with the same axis ($r = -0.41$) (**Table 6**).

Table 6. Correlation of the Essential Oil Components with the Two Main Axes of PCA of the Argentinean and European Coriander Essential Oil Data Set

	r			
	Argentinean		European	
component	axis 1	axis 2	axis 1	axis 2
α-pinene	−0.93	−0.33	0.90	−0.19
camphene	−0.23	−0.22	0.63	0.003
β-pinene	−0.94	−0.23	0.81	−0.42
sabinene	−0.94	−0.23	0.85	−0.11
myrcene	−0.89	−0.37	0.81	−0.34
limonene	−0.69	−0.38	0.79	−0.14
γ-terpinene	−0.91	−0.41	0.63	−0.67
p-cymene	−0.21	0.28	0.000	0.83
terpinolene	−0.12	−0.11	0.54	−0.74
linalool	0.99	−0.15	−0.99	−0.13
camphor	0.31	0.10	−0.46	0.44
terpinen-4-ol	−0.30	0.67	0.34	−0.55
(*E*)-2,2-decenal	−0.14	0.65	0.11	−0.36
α-terpineol	−0.80	−0.33	−0.47	0.17
geranyl acetate	−0.36	0.13	−0.26	0.78
geraniol	−0.54	0.04	0.17	−0.83

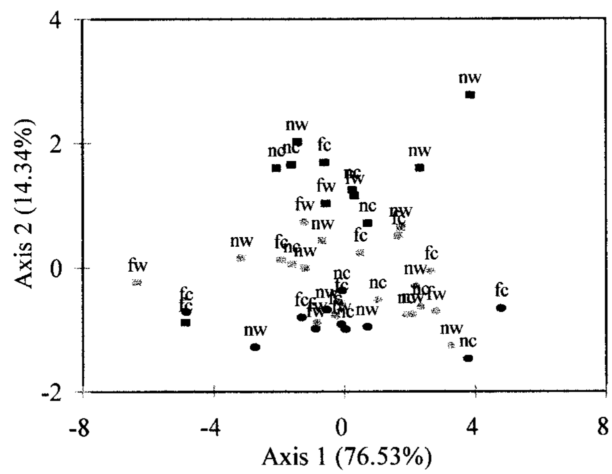

Figure 4. PCA of terpenoid composition from the European landrace in 1996 and 1997: (circles)1996; (squares) 1997. Soil degradation is designated by the darkness of the symbol [low (black); high (gray)]. Labels refer to fertilization [(f) fertilizer; (n) no fertilizer] and to weed infestation level [(w) not weeded; (c) weeded].

In the European coriander landrace, although axis 1 explained a great proportion of the variation (76.53% of variance), apparently this variation was not attributed to a specific contrast between the studied treatments, whereas axis 2 (14.34% of variance) presented a contrast between years and, within the 1997 year, a contrast between locations (**Figure 4**). The correlation between constituents and axis 2 indicated the specific discriminant power of the following compounds: geraniol ($r = -0.83$), *γ*-terpinene ($r = -0.67$), geranyl acetate ($r = 0.78$), and *p*-cymene ($r = 0.83$) (**Table 6**).

The ANOVA showed some differences in the composition of the main volatile constituents of coriander fruits related to the environment (**Tables 7** and **8**). In the Argentinean coriander landrace we observed significant differences ($P \leq 0.05$) between main factors: year, location, and fertilization for geranyl acetate. We also observed the following significant ($P \leq 0.05$) interactions: year × fertilizer for linalool and geraniol, year ×

Table 7. Mean and ANOVA of the Major Components of the Argentinean Coriander Essential Oil

factor	level	essential oil content (%; v/w dry fruit)	α-pinene[a] (%)	γ-terpinene[a] (%)	linalool[a] (%)	camphor[a] (%)	geranyl acetate[a] (%)	geraniol[a] (%)
year (Y)	1996	0.29	4.39	5.65	77.70	2.42	1.44	2.29
	1997	0.33	2.13	2.78	82.96	3.05	1.13	1.98
locations (L)	high	0.38	3.26	4.31	81.05	2.8	1.13	2.23
	low	0.23	3.27	4.12	79.61	2.67	1.44	2.04
fertilizer (F)	without	0.30	3.31	4.15	80.32	2.62	1.12	2.13
	with	0.31	3.22	4.29	80.34	2.85	1.45	2.14
weeds (W)	without	0.32	3.21	4.07	80.29	2.72	1.34	2.17
	with	0.30	3.31	4.36	80.37	2.76	1.24	2.11
Y		0.26	0.0001	0.0001	0.0001	0.004	0.009	0.03
L		0.003	0.98	0.53	0.06	0.45	0.009	0.15
F		0.65	0.72	0.62	0.97	0.16	0.0004	0.91
W		0.61	0.72	0.31	0.91	0.80	0.23	0.43
Y × L		0.01	0.11	0.03	0.39	0.95	0.46	0.51
Y × F		0.05	0.12	0.20	0.04	0.56	0.10	0.05
Y × W		0.23	0.77	0.77	0.83	0.39	0.03	0.03
L × F		0.09	0.30	0.27	0.27	0.99	0.83	0.15
L × W		0.23	0.83	0.98	0.89	0.47	0.96	0.54
F × W		0.11	0.77	0.88	0.54	0.53	0.95	0.20
Y × L × F		0.56	0.57	0.89	0.90	0.20	0.78	0.92
Y × L × W		0.61	0.92	0.73	0.63	0.24	0.12	0.02
Y × F × W		0.25	0.67	0.62	0.90	0.28	0.52	0.85
L × F × W		0.90	0.96	0.86	0.45	0.80	0.92	0.09
Y × L × F × W		0.57	0.32	0.33	0.95	0.59	0.29	0.77

[a] Percentages calculated by GC peak area integration.

Table 8. Mean and ANOVA of the Major Components of the European Coriander Essential Oil

factor	level	essential oil content (%; v/w dry fruit)	α-pinene[a] (%)	γ-terpinene[a] (%)	linalool[a] (%)	camphor[a] (%)	geranyl acetate[a] (%)	geraniol[a] (%)
year (Y)	1996	1.62	5.87	4.75	72.26	4.65	1.68	3.92
	1997	1.34	4.95	3.89	73.64	4.92	2.31	2.76
locations (L)	high	1.90	5.6	4.34	73.14	4.79	1.94	3.35
	low	1.05	5.22	4.3	72.76	4.78	2.05	3.33
fertilizer (F)	without	1.48	5.69	4.43	72.23	4.76	1.95	3.31
	with	1.47	5.13	4.21	73.67	4.81	2.04	3.37
weeds (W)	without	1.48	5.28	4.24	73.08	4.86	1.97	3.28
	with	1.48	5.54	4.4	72.82	4.71	2.02	3.4
Y		0.005	0.02	0.006	0.08	0.01	0.002	0.0001
L		0.0001	0.26	0.83	0.59	0.88	0.52	0.87
F		0.89	0.09	0.32	0.05	0.38	0.47	0.68
W		0.99	0.42	0.46	0.70	0.02	0.75	0.37
Y × L		0.0001	0.15	0.48	0.04	0.50	0.27	0.23
Y × F		0.15	0.95	0.45	0.47	0.81	0.15	0.34
Y × W		0.81	0.94	0.62	0.84	0.24	0.96	0.21
L × F		0.03	0.26	0.08	0.98	0.70	0.99	0.54
L × W		0.26	0.41	0.59	0.18	0.10	0.97	0.60
F × W		0.25	0.44	0.93	0.33	0.90	0.67	0.47
Y × L × F		0.64	0.96	0.51	0.62	0.12	0.14	0.53
Y × L × W		0.13	0.12	0.51	0.04	0.58	0.65	0.68
Y × F × W		0.31	0.25	0.70	0.24	0.84	0.71	0.86
L × F × W		0.28	0.07	0.06	0.10	0.68	0.79	0.34
Y × L × F × W		0.10	0.73	0.27	0.44	0.75	0.10	0.53

[a] Percentages calculated by GC peak area integration.

weediness for geranyl acetate, year × location for γ-terpinene, and year × location × weeding for geraniol. In the European coriander landrace, we observed significant ($P \leq 0.05$) differences between main factors: fertilizer for linalool, weeding for camphor, and year for camphor, α-pinene, γ-terpinene, geranyl acetate, and geraniol. We also observed significant ($P \leq 0.05$) year × location × weeding interaction for linalool.

We tested differences between locations with the test of effect slices. In the Argentinean coriander landrace, the significant two-way interaction, year × location, for γ-terpinene was caused by a significant difference due to location in 1997 ($P = 0.05$). The significant three-way interaction, year × location × weeding, for geraniol was caused by a significant difference due to location for the year 1996 with weed treatment ($P = 0.02$) but no significant location effect without weeds in 1996 or in 1997 irrespective of weed treatment. In the European coriander landrace, the significant three-way interaction, year × location × weeding, for linalool was caused by a significant difference due to location for the year 1997 without weed treatment ($P = 0.008$) but no significant location effect with weeds in 1997 or in 1996 irrespective of weed treatment.

In previous studies we observed that Argentinean coriander landrace produced high biomass and fruit yield in good environments (low soil degradation and high water availability), and the European coriander landrace produced similar biomass in the different environments tested. Essential oil yields in the two landraces were higher in the poorer environments (*13*).

The ANOVA showed some differences in the essential oil content (percent v/w) of coriander fruit (dry fruit) related to the environment (**Tables 7** and **8**). Essential oil concentration was greater for both coriander landraces, mainly in poor environments (high soil degradation and low water availability). The Argentinean coriander essential oil concentration was lower for the fertilizer treatments than for the rest of the treatments during 1996.

We tested differences between locations for the significant two-way interactions (**Tables 7** and **8**) with the test of effect slices. In both coriander landraces essential oil concentration was higher for the location with high soil degradation ($P = 0.001$) for 1997. In the European coriander landrace essential oil concentration was lower in the location with low soil degradation irrespective of fertilizer treatment ($P = 0.0001$).

DISCUSSION

The main factors that accounted for the observed variance were genotype and year, in accordance with previous studies on other coriander genotypes, showing organoleptic variation between plants from different origins (*42*) and important environmental effects on the composition of the essential oil (*43*) (**Figure 2**). The essential oil of both landraces produced the same compounds, but in different proportions. These proportions changed in response to environmental variation, and the sensitivities to this variation were different between landraces (**Tables 7** and **8**). The strong contrast between years and treatments observed with the multivariate analysis indicated that the Argentinean landrace was more sensitive to environmental change than the European landrace (**Figures 2−4**). Our results show that climate during the growing season has a strong influence on essential oil content. Considering that linalool is the main component of the essential oil in the plant from the fourth week of the growing cycle (*44*), environments that favor seed development may also favor linalool content (*43*, *45*). The 1997 growing season favored fruit yield related to higher rainfall and lower mean temperatures during the seed-filling period compared with the 1996 growing season (*13*). Therefore, the climatic differences between years could also explain the response of both coriander landraces to the conditions that prevailed during the 1997 growing season, thus favoring the production of linalool and camphor (**Tables 7** and **8**).

Results indicated that some changes in the major components due to fertilization, weeding, and location may be attributed to the characteristics of the year. Most essential oil compounds presented a high plasticity for the Argentinean landrace, whereas only linalool and camphor concentration presented high plasticity for the European landrace. We can then conclude that the environmental effects of location, fertilizer, and weediness were responsible for the variation in oil composition of coriander landraces by altering the concentration of their major components.

Essential oil concentration increased under limited site condition. This result confirmed our expectations that production of carbon-based secondary metabolites would be increase by both biotic and abiotic stresses (*2*, *3*, *6*).

Soil condition could affect assimilate availability, which is an important regulatory factor for essential oil content and composition. When essential oil content is expressed as a percentage of seed weight, content and composition depend on the absolute amount of oil per seed and the ratio of the main compounds determined by assimilate availability (*9*). Assimilate availability was probably different between locations, related to the soil degradation promoted by their cropping histories, and also between fertilization and weediness treatments.

It is interesting to point out that weed infestation may also change plant resource acquisition, allocation, and partitioning (*46*, *47*). These changes may in turn play a role in weed environment (*16*); however, it is hard to estimate the ecological significance of these changes because of the complexity of those problems.

The variations in the proportion of the coriander essential oil constituents related to the environment may have economic and ecological consequences. From an economic point of view, the market demands specific qualities of products. In this sense, both coriander landraces meet these specifications, but the European coriander may have some advantages because its composition was more stable than that of the Argentinean one. However, coriander oil is also used as a raw material for the isolation of natural (+)-linalool, a highly priced aromatic product. The Argentinean landrace had greater linalool proportion and lower α-pinene, camphor, and geraniol proportions than the European landrace (**Table 4**). Consequently, the essential oil produced by the Argentinean landrace can be regarded as being of promissory commercial quality where the isolation of (+)-linalool is concerned (*45*, *48*).

From an ecological point of view, considering that the oil in the fruit is related to the volatile compounds emitted by the crop (*49*), differences in the chemical signals emitted may produce different impacts on the arthropod community. It is important to remark that host chemical shifting is an important mechanism by which plants regulate insect fauna (*50*). Many different insect species are pollinators or visitors of coriander (*45*). More stable chemical signals, such as those given by the European landrace, may transmit arthropod-specific information, whereas variable chemical signals may be related to generalist arthropod species (*51*). The relationship between the environmental conditions and the emission of volatile compounds could be used as a way to improve agricultural practices. Particular essential oil emissions could then be targeted to attract communities of arthropods that are neutral or positive to crop production.

The main observed differences in the essential oil composition were related to the relative proportion of the constituents and not to the presence/absence of a particular component. Both genetic and phenotypic variations contributed to differences in the concentration of volatile terpenes in the current experiments, and the magnitudes of these differences varied between landraces. Greater phenotypic variation of the Argentinean coriander could be due to the minor selection pressure that this landrace received. The interaction among environmental factors (soil degradation, fertilization, and weediness) and genotypic differences between coriander landraces generated specific phenotypic responses reflected in changes in the concentration of volatile terpenes. These responses showed the greater phenotypic response of the Argentinean landrace. In both coriander landraces better conditions for fruit production favored linalool and camphor. Oil composition was sensitive to the year variation in weather conditions as well as in soil environment caused by cropping history. Weeds and fertilization produced a lower effect.

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