Effect of cumin seed (*Cuminum cyminum* L.) essential oil from Catamarca, Argentina, on the stored maize pests *Sitophilus zeamais* and *Fusarium verticillioides*

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DOI: 10.31047/1668.298x.v40.n1.38788

SUMMARY

The essential oil composition of *Cuminum cyminum* L. from Catamarca province, Argentina, and its insecticide and antifungal activities were studied, with the major constituents detected by gas chromatography (GC) and gas chromatography-mass spectrometry (GC/MS) being: cuminaldehyde (20.58 %), ϒ-terpinene (20.43 %), *p*-cymene (17.35 %) and β-pinene (13.75 %). Insecticidal activity was tested against *Sitophilus zeamais* Motschulsky. The results showed that cumin oil lethal concentrations (LC) LC_{50} and LC_{95} values were 66.39 µL/L air and 370.14 µL/L air, respectively. Moreover, the essential oil had a repellent effect at 4 µL/L and 0.4 µL/L and an inhibition of acetylcholinesterase activity of 88.39 % and 47.75 % at concentrations of 9.2 and 2.3 mg/L, respectively. Antifungal activity against *Fusarium verticillioides* was tested at 250,500 and 1000 µL/L. For the highest concentration of cumin essential oil, the mycelia growth was inhibited by around 80 %. Lag phase and growth rate of *F. verticillioides* was affected considerably and showed concentration dependence. The results obtained in this study revealed the possible use of cumin oil as a natural alternative in controlling *S. zeamais* and *F. verticillioides,* the main pests of stored maize.

Key words: cuminaldehyde, insecticidal effect, repellence-attraction, antifungal activity, acetylcholinesterase

Quiroga, V. del V., Pizzolitto, R. P., Zunino, M. P., Dambolena, J. S., Herrera, J. M. y Zygadlo J. A. (2023). Efecto del aceite esencial obtenido de semillas de comino (*Cuminum cyminum* L.) de Catamarca, Argentina, sobre las plagas de maíz almacenado, *Sitophilus zeamais* y *Fusarium verticillioides*. *Agriscientia 40*: 29-39

Fecha de recepción: 21/09/2022; fecha de aceptación: 07/07/2023.

RESUMEN

Se estudió la composición del aceite esencial de *Cuminum cyminum* L. de la provincia de Catamarca, Argentina, y su actividad insecticida y antifúngica. Los principales constituyentes detectados por GC y GC/MS fueron: cuminaldehído (20,58 %), ϒ-terpineno (20,43 %), *p*-cimeno (17,35 %) y β-pineno (13,75 %). Se evaluó la actividad insecticida contra *Sitophilus zeamais* Motschulsky. Los resultados mostraron valores de concentración letal (CL) CL_{50} y CL_{95} del aceite de comino de 66,39 µL/L y 370,14 µL/L de aire, respectivamente. Además, el aceite esencial tuvo un efecto repelente a 4 µL/L y 0,4 µL/L y una inhibición de la actividad acetilcolinesterasa de 88,39 % y 47,75 % a concentraciones de 9,2 y 2,3 mg/L, respectivamente. La actividad antifúngica contra *Fusarium verticillioides* se evaluó a 250, 500 y 1000 µL/L. En el caso de la concentración más alta de aceite esencial de comino, se observó una inhibición del desarrollo fúngico de aproximadamente 80 %. La fase de latencia y la tasa de crecimiento de *F. verticillioides* se vieron afectadas considerablemente y fueron dosis-dependiente. Los resultados obtenidos en este estudio revelaron el posible uso del aceite de comino como alternativa natural en el control de *S. zeamais* y *F. verticillioides*, principales plagas del maíz almacenado.

Palabras clave: cuminaldehído, efecto insecticida, repelencia-atracción, actividad antifúngica, acetilcolinesterasa

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INTRODUCTION

Cuminum cyminum L. (*Apiaceae*) is a shrub growing up to 40 cm high and cultivated for its seeds and essential oils since ancient times. Nowadays, cumin is found among the spices with the largest global marketing and is used in gastronomy and traditional medicine in countries such as India, Turkey, Iran, Pakistan and China. As a flavoring additive it has now been integrated in the western menu as a result of increased consumption of exotic or ethnic foods. To cover this higher demand for cumin seed and its essential oil, many producing countries should increase their crop areas and non-producers need to incorporate growing areas for the first time.

Argentina is among the most important South American exporters of cumin seeds, with a growing area of 5.95 square kilometers and a production of 900 Tons (Cameroni, 2012; Sánchez et al., 2020). Cumin growing areas in Argentina, traditionally represented by the provinces of Catamarca and Salta, have recently expanded to the provinces of La Rioja and Tucumán (Cameroni, 2012; Sánchez, 2012). A variety known as INTA Sumalao N°1 (Murua Carrizo, 2013) is the preferred type cultivated in Argentina. However, information concerning the composition of the essential oil of

cumin cultivated in Argentina is scarce (Bandoni et al., 1991). From previous studies, the analysis of essential oils of cumin has always shown β-pinene; ϒ-terpinene; *p*-cymene, *p*-mentha-1,4-dien-7-al and cuminaldehyde to be the main compounds, regardless of their geographical origins (Bandoni et al., 1991; Beis et al., 2000; Jalali-Heravi et al., 2007; Li et al., 2009; Derakhshan et al., 2010; Oroojalian et al., 2010; Bettaieb et al., 2011; Gohari and Saeidnia, 2011). On the other hand, *p*-mentha-1,3-dien-7-al, phellandral, acoradiene and 2-caren-10-al are constituents that are not always present in some essential cumin oils (El-Sawi and Mohamed, 2002; Gachkar et al., 2007; Allahghadri et al., 2010; Bettaieb et al., 2011; Yeom et al., 2012; Kim et al., 2013; Kedia et al., 2014). The international standard ISO 9301 for cumin seed oil (*C. cyminum* L.) shows that the major constituents of the chromatographic profile are: *p*-mentha-1,3-dien-7-al; *p*-mentha-1,4-dien-7-al; and *p*-mentha-3-en-7-al, with cuminic aldehyde, β-pinene and ϒ-terpinene being the main components (ISO 9301).

Cumin oil, in addition to its flavouring properties, has also shown antifungal activity (Hashem et al., 2010; Gohari and Saeidnia, 2011; Kedia et al., 2014) and antimicrobial activity. Thus, Gachkar et al. (2007) have reported bioactivity against diverse microorganisms: they have observed an inhibitory effect on *Escherichia coli, Staphylococcus aureus* and *Listeria monocytogenes* growth. Sharifzadeh et al. (2016) found minimal inhibitory concentration (MIC) values ranged from 1000 to 2000 mg/mL for the *Aspergillus* and *Penicillium* species tested. In addition, repellent and insecticidal activities of cumin oils have been reported against the rice weevil *Sitophilus oryzae* (Chaubey, 2011; Kim et al., 2013). Thus, this pest control capacity of cumin oil could be used to avoid the application of synthetic pesticides to control an infestation of insects or to prevent the growth of fungi on the stored food. In corn kernel silos, two pests of great significance are *S. zeamais* (Motschulsky) (Coleoptera: Curculionidae) and *F. verticillioides* (Zunino et al., 2015; Peschiutta et al., 2022; Brito et al., 2022). The former is a primary pest of stored maize that feeds on healthy grains, with the damage generated by its presence favouring fungal infections and the occurrence of secondary metabolites. The latter pest is the main fungal pathogen of maize plant and major fumonisin B_1 (FB_1) producer (Chulze, 2010). In this investigation, we studied the *C. cyminum* essential oil composition from Catamarca (Argentina) and its fumigant insecticidal and antifungal activities against the maize weevil and *F. verticillioides.*

MATERIAL AND METHODS

Plant material and essential oil obtainment

C. cyminum L. seeds were collected within the territory of the province of Catamarca, Argentina, during 2008-2010. The study area was between longitude -27.39° and -28.46° and latitude -65.73° and -67.25°. After drying the seeds at room temperature (30 °C), the plant material was hydrodistilled for five hours in a full glass Clevenger type apparatus. The oil was then separated, dried using anhydrous sodium sulphate, and stored in dark glass bottles in a freezer at -4 ˚C until being used. Four samples of cumin oil were analysed in this study.

Essential oil analysis

The gas chromatography (GC) study was performed using a Perkin-Elmer 500 gas chromatograph equipped with a flame ionization detector. A DB-5 fused silica capillary column (30 m x 0.25 mm, film thickness 0.25 µm, J&W Scientific Inc., Rancho Cordova, California, United States of America) was utilized with the working conditions being as follow: injector and detector temperature 250 °C and 265 °C, respectively; carrier gas, nitrogen; the oven temperature program 40 °C-250 °C, at a rate of 4 °C/min. The GC/MS equipment used was a Perkin Elmen Clarus 600 gas chromatograph coupled to a quadruple EI mass analyzer, with an apolar DB-5 capillary column (30 m × 0.25 mm, 0.25 µm film thicknesses). Helium was used as the carrier gas at a 0.8 ml/min flow rate. The mass spectrometer had an ionization potential of 70 eV, and the injector and the GC/MS interface temperatures were maintained at 290 °C and 300 °C, respectively. The mass spectra were recorded at 70 eV, and the mass range was from m/z 50 to 300. The ion source and the detector temperatures were maintained at 250 and 150 °C, respectively, and under a split condition (8:1), a 1 µl sample was injected.

Identification of compounds

The compounds of essential oil were identified by their retention index (RI) relative to the C_5-C_{24} n-alkanes (Sigma Aldrich, Buenos Aires, Argentina), by comparison of the mass spectra with those available in the NIST and Willey libraries and those of commercial standards by co-injection (Sigma Aldrich Co. Buenos Aires, Argentina). The peak area percentages were calculated from the

capillary column without the use of FID response factors.

Insects

The insects were unsexed adults of *S. zeamais* Motschulky (Coleoptera: Curculionidae) whichwere kept under controlled conditions (26 °C, 60-70 % relative humidity and a 12 h: 12 h lighting regime (D:L)), and reared on whole maize grains (Food and Agriculture Organization, 1974). The adult weevils used in all the experiments were approximately two weeks old, and the bioassays were carried out in darkness and under temperature (28 °C) and relative humidity (70 %) control.

Fungal strain and inoculum preparation

The fungal strain employed in the antifungal tests was *F. verticillioides* (Sacc) Niremberg (= F. *moniliforme* Sheldon teleomorph *G. fujikuroi* [Sawada] Ito in Ito & Kimura Leslie and Summerel, 2006]) strain M3125, which was provided by Dr. Robert Proctor from the United States Department of Agriculture (Agricultural Research Service, National Centre for Agricultural Utilization Research, Peoria, Illinois). Fungal conidia were harvested from 7-day old culture on Czapek-Dox agar medium employing aqueous solution. The conidial concentration (10^6 conidia/mL) was adjusted using a Neubauer chamber.

Insecticidal activity

The insecticidal activity against *S. zeamais* was evaluated by fumigant toxicity analysis as described by Huang et al. (2000) with some modifications. Concentrations corresponding to 18.75 to 300 µL/L air of essential oil doses were applied to Whatman filter paper disks (2 cm diameter), which were placed on the underside of the screw cap of the fumigation chambers (30 ml-glass vials). Then, ten weevils were placed in each chamber. After 24 h, insect mortality was verified, and the LC_{50} and LC_{95} values were calculated according to Finney (1971).

Five replicates were carried out per essential oil dose and the control treatment was performed under the same conditions without the addition of cumin oil.

Repellent/Attraction Bioactivity

A two-choice olfactometer was employed to evaluate the behavioral response of *S. zeamais* adults to cumin oil (Herrera et al., 2015). Two flasks (250 mL) were connected with a glass tube (30 cm × 1 cm of diameter) and in the middle (15 cm from the two flasks) a 1 cm × 1 cm small hole was made. The connections between the two flasks and the tube were sealed with rubber plugs, which were covered with parafilm to prevent gas leakage. The cumin oil (dissolved in n-hexane) was added to a filter paper of 2 cm diameter, which was placed inside the treatment flask. The solvent (n-hexane) was placed in a filter paper in the control flask. Twenty insects, deprived of food for at least 24 h, were placed in the hole of the glass tube. After 2 h, we recorded the location of the insects in the flasks. Repellent/Attraction bioactivity assays were replicated five times.

A response index (RI) was calculated by the following equation: $RI = [(T - C)/Tot] \times 100$. Where T is the number of insects responding to the treatment; C is the number of insects responding to the control; and Tot is the total number of insects released (Phillips et al., 1993). Positive (+) values of RI indicate attraction to the treatment. Negative (–) values of RI indicate repellence to the treatment.

In vitro AChE inhibition tests

The acetylcholinesterase (AChE) activity was evaluated by employing a 96-well microplate method proposed by Brühlmann et al. (2004), with modifications.The effect of different concentrations of *C. cyminum* EO (9.2 and 2.3 mg/L) on AChE activity was evaluated using *S. zeamais* adults (0.5 g, approximately 100 adults) homogenized in 5 mL of 0.1 M ice-cold phosphate buffer (pH 7.4) using a Teflon glass tissue homogenizer. Then, the homogenates were centrifuged (5000 rpm for 20 min at 0 °C) and supernatants were used as the enzyme source for AChE activity determination. A colorimetric method described by Ellman et al. (1961) was used to determine the inhibition of AChE, as a percentage calculated as: AChE inhibition % = (ODC – ODT/ODC) × 100, whereas ODC is the optical density of control and ODT is the optical density of the treatment. All the treatments were repeated three times.

Effect of essential oil on fungal growth

F. verticillioides inhibition was tested by the plate dilution method using Czapek-dox agar. The culture medium was autoclaved (120 °C for 15 minutes) and cumin EO was added before cooling at 45 °C, to obtain concentrations of 250, 500 and 1000 µL/L. Then 10 µL of the conidia suspension,

prepared as described above, was inoculated centrally in the Czapek-dox agar plates, and was incubated at 28 °C until the fungal growth reached the edge of the plate. The control treatment was prepared using Czapek-dox agar plates without the addition of EO and five replicates were performed per essential oil dose. The periodical measurement of two right-angled diameters of the colonies was used to determine the radial mycelial growth, colony diameters versus time were plotted, and the radial growth rates (mm/day) were evaluated from the slope by linear regression, with lag phase being determined as the abscissa from the growth rate curves.

Statistical analysis

Data were analyzed using InfoStat Software (Di Rienzo et al., 2017). Behavioral responses and anti-AChE activities were evaluated by Duncan's multiple range test at $p \leq 0.05$. The LC_{50} and LC_{95} values were obtained using Probit analysis (Finney, 1971). In the antifungal bioassays, data were evaluated through two-way variance analysis (ANOVA). Data normality was tested using the Shapiro–Wilk test. Comparisons between treatments were performed by the DGC (Di Rienzo, Guzmán and Casanoves) test (Di Rienzo et al., 2002). Results giving $p < 0.05$ values were considered significantly different.

RESULTS AND DISCUSSION

The essential oil composition obtained from cumin seeds is presented in Table 1. The cumin essential oil content, expressed on a dry basis, was 4.4 ± 0.4 ml per 100 g of ground dry cumin subjected to hydro distillation. The essential oil obtained from these cumin seeds were pale yellow and had a pungent odor.

As a result of our GC-MS studies, a total of 27 compounds were identified for the essential cumin oils, with β-pinene (13.75 %), *p*-cymene (17.35 %), ϒ-terpinene (20.43 %), cuminaldehyde (20.58 %), 2-caren-10-al and *p*-mentha-1,4-dien-7-al (9.88 %) that represents more than 89 % of the total compounds. The bibliography reports β-pinene, ϒ-terpinene, cuminal and *p*-mentha-1,4-dien-7-al being the major compounds of cumin oil

Table 1. Chemical composition of *Cuminum cyminum* L. essential oil from Catamarca

Peak No.	Compounds	Retention Indices	Percentage (%) ± S.E	Identification
1	α-thujene	921	0.16 ± 0.11	GCMS, RI
2	α-pinene	934	0.65 ± 0.11	GCMS, RI
3	sabinene	970	0.60 ± 0.12	GCMS, RI
4	β-pinene	975	13.76 ± 2.24	GCMS, Co, RI
5	β-myrcene	990	0.76 ± 0.16	GCMS, Co, RI
6	α-phellandrene	1001	0.10 ± 0.04	GCMS, RI
7	δ-3-carene	1009	0.40 ± 0.20	GCMS, RI
8	*p*-cymene	1022	17.35 ± 4.66	GCMS, Co, RI
9	limonene	1027	0.50 ± 0.28	GCMS, Co, RI
10	ϒ-terpinene	1057	20.43 ± 3.23	GCMS, Co, RI
11	*cis*-sabinene hydrate	1066	0.06 ± 0.01	GCMS, RI
12	*trans*-pinocarveol	1137	0.31 ± 0.43	GCMS, RI
13	sabina ketone	1155	0.28 ± 0.42	GCMS, RI
14	terpinen-4-ol	1175	0.47 ± 0.65	GCMS, Co, RI
15	cuminaldehyde	1237	20.58 ± 0.48	GCMS, Co, RI
16	phellandral	1274	0.14 ± 0.02	GCMS, RI
17	2-caren-10-al	1281	7.76 ± 3.41	GCMS, RI
18	*p*-mentha-1.4-dien-7-al	1287	9.88 ± 2.95	GCMS, RI
19	β-caryophyllene	1417	1.30 ± 2.54	GCMS, Co, RI
20	β-farnesene	1451	0.46 ± 0.17	GCMS, RI
21	acoradiene*	1467	0.20 ± 0.10	GCMS, RI
22	β-chamigrene	1474	0.17 ± 0.11	GCMS, RI
23	caryophyllene oxide	1581	0.14 ± 0.14	GCMS, RI
24	carotol	1595	0.22 ± 0.23	GCMS, RI

Percentages were calculated based on results obtained on column DB-5. GCMS = mass fragmentation; RI = Retention index of compounds was determined on DB-5 column. Co = co-injection with commercial standard.
(*) Unidentified isomers.

using various extraction methods (Li et al., 2009; Allahghadri et al., 2010; Martinez-Velazquez et al., 2011; Abbdellaoui et al., 2019). Similar results were obtained in this investigation with cumin essential oil from Catamarca (Argentina). Moreover, our study also showed 20 compounds present at low amounts (>1.0 %). Several studies have reported the composition of essential oils is region dependent (Zygadlo, 2011; Lopez et al., 2012; Van Baren et al., 2015) and cumin oil is not an exception (El-Sawi and Mohamed, 2002; El-Kamali et al., 2009; Bettaieb et al., 2011). In this regard, when we compared the chemical composition of cumin essential oils from San Juan and La Rioja province (Argentina) reported by Bandoni et al. (1991) with that obtained in the present study from cumin seeds from Catamarca, some differences were observed. Bandoni et al. (1991) reported a high concentration of 1,4-*p*-menthadien-7-al (<19.4 %) and the presence of 1,3-*p*-menthadien-7-al, which is in agreement with ISO 9301, while our analysis showed a low concentration of *p*-mentha-1,4-dien-7-al (9.88 ± 2.95 %), with *p*-mentha-1,3-dien-7-al not being detected. However, some authors have suggested that *p*-mentha-1,3-dien-7-al is an artifact formed during the storage of ground seeds or in the distillation of oils (Bandoni et al., 1991; Sowbhagya et al., 2008).

The insecticidal, repellent and acetylcholinesterase inhibition activities of the cumin oil on adult maize weevil *S. zeamais* were tested, and the results of fumigant insecticide activity are shown in Table 2. The LC_{50} and LC_{95} were 66.39 µL/L air and 370.14 µL/L air, respectively, with the inhibition of AChE activity by cumin oil being 88.39 % and 47.75 % for concentrations of 9.2 and 2.3 mg/L. In addition, the behavioral response of *S. zeamais* to cumin essential oil revealed a repellent effect at 4 µL/L and 0.4 µL/L (Table 2). However, a minor repellency effect of cumin essential oil against *S. zeamais* was observed by Rosa et al. (2019). Earlier investigations have shown a significant insecticidal activity of cumin essential oil against *S. oryzae* and *S. granarius* (Abdelgaleil et al., 2009; Chaubey, 2011; Kim et al., 2013), but there is scarce bibliographic information on the insecticidal activity of cumin essential oil against *S. zeamais* (Rosa et al., 2019). The toxic effect of cumin oil on *S. oryzae* has been reported with the following LC_{50} values: 0.136 mL/mL air (Lashgari et al., 2014), 0.67 µL/cm^3 (Chaubey, 2011) and 4.75 mg/L air (Kim et al., 2013). *S. granarius* reported 80 % mortality when exposed to 16 µL/L air of cumin essential oil (Ziaee et al., 2014); while the data of Rosa et al. (2019) revealed a low fumigant toxicity, 229.5 mg/L, against *S. zeamais*. Our results revealed an LC_{50} of 66.39 µL/L air for cumin oil from Argentina on *S. zeamais*. The differences observed in the lethal concentrations mentioned above could be due to a variation in the essential oil compositions and also to differences in responses among the *Sitophilus* species (Germinara et al., 2008; Niewiada et al., 2005).

As cuminaldehyde, 2-caren-10-al, *p*-mentha-1,4-dien-7-al are the main carbonyl components of cumin oil (Jirovetz et al., 2005; Martinez-Velazquez

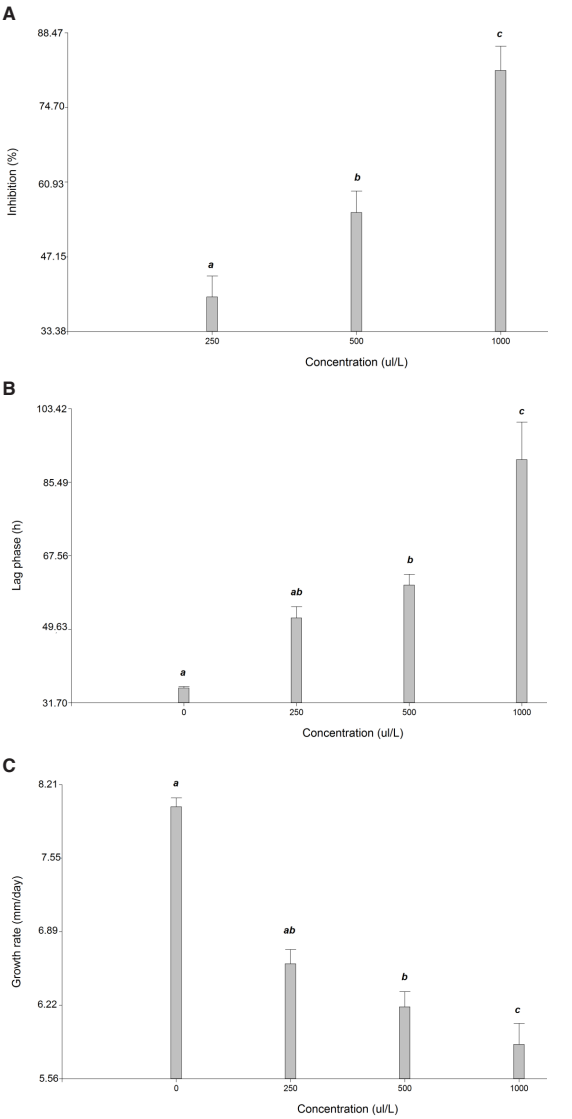

Figure 1. *Cuminum cyminum* L. antifungal effect on *Fusarium verticillioides* M3125 growth. **A.** Fungal growth inhibition (%). **B.** Lag phase (h). **C.** Growth rate (mm/day).
Bars with different letters are statistically different ($p < 0.05$).

Table 2. Bioactivity of *Cuminum cyminum* L. essential oil from Catamarca on *Sitophilus zeamais* (**A**: Fumigant toxicity. **B**: Anti-AChE activity. **C**: Behavioral response)

Bioactivity							
A) Fumigant toxicity		**LC_{50}** (µL/L air)	**95% Confidence interval** (µL/L air)	**LC_{95}** (µL/L air)	**95% Confidence interval** (µL/L air)	**$(X^2)^a$**	**Slope ± E.E.**
	EO	66.39	43.64-102.52	370.14	201.30-1374.4	36.63	2.20 ± 0.11
	DDVP[b]	<0.06					
B) Anti-AChE activity		**Concentration** (mg/L)					
		9.2		**2.3**			
Inhibition percentage (%)		88.39 ± 15.45[a]		47.75 ± 25.19[b]			
C) Behavioral response (repellence)		**Concentration** (µL/L air)					
		0.05	**0.4**	**4.0**			
Response Index (RI) Mean ± S.E	EO	-3.5 ± 27.2[a]	-63.1 ± 33.8*[b]	-56.1 ± 16.0**[b]			
	Propionic acid[b]	2.60 ± 12.37	-49.9 ± 13.47*	-78.0 ± 7.16**			

[a]Chi-square values. Significant at $p < 0.05$ level.
[b]Compounds were used as positive controls. Treatments were conducted under the same conditions of positive control reported by Zunino et al. (2015).
In behavioral responses *$p \leq 0.05$; **$p < 0.01$; ***$p < 0.001$ (significant response to experimental stimulus; paired-sample t test).
In behavioral responses and anti-AChE activity, values that have different letters in the same row are significantly different from each other according to Duncan's multiple range test at $p \leq 0.05$.

et al., 2011; Ziaee et al., 2014) they may be responsible for the insecticidal activity. Related to this, the aldehyde compound concentration (cuminaldehyde, 2-caren-10-al and *p*-mentha-1,4-dien-7-al) of the cumin essential oil analyzed in the present study was 38.32 %, while the carbonyl content of the cumin oils studied by Kim et al. (2013) and Ziaee et al. (2014) was 17.67 % and 65.6 %, respectively. A previous report found that aldehydes had higher levels of insecticidal activity (Zunino et al., 2015), and the toxic effect of cuminal on *S. oryzae* has been reported with the following values of LC_{50}: 1.12 mg/L air (Kim et al., 2013) and 71.4 mg/L air (Abdelgaleil et al., 2009). Although insecticidal activity may be more complex than just a simple inhibition of AChE activity, the terpenes ability to inhibit this enzyme is frequently a measure of these natural products insecticidal potency (Lopez and Pascual-Villalobos, 2010; 2015).

In this study the effect of cumin oil on AChE activity in *S. zeamais* adults, was tested to identify this essential oil possible target site. *C. cyminum* oil from Catamarca, Argentina, showed a high inhibition rate (88.39 %) at a concentration of 9.3 mg/L, revealing a direct relationship between AChE activity and insecticidal ability. Although the inhibition of AChE activity by cumin oil may change with insect species (Abdelgaleil et al., 2009), the reported toxicity of cumin oils on AChE activity from *S. oryzae* was generally in agreement with the results of the present study (Abdelgaleil et al., 2009; Chaubey, 2011; Kim et al., 2013).

The antifungal activity of essential oil of cumin seeds from Catamarca (Argentina) against *F. verticillioides* M3125 are shown in Figure 1. The bioactivity was tested at 250,500 and 1000 µL/L and, at the highest concentration of cumin essential oil, the mycelia growth of *F. verticillioides* was inhibited by around 80%, while inhibitions of 55 % and 40 % were shown at 500 and 250 µL/L essential oil concentrations, respectively, thus revealing a dose dependent effect (Figure 1a). Moreover, our results showed that the *F. verticillioides* lag phase was critically affected by an increase of the cumin oil concentration (Figure 1b). The adaptation phase was slightly more than one day, which by increasing the concentration from 250 µL/L to 1000 µL/L extended this lag phase to three days with respect to the start of mold growth. It can be observed in Figure 1c that fungal growth was affected considerably with the greatest reduction observed at 1000 µL/L. Regarding antifungal activity, in the present study, cumin oil treatment resulted in the reduction of fungal growth, with the lag phase and growth rate showing significant differences with the control at concentrations of up to 500 ppm. These results are in agreement with the findings of Hashem et al. (2010) who reported *C. cyminum* essential oils having an antifungal effect against different species of *Fusarium*. Moreover, Mohammadpour et al. (2012) and Yooussef et al. (2016) demonstrated a biological activity against *Aspergillus* species.

CONCLUSION

In summary, the results obtained in this study indicate that the essential oil of C. *cyminum* seeds from Catamarca, rich in cuminaldehyde, ϒ-terpinene, p-cymene and β-pinene, has biological activity against *S. zeamais* and *F verticillioides*. These findings suggest that cumin oil can be used as a natural alternative to chemical pesticides to prevent *S. zeamais* infestation on stored corn, using concentrations of 4 µL EO/L air to repel weevils. This study also suggests that employing cumin oil concentration superior to 1000 µL EO/L induces significant inhibition of fungal and insecticidal activities.

ACKNOWLEDGEMENTS

Financial support for this work came from the following sources: Secretaría de Ciencia y Tecnología de la Provincia de Catamarca, SUCYTCA (PROCAICyT 2014-4), Universidad Nacional de Catamarca (SECyT-SPU), FONCyT (PICT 2019-2703; 2018-3697), Universidad Nacional de Córdoba (SECyT) and CONICET (PIP 11220200102478). The authors also wish to express their gratitude to Dr. S. Fuentes, to Lic. L Favore, to Ing. G Alemmanno, to Prof. A Leiva, to Prof. L Montivero and to Tec. E Soriano. We also thank Dr. Marcela Palacio and Damian Barrionuevo (M.S.) for their technical assistance and Dr. Paul D. Hobson for revising the English language.

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