Toxicity Effects of Lamiaceae, Geraniaceae, and Myrtaceae Essential Oils on Angoumois Grain Moth (Sitotrogacerealella) Female Adults

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Research Article

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Abstract

The use of plant essential oils as eco-friendly and bio-rational insecticides has emerged as a promising alternative to hazardous fumigant pesticides for controlling stored product insect pests. This study investigated the vapor toxicity of essential oils obtained from the Lamiaceae, Geraniaceae, and Myrtaceae plant families against *Sitotroga cerealella* (Olivier) female adults, commonly known as the Angoumois grain moth. Gas chromatography-mass spectrometry analysis revealed Thymol (56.36%), Citronellol (39.7%), Eugenol (80.0%), and Carvacrol (42.28%) as the primary components in *Thymus vulgaris*, *Pelargonium roseum*, *Syzygium aromaticum*, and *Satureja hortensis*, respectively. Probit analysis and fiducial Limit (FL) calculations determined the 24-hour toxicity (LC_{50}) of the essential oils diluted in acetone (10%), resulting in LC_{50} values of 20.125 (19.002–21.372), 14.193 (13.044–15.575), 14.189 (12.570-15.879), and 13.562 (11.978–15.323) µgL-1(air) for *T. vulgaris*, *P. roseum*, *S. aromaticum*, and *S. hortensis*, respectively. Additionally, sublethal effects were observed at LC_{25} during the first generation. The treatments significantly impacted oviposition ($F_{4,10}$=81.93; P < 0.0001), egg hatchability ($F_{4,10}$=23.49; P = 0.0001), survival rate of larvae-pupae ($F_{4,10}$=259.86; P = 0.0001), and egg duration ($F_{4,10}$=9.71; P = 0.0018), leading to decreased values in these parameters. The essential oils derived from these four plant species demonstrate remarkable potential as eco-friendly components in the management of *S. cerealella*. Their vapor toxicity and sublethal effects on female adults underscore their effectiveness as sustainable tools within integrated pest management strategies for stored product pest control.

Introduction

The Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), is a major pest of many stored grains including wheat (Ghodjani et al. 2023), barley (Karimi-Pormehr et al. 2018), sorghum (Hassan et al. 2014), maize (Demissie et al. 2015) and rice (Akter et al. 2013). Its infestation starts in the standing crop in the field and continues in stored products at post-harvest conditions (Bushra and Aslam, 2014). The crop damage caused by the larvae of this cosmopolitan pest (Cotton, 1960) is directly due to creating a gallery in the grains during feeding on the endosperm and embryo, besides indirect damage due to the following attacks by pathogens, and certain secondary insects (Hill, 2002; Throne and Weaver, 2013; Hashem et al. 2014). Such damage causes extensive economic losses quantitatively up to 100% and qualitatively as per a reduction in the germination potential of infested seeds and decrease in nutritional and commercial value (Zettler and Arthur, 2000, Hansen et al. 2004; Mele, 2007).

A common method for the management of *S. cerealella* as a stored product pest is applying synthetic fumigant insecticides. However, continuous application of these chemicals may lead to insect pest resistance, environmental health hazards such as ozone depletion, toxicity to beneficial or non-target organisms, and the outbreak of secondary pests as the most well-known side-effects and environmental imbalance (Kao and Tzeng, 1992; Hansen and Jensen 2002; Wang et al. 2011; Wang et al. 2012; Hill et al. 2017; Pathak et al. 2022). Thus, the utilization of potential alternative procedures for the management of this pest insect has been evaluated to decline the population of *S. cerealella* below the economic injury levels in post-harvest storage (Bushra and Aslam, 2014). Yet, they should be practical, cost-effective, and convenient to use (Ayvaz et al. 2008). There are many studies focus on plant derivatives as biochemical pesticides which are less harmful to the environment and enhance the efficiency of natural enemies thus can help to reduce the application of chemical insecticides (Adeyemo and Adesanya, 2019; Boukouvala et al. 2019; Boate Ukoroije and Abalis Otayor, 2020; Fernandes et al. 2020; Pang et al. 2020; Islam et al. 2021; Shah et al. 2023). High volatility belonging to the plant species essential oils has several benefits such as instability of the formation of residues, thus making it a good candidate for management in stored-product conservation environments (Shaaya et al. 1991; Negahban and Moharramipour, 2007). A significant amount of the essential oil constituents are monoterpenoids, which are secondary plant chemicals with little metabolic importance. The acute toxicity and side effects of a large number of essential oils or their components have been assessed against several stored product insects including *S. cerealella* (Ayvaz et al. 2010; Adjalian et al. 2015; Wu et al. 2020). The metabolites comprising the essential oils can interfere with metabolism, biology, and physiological functions of insect pests. These components by reducing the energy reservoir especially by declining protein, and lipid content, affect reproduction function negatively. On the other hand, loosing glycogen is generally related to locomotion behavior, and flight ability (Campolo et al. 2018). Also, essential oils possess neurotoxic actions which lead to paralysis followed by death (Houghton et al. 2006; Piri et al. 2020). Inhibition of acetylcholinesterase was estimated as the most common result in the stored product pests exposed to the essential oils (Kim et al. 2013; Bhavya et al. 2018). Although in some studies, there was not a direct correlation between insect toxicity and inhibition of acetylcholinesterase (Lee et al. 2001). Changing the activity of detoxifying enzymes (Chauhan et al. 2022; Li et al.

2022) and creating histological modifications are the other essential oils mode of actions (Santos et al. 2021; Plata-Rueda et al. 2022).

There are several studies have been reported that plant species compounds belong to the families of Lamiaceae, Geraniaceae, and Myrtaceae had insecticidal activity against stored product pests as fumigants (Lee et al. 2001; Kostyukovsky et al. 2002; Negahban and Moharramipour, 2007; Bounoua-Fraoucene et al. 2019; Yang et al. 2020; Demeter et al. 2021). In the present study, the chemical constituents of essential oils from *Thymus vulgaris* L. (Lamiaceae), *Satureja hortensis* L. (Lamiaceae), *Pelargonium roseum* Ait. (Geraniaceae), and *Syzygium aromaticum* L. (Myrtaceae) were determined. Also, fumigant activity of these essential oils was tested against the adult stage of *S. cerealella* to evaluate the bioassay during 24 h. In addition, sublethal effects of the essential oils were studied on several biological parameters including development time, fecundity, fertility, sex ratio, and survival.

Materials and Methods

Plant Materials and Extraction of Essential Oil

The aerial parts of *Thymus vulgaris* L., *Satureja hortensis* L., *Pelargonium roseum* Ait., and *Syzygium aromaticum* L. were provided at the full-flowering stage on June 2021. Plants were dried in shade at room temperature (24±1 °C) and ground in a grinder. The extractions were run using a Clevenger-type apparatus through hydrodistillation with 50 g dried powder and 600 mL distilled water for 3 hours. Then anhydrous sodium sulfate was utilized to remove water after extraction. The extracted oils were finally kept at 4 °C for the next experiments (Rahmani et al. 2020).

Gas Chromatography–Mass Spectrometry Analysis

Gas chromatography–mass spectrometry (GC–MS) analyses were performed on a HP-6890 gas chromatograph (Hewlett-Packard, USA) using a 5973 mass-selective detector (Hewlett-Packard, USA) run in Zakariya *Razi Laboratory Complex*, *Science and Research Branch*, *Islamic Azad University*, Tehran, Iran. A HP-5 MS capillary column (30 m × 0.25 mm with a phase thickness of 0.25 mm) was used for separating the ingredients with helium as carrier gas at a 1.0 mL/min flow rate. The temperature program of oven was 60˚C for 3 min, 6 °C min^{-1} ramp rate to 250 °C and held constant for 3 min. The mass spectra were recorded at 70 eV of ionization voltage with a scan time of 1 second and mass range of 50–550 m/z. The ionization mode was electron impact and the temperature of the ionization source was kept at 250˚C at 3 min. For recognizing each compound, its mass spectra were compared to those stored in the Wiley 7.0 and Adams mass spectral-retention index libraries (Adams 2007).

Insect Rearing

The strain of Angoumois grain moth, *Sitotroga cerealella was provided from* Biological Control Department, Iranian Research Institute of Plant Protection, Tehran, Iran, where it was collected in 2021. *The insects were* associated with barely and maintained in an incubator at 27 ± 1 °C, 65 ± 5% RH and 14L: 10D h photoperiod. The individuals were raised in a plastic box (10Í8Í5 cm) with a hole covered with a mesh net for ventilation, containing wet barely seeds as a diet for the larvae. After emergence of the lepidopteran adult moths, for avoiding the population outbreak, they were transferred to the other plastic boxes for oviposition and producing next generation. The population was reared for several generations before beginning of the experiments. Adult insects (24 h old) were used for fumigant toxicity experiments. They were fed with sucrose solution (10%) for increasing their fecundity.

Adult Bioassays

Fumigant toxicity bioassay of the essential oils diluted in acetone (10%) was examined on the adult stage of *S. cerealella*. The experimental units were plastic vials with 400 cm^3 volume containing both males and females set at 27 ± 1 °C, 65 ± 5% RH and 14L: 10D h photoperiod. Different concentrations of the essential oils were put on a piece of Whatman filter paper (No. 1, diameter 2.0 cm) using a micropipette, then attached to the undersurface of the containers lid. For measuring the median lethal concentrations of the essential oils, and after preliminary tests, concentrations between 25% and 75% mortality as minimum and maximum mortality, respectively, the other concentrations were chosen based on logarithmic distance (Robertson *et al.* 2007). In this study, different concentrations of every oils in the container were as follows: *T. vulgaris* (12.5, 15.55, 19.35, 23.6, 30 μgL^{-1}(air)), *S. hortensis* (5, 7.45, 11.15, 16.7, 25 μgL^{-1}(air)), *P. roseum* (7.5, 9.72, 12.8, 16.9, 22.5 μgL^{-1}(air)), and *S. aromaticum* (5, 7.45, 11.15, 16.7, 25 μgL^{-1}(air)). In the control, there was no essential oil and only the solvent (acetone AR, ≥99.5%) was applied (Chaubey 2012; Rossi and Palacios 2013; Rahmani and Azimi, 2020). The containers were ready with 15 adults at the same age, and 270 individuals were used totally during the bioassays. The experiments were replicated three times for each treatment on different days and the mortality was documented after 24 hours.

Sublethal Effects of Essential Oils On Biological Parameters

To study the long-term effects of the essential oils on the biological parameters of *S. cerealella,* more than 100 newly emerged adults were exposed to the LC_{25} of each oil (Table 2). After 24 h, the surviving individuals were transferred to the new box, with sufficient barley seeds letting them mate and lay their eggs. Each seed with one egg on its surface was transferred to one small box (6 cm diameter, with a height of 3 cm) sealed with parafilm tape and recognized with a number. The experimental units were checked every day to assess the development time and survival rate until the emergence of the adults. Then the males and females in each treatment and the control were paired and checking the fertility and survival continued until the death of all individuals. In each treatment, and whenever there were not adequate males for paring, one male from the colony was added to the experimental unit. The sublethal experiment was conducted with three replications, and 32 individuals were used in each replicate. Since most of the preadult stages were in the galleries hidden in the seeds, so they were out of sight, we did not separate the larval instars and pupae stage from each other to avoid gathering wrong data.

Data Analysis

The concentration-mortality regression for estimating lethal toxicity was taken using Probit analysis (Polo-PC Probit and Logit analysis; LeOra Software 1987). Differences in toxicity were considered significant when 95% fiducial Limit (FL) did not overlap (Adams *et al*. 1990).

One-way analysis of variance (ANOVA) was employed for analyzing the mean and standard deviation values of all biological parameters. Fisher’s least significant difference (LSD) multiple comparisons were then used to separate the means among the treatments for each parameter. All the statistical analyses were analyzed using SAS (version 9.1.3) software (SAS institute Inc. 2003). *P*-values below 0.05 were regarded as significant.

Results

Chemical Composition of Essential Oil

The chemical components of the essential oils in addition to their amounts, and retention time analyzed by gas chromatography–mass spectrometry are summarized in Table 1. α-Pinene, and Limonene were detected in all of the four plant species, although their amount was equal or lower than 1.5%. On the other hand, the most significant components in *T. vulgaris*, *P. roseum*, and *S. aromaticum* were Thymol (56.36%), Citronellol (39.7%), Eugenol (80.0%), respectively. Also, the main ingredients in *S. hortensis* were γ-Terpinene (40.93%), and Carvacrol (42.28%). *P*-Cymene (17.25%) in *T. vulgaris*, as well as Geraniol (17.6%), and Citronellyl formate (11.2%), both in *P. roseum* were recorded as the high amount components.

Fumigant Toxicity

Short term vapor toxicity of four oils extracted from *T. vulgaris*, *S. hortensis*, *P. roseum* and *S. aromaticum* against the adult moths are indicated in Table 2. According to the concentration causing 50% mortality (LC_{50}), all the tested oils were toxic to the Angoumois grain moth during 24 hours. Probit analysis, and fiducial Limit (FL) showed that toxicity of the three oils including *S. hortensis* (LC_{50} 13.562 (11.978-15.323) μgL^{-1}(air)), *P. roseum* (LC_{50} 14.193 (13.044-15.575) μgL^{-1}(air)) and *S. aromaticum* (LC_{50} 14.189 (12.570-15.879) μgL^{-1}(air)) did not have any significant difference, while *T. vulgaris* (LC_{50} 20.125 (19.002-21.372) μgL^{-1}(air)) was less toxic against the adult moths (Table 2).

Effects of Essential Oils Low Concentration on Biological Parameters

The mean number of eggs oviposited by females reduced, significantly. This reduction in *T. vulgaris* treatment was higher than the other oils, as in this treatment, the mean number of eggs was calculated about 8 times lower than the control. A significant increase was observed in egg duration compared with the control. This increase was higher in *S. aromaticum* essential oil treatment. Also, embryo, and larvae-pupae survival rates declined, significantly; thus pre-adult mortality rate increased. On the other hand, larvae-pupae development, and sex ratio were not different significantly from each other, and with the control (Table 3).

Discussions

Our study showed that the essential oils were rich in monoterpenoids (thymol, citronellol, γ-terpinene, *p*-cymene, and geraniol), phenols (eugenol), and phenolic monoterpenoid (carvacrol). The type of the ingredients, as well as their content, were almost near to the analysis resulting from other studies. In most investigations, eugenol was considered the most abundant phytoconstituent of *S. aromaticum* buds and leaves with an amount of 70–85% followed by β-caryophyllene (4.4–19.5%), and eugenyl acetate (2.1–16%) (Randriamiharison and Gayadou, 1987; Pino et al. 2001; Srivastava et al. 2005; Mittal et al. 2014). Gopalkrishnan et al. (1984) showed that during the plant maturation, the composition of the bud oil changes to the increase in eugenol content, maybe because of enzymatic hydrolysis of eugenyl acetate to eugenol.

In different species of *Thymus* oils, thymol (52.2%), and *p*-cymene (17.03%) were reported as the main components analyzed by GC/MS (Aksit et al. 2022). Dabiri et al. (2011) recognized Citronellol (27.3%) followed by citronellyl formate (17.2%) as the highest components amount of *P. roseum*, while they could not detect geraniol. Instead, in the study performed by Tabari et al. (2017), geraniol (18.5%) was a major component of this plant after citronellol (35.9%). According to Doimo et al. (1999), temperature was a critical factor affecting the citronellol/ geraniol ratio, as geraniol concentrations fell in winter and citronellol concentrations increased in late winter-spring. high citronellol/ geraniol ratios indicated cold stress in geranium plants. In addition to the climatic factors (Katar et al. 2017), utilizing numerous procedures, post and during oil extraction may give us different amount of components. Sefidkon et al. (2006) found that during the different drying methods, amount values of carvacrol and c-terpinene as two main components of the *S. hortensis* oil were 46.0–48.1% and 37.7–39.4%, respectively. Also, they detected carvacrol with rate of 12.3–46% and c-terpinene, 37.7–70.4% through different distillation methods.

The major factors recognizing the toxicity of a plant are insect species, the route of exposure, and the phytochemicals (Regnault-Roger et al. 1997). Also, the time of exposure, temperature, and humidity are factors with influence on the activity of the test chemicals as vapor toxicants under isolates conditions (Pandey et al. 2009).

The insecticidal toxicities of the essential oils appear to be connected to their chemical composition (Park et al. 2017). Previous studies revealed that fumigant toxicity of thymol against *Sitophilus oryzae* adults caused 100% mortality during 24 h. The short-term insecticidal effects of eugenol, and carvacrol were 85% and 75%, respectively. However, some other components such as camphor, linalool, and borneol that their amounts were too low in the essential oils of our study lead to 85–100% mortality after one day of exposure (Rozman et al. 2007). As a result, sometimes the type of a compound is as critical as its amount in its noxiousness. In addition, the insecticidal activities of the ingredients separately may vary with insect species, as *S. oryzae* in the study performed by Rozman et al. (2007) was more sensitive than *Rhyzopertha dominica* and *Tribolium castaneum*.

Due to the chemical complexity of essential oils, several mechanisms can be involved in the phytochemical pattern of the oils, and in the sensitivity of the insect species (Regnault-Roger, 1997). Thus, almost internal synergy or a mixture effect of the main components of plant essential oils can determine the noxiousness of the phytochemicals (Bekele and Hassanali, 2001) and that is the reason why in several studies, essential oils may be more effective biopesticides compared with their active ingredients separately (Magierowicz et al. 2018).

The insecticidal effect of monoterpenes such as thymol and carvacrol is due to targeting the cells of insect pests, causing disorganization in the cell membrane, leading it to lose permeability (Medeiros et al. 2011). Some others such as linalool was identified as an inhibitor of acetylcholinesterase (Ryan and Byrne, 1988). Eugenol besides the other phenolic compounds distinguishes the biological activity of *S. aromaticum* against pathogens (Chaieb et al. 2007), and arthropods (Huang et al. 2002) by changing cell morphology through chromatin condensation and fragmentation (Fernandes et al. 2020) in addition to the inhibition of a nerve conduction carboxylesterase and a detoxifying glutathione S-transferase (Zhang et al. 2023).

In the present study, several biological parameters were affected by low concentration of the extracted oils. The reproduction inhibition and prevention of egg hatchability by essential oils belonging to Lamiaceae, and Myrtacae families were observed previously (Konstantopoulou et al. 1992; Regnault-Roger and Hamraoui, 1994). For example, the average egg number of *Musca domestica* female adults affected by volatile LC_{30} of *T. vulgaris*, was recorded 4 times lower than the control. Also, only 50% of the larvae from the eggs emerged, and pre-adult mortality was 100% (Roman, 2007). In addition, fumigant toxicity of monoterpenoids separately including carvacrol, thymol, and terpineol indicated strong inhibition of oviposition. These compounds besides eugenol, linalool (Regnault-Roger and Hamrouni, 1995), and citronellol (Brari and Thakur, 2016) with efficient vapor toxicity and reproduction interfering as the oviposition deterrence, and egg hatchability inhibitor, may be promising compounds in stored products pests management.

Conclusions

In the present study, all essential oils from four plant species including *T. vulgaris*, *S. hortensis*, *P. roseum*, and *S. aromaticum* showed vapor toxicity during 24 h against female adults of the Angoumois grain moth, *S. cerealella*. Existing a mixture of phytochemicals with important, and high amount ingredients such as thymol, carvacrol, eugenol, citronellol, *p*-cymene, γ-terpinene, and geraniol makes these oils poisonous for the insect pest. In addition to the acute toxicity, the oils in the volatile concentration caused 25% mortality in adults, leading to several biological side-effects. For getting a better understanding of the insecticidal potential of these ingredients, alone or blend against this stored product moth, we need to perform more experiments.

Declarations

The authors declare that they have no known competing financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

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Tables

Table 1. Chemical constituents of the essential oils extracted from *T. vulgaris*, *S. hortensis*, *P. roseum*, and *S. aromaticum.* / Constituyentes químicos de los aceites esenciales extraídos de T. vulgaris, S. hortensis, P. roseum y *S. aromaticum*.

compound	Mean composition (% relative area)				Retention time (min)			
	T. vulgaris	*S. hortensis*	*P. roseum*	*S. aromaticum*	*T. vulgaris*	*S. hortensis*	*P. roseum*	*S. aromaticum*
α-Thujene	0.95	1.91			15.50	1.89		
α-Pinene	0.76	1.50	0.5	0.05	15.73	1.88	15.53	6.14
Camphene	0.3	1.1			16.01	1.87		
Octen-3-ol	0.65				16.19			
β-Pinene	1.62	0.79		0.49	16.25	2.16		8.90
Myrcene	0.3	2.47	low rate		16.71	3.48	16.46	
α-Terpinene	1.4	4.03		0.25	17.31	5.4		10.19
P-Cymene	17.25	2.24	0.1		17.47	26.51	17	
Limonene	0.3	0.34	0.3	0.30	17.51	19.48	17.06	12.66
1.8-Cernede	0.63				17.67			
γ-Terpinene	9.52	40.93		0.70	17.99	33.51		14.59
Terpinene	0.73				18.25			
Linalool	1.87		6.9	0.75	18.48	18.25		15.08
Camphor	0.2				18.77			
Borneol	0.98				20.23			
Carvacrol	2.6	42.28			22.08	32.01		
Thymol	56.36				21.96			
E-Carvacrol	1.23				24.47			
β-Bisabolene	0.29	0.62			27.51	10.01		
Carvacrol methylether	0.71				2097			
δ-Cadinene	0.18		0.4		28.22		25.36	
α-Terpineol	-	0.05	0.5		20.51	7.57	19.76	
Thymol methyl ether	0.88				20.83			
γ-Cadinene	-		0.1		27.56		25.21	
α-phellandrene	-	0.28		0.40	17.14	3.61		9.97
Sabinene		0.09				1.75		
β -phellandrene		0.32		0.75		21.16		7.60
Terpinen-4-ol		0.12				8.92		
Methyl		0.06				7.32		
β-caryophyllene		0.82		2.27		12.01		23.54
Spathulenol		0.01				1.12		
cis-linalool oxide			0.1				17.78	

trans-linalool oxide	low rate		18.06	
cis-rose oxide	1.3		18.43	
trans-rose oxide	0.4		18.70	
Menthone	3		19.13	
iso-menthone	4.1		19.3	
γ-terpineol	low rate		19.98	
Citronellol	39.7		20.38	
Neral	0.2		20.58	
Geraniol	17.6		20.81	
Geranial	0.4		21.06	
Citronellyl formate	11.2		21.18	
Geranyl formate	4.3		21.63	
α-Cubebene	0.1	0.30	22.41	23.90
Citronellyl acetate	0.6		22.5	
α-Copaene	0.3		22.9	
β-bourbonene	0.8		23.11	
Geranyl acetate	0.6		22.98	
(E)-Caryophyllene	1.2		23.61	
6,9-Guaiadiene	0.1		24.03	
Citronellyl propionate	1.2		24.06	
Geranyl propionate	0.5		24.6	
α-Muurolene	low rate		25.0	
trans-Calamenene	0.5		25.35	
Citronellyl butyrate	0.3		25.5	
α-Calacorene	low rate		25.7	
Geranyl butyrate	1.0		26.03	
10-epi-γ-Eudesmol	3.6		27.03	
m-Cymene		0.04		11.57
Eucalyptol		0.50		13.90
Eugenol		80.0		21.78
Benzyl acetate		0.30		21.80
4-Terpineol		0.22		22.12
α-Guaiene		0.71		24.02
Eugenyl acetate		5.01		25.92
Globulol		0.40		28.33
Cubenol		0.57		30.72

Elixene	0.43	32.66
α-Cadinol	0.57	36.75
Germacrene D	0.60	37.04
(+)-Cycloisosativen	0.45	44.76
Nerolidyl acetate	0.25	45.10
α-Farnesene	0.99	50.0

Table 2. Fumigant toxicity of essential oils from *T. vulgaris*, *S. hortensis*, *P. roseum*, and *S. aromaticum* against the adult stage of *S. cerealella.* / Toxicidad fumigante de aceites esenciales de *T. vulgaris*, *S. hortensis*, *P. roseum* y *S. aromaticum* contra la etapa adulta de *S. cerealella*.

Essential oils	number of insects	Concentration μg/L(air) (95%FI)$^{-1}$		Slope±SE	X^2(df)
		LC_{25}	LC_{50}		
T. vulgaris	270	16.545 (15.280-17.602)	20.125 (19.002-21.372)	7.92±0.89	5.46(13)
S. hortensis	270	9.445 (7.714-10.821)	13.562 (11.978-15.323)	4.29±0.62	10.49(13)
P. roseum	270	10.891 (9.704-11.903)	14.193 (13.044-15.575)	5.86±0.67	13.09(13)
S. aromaticum	270	10.408 (8.511-11.848)	14.189 (12.570-15.879)	5.01±0.77	6.95(13)

Table 3. Sublethal effects (LC_{25}) of essential oils of *T. vulgaris*, *S. hortensis*, *P. roseum*, and *S. aromaticum* on life parameters of *S. cerealella.* / Efectos subletales (CL_{25}) de los aceites esenciales de *T. vulgaris*, *S. hortensis*, *P. roseum* y *S. aromaticum* sobre los parámetros de vida de *S. cerealella.*

Biological parameters (± SE)	control	*T. vulgaris*	*S. hortensis*	*P. roseum*	*S. aromaticum*	P	F	df
Embryo development (day)	8.76±0.07c	11.56±0.39ab	11.91±0.52ab	11.06±0.61ab	12.85±0.38a	0.0018	9.71	4,10
Larvae-Pupae development (day)	20.20±0.57a	19.33±0.74ab	16.90±1.22b	16.96±0.57b	17.50±0.74ab	0.088	2.75	4,10
Fertility (embryo survival rate (%))	90.62±2.79a	35.55±8.13b	43.33±3.44b	30.41±0.37b	37.14±4.12b	<0.0001	23.49	4,10
Larvae-Pupae survival rate (%)	96.53±0.11a	16.66±2.98c	34.44±1.98b	19.58±1.76c	20.69±1.22c	<0.0001	259.86	4,10
Pre-adult mortality rate (%)	12.49±2.79c	83.32±2.98a	65.55±1.98b	80.41±1.76a	79.30±1.22a	<0.0001	139.76	4,10
Female individuals (%)	47.73±5.64	25±12.91	43.96±5.24	51.13±16.37	46.3±14.21	0.66	0.61	4,10
Male individuals (%)	52.27±5.64	75±12.91	56.04±5.24	48.87±16.37	53.7±14.21	0.66	0.61	4,10
Fecundity (mean number of eggs)	15.66±0.38a	2.0±0.89d	8.15±0.06b	5.51±0.37c	5.0±0.46c	<0.0001	81.93	4,10

Mean values in a row followed by different uppercase letters are significantly different (LSD) (P<0.05)