Eucalyptus dundasii Maiden essential oil, chemical composition and insecticidal values against *Rhyzopertha dominica* (F.) and *Oryzaephilus surinamensis* (L.)

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Abstract: The insecticidal effects of *Eucalyptus dundasii* Maiden essential oil was studied on the adults of the lesser grain borer, *Rhyzopertha dominica* (F.), and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.). Essential oil was obtained by the hydro-distillation method and essential oil composition was analysed by GC-MS. Chemical analysis indicated that 1,8-cineole (54.15%), *p*-cymene (12.41%), α-thujene (11.37%), and E-caryophyllene (6.7%) were major constituents. For *R. dominica* and *O. surinamensis*, the LC_{50} of *E. dundasii* essential oil was 41.69 and 57.92 $\mu l \cdot l^{-1}$ of air, respectively. Increasing the concentration of the essential oil and the exposure time, increased mortality. The durability of fumigant toxicity on *O. surinamensis* adults was higher than on *R. dominica* adults and was statistically different. Based on the mean of the repellent indexes and the standard deviation, *E. dundasii* essence was repellent for both insects at 70, 140, and 280 $\mu l \cdot l^{-1}$ of air concentrations. Statistical analysis showed that Relative Growth Rate (RGR) in *O. surinamensis* was higher than in *R. dominica*, and the Relative Consumption Rate (RCR), the Efficiency of Conversion of Ingested food (ECI), and the Feeding Deterrence Index (FDI) in *O. surinamensis* was lower than in *R. dominica*. The many diverse bio-effects of *E. dundasii* essential oil confirmed that it is a good candidate for management of *R. dominica* and *O. surinamensis*.

Key words: essential oil, *Eucalyptus dundasii*, insecticidal bio-effects, Myrtaceae, *Oryzaephilus surinamensis*, *Rhyzopertha dominica*

Introduction

The human population increase has led to several problems, especially in respect to food losses. Throughout the world, storage pests damage 10–40% of stored agricultural crops (Raja *et al*. 2001). *Rhyzopertha dominica* (F.) and *Oryzaephilus surinamensis* (L.) are very important insect pests. They feed on grains, dried fruits, nuts, dough, sugar, candies, tobacco, dried meat, and a number of plant products meant for human consumption (Metcalf and Flint 1979; Van Zyl *et al*. 2006). The detrimental environmental issues caused by the overuse of insecticides have become a matter of great concern for scientists (Koul *et al*. 2008). Currently, the extensive utilisation of synthetic insecticides such as phosphine aim to control storage pests. These insecticides bring about such serious problems as contamination of the environment, lethal effects in non-targeted organisms, and insect resistance (Collins *et al*. 2005; Jovanović *et al.* 2007).

Essential oils are very interesting natural plant products and among other qualities they possess various biological properties. These materials degrade rapidly in air and moisture, and are readily broken down by detoxification enzymes. This is a very important point, because rapid breakdown means less persistence in the environment and reduced risks to non-target organisms. Although natural enemies are sensitive to direct contact with such materials, the predators and the parasitoids which attack the product following 1–2 days of treatment, are not affected by the toxin (Isman 2006). Plant oils are generally considered broad-spectrum and safe for the environment because the array of compounds the oils contain quickly biodegrade in the soil (Rajendran and Sriranjini 2008; Devi and Maji 2011). The essential oils of several plant species such as: Apiaceae, Asteraceae, Cupressaceae, Lamiaceae, Lauraceae, Myrtaceae, Rutaceae, Poaceae, Piperaceae, and Zingiberaceae are characterised by insecticidal properties (Tripathi *et al*. 2009; Isman *et al*. 2010; Regnault-Roger *et al*. 2012; Ebadollahi 2013; Mahmoodi *et al.* 2014).

The eucalyptus belonging to the Myrtaceae family has 700 species distributed throughout the world (Brooker and Kleinig 2006; Tandon *et al.* 2008). The eucalyptus is a naturally-green, tall tree covered with odorous branches full of essence-based centers. The eucalyptus provides expensive commercial essential oils to be used in perfume-producing and medicinal industries (Brooker and Kleing 2006). The leaves and oil of many eucalyptus species are used for respiratory ailments, like bronchitis, and are characterized as being antioxidant and anti-inflammatory (Grrassmann *et al*. 2000; Juergens *et al*. 2003; Batish *et al.* 2008).

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Iran has a huge number of plants like the eucalyptus, which are highly transmittal and characterised by medicinal properties. In this study, the insecticidal activity in the essential oil from the leaves of *Eucalyptus dundasii* Maiden grown in Iran, and the fumigant toxicity, repellent, and feeding deterrence index (FDI), as well as the chemical composition were investigated against adults of *R. dominica* and *O. surinamensis* as two major stored product insect pests. This approach will allow identifying natural and safer agents for the development of bio-rational insecticides.

Materials and Methods

Plant materials

Eucalyptus leaves were collected from Koshkak Station in Shoshtar, Khozestan province, Iran. They were inserted into paper pockets, kept in the dark under appropriate air conditioning, to be then stored in a refrigerator at 4°C.

Essential oil extraction

An amount of 70 g of milled plant leaves together with 1,000 ml of distilled water were put into a Clevenger apparatus for 4 h of hydrodistillation. The obtained light yellowish essential oils with 1.53% yield, were stored in glass containers in a refrigerator at 4°C (Negahban *et al*. 2007).

Insect rearing

The insects used in this study were the lesser grain beetle borer, *R. dominica*, and the saw-toothed grain beetle, *O. surinamensis* which were collected from the insect breeding room located in the Entomology Section of Evin Research Center, Tehran, Iran. Square-like containers made from fiberglass with a volume of 1 l, were used for the purpose of breeding the insects. For ventilation, a piece if fine muslin was put on the container caps. The lesser grain borer and the saw-toothed grain beetle were reared on wheat and whole meal flour as well as yeast, respectively. To remove any likelihood of contamination, the incorporated wheat was refrigerated at –10°C for 72 h. Insect rearing was done in an incubator at 27±1°C, the relative humidity (RH) was 65±5%. All the experiments were conducted in the abovementioned conditions. Adult insects that were 1 to 7 days old were used in all the stages of the treatment.

Bioassays

To determine the fumigant toxicity of *E. dundasii* essential oil on adult insects, effective concentrations of essential oil were obtained for the death of 20 to 80% of the treated insects during the initial tests. The tests were run in glass cylinder containers having shield with a volume of 40 ml as fumigant chambers. Twenty adult insects were kept in the glass containers. Concentrations of 30, 37.5, 45, 57.5, and 75 $\mu l \cdot l^{-1}$ of air of *E. dundasii* essential oil for *R. dominica* adults, and 25, 37.5, 52.5, 77.5, and 112.5 $\mu l \cdot l^{-1}$ of air for *O. surinamensis* adults were chosen. The essential oil was put on filter paper using a sampler. Immediately, the glasses were recapped. The sides of the cap were covered with strips so as to prevent the outlet of essential oil. The number of dead insects was counted after 24 h. Insects incapable of moving their heads, antennae, and body were also considered to be dead. This test was done four times and all procedures for the controls were done without essential oil concentrations.

For studying the lethal time values, three concentrations of 100, 200, and 500 $\mu l \cdot l^{-1}$ of air of *E. dundasii* essential oil higher than LC_{50} were chosen for analysing the rate of death. Twenty adult insects were put into cylinder glasses. The glasses had a volume of 40 ml. The experiment was conducted as mentioned above. The number of dead insects was counted daily and this experiment was repeated four times. This means that separate tests were used for each time interval.

The effect of the repellency of the essential oil was tested according to Lopez *et al*. (2008). Three plastic containers with perforated holes on the two sides were connected to each other through a small pipe for each connection. The pipe was 5 cm in length. Three plastics containers were connected to one another while the container placed inside of the middle container was considered to be the control, and the other was a treated one. The control container contained 40 wheat seeds which were wetted with 1 ml of acetone as a solvent, whereas the treatment container contained 2.8, 5.6, and 11.2 µl of *E. dundasii* essential oil diluted with a 4 : 1 ratio of acetone. Fifty adult insects were kept hungry for 24 h, then the insects were placed into the middle container. During the experiment, the containers were capped and the number of insects were counted after 24 h followed by a calculation of repellency percent. This experiment was repeated three times. The essential oil repellent index (RI) was calculated using the Kogan and Goeden (1970) formula:

$$RI = 2G/(G + P),$$

where: G – the number of adult insects in the treatment area, and P – the number of adult insects in the control area.

For each calculated RI, the mean and standard deviation were determined. If the mean was lower than 1 – SD, it meant the essential oil concentration had a repellent property. If the mean was higher than 1 + SD, it meant the essential oil concentration had an attractant property. If the mean fell between 1 – SD and 1 + SD<, it meant the essential oil concentration was neutral. To categorise the repellent effect of the essential oils, the method of Tapondjou *et al*. (2005) was used. Five groups were formed based on the mean of percent repellency (PR): Class 0: PR = 0–0.1%; Class I: PR = 0.1–20%; Class II: PR = 20.1–40%; Class III: PR = 40.1–60%; Class IV: PR = 60.1–80%, and Class V: PR = 80.1–100%.

When analysing the durability of essential oil with fumigant toxicity, four concentrations were used so as to cause higher rates of deaths. The obtained results were only acceptable at the highest concentration, from a statistic aspect. Cylinder-like, capped glasses with a 40 ml volume were used. A twenty $\mu l \cdot l^{-1}$ of air concentration of

the essential oil was treated on the filter paper inside the glasses caps. The glasses were capped and to ascertain the impenetrability of air, they were tightened with strips. This experiment was repeated three more times. Twenty adult insects were placed in the test glasses one day after placing essential oil in the glasses. The dead insects were counted after 24 h. Then, insects which were three days old were added to the containers and the number of dead insects was recounted after 24 h. This trend followed for 5 and 7 days, and as long as there were insects that were living.

To analyse the growth rate of the tested insects, 5 g of wheat were put into the 40 ml test glasses. Then, the seeds were treated with 0.5, 1, 1.5, 2, and 3 µl of eucalyptus. The eucalyptus had been diluted in 1 ml of acetone. In the control treatment, 1 ml acetone was used. Twenty weighed adult insects were released in the containers and were kept and fed there for three days. Following three days of treatment, both the insects and wheat were weighed and nutritional indexes were estimated as follows (Huang *et al*. 2000):

– relative growth rate (RGR) = $\frac{(A - B)}{(B \times day)}$,

where: A – the live insect weight in mg for each one, B – the initial insect weight in mg for each one, and day – the treatment duration (three days);

– relative consumption rate (RCR) = $\frac{D}{(B \times day)}$,

where D – the amount of ingested food in mg for each one;

– efficiency of conversion of ingested food (ECI) =

$$= \%ECI = \frac{RGR}{RCR} \times 100,$$

where RGR – relative growth rate;

– feeding deterrence index (FDI) = %FDI = $\frac{(C - T)}{C} \times 100$,

where: C – the amount of ingested food in the control group, and T – the amount of ingested food in the treatment group (mg for each one).

Chemical analysis of essential oils

A performance of the gas chromatography analysis (GC) was done using a Thermo-UFM equipped with a flame ionization detector (FID) and interfaced with a Eurochrom 2000 data processor. A non polar PH-F column [10 m × 0.1 mm (0.4 mm film thickness)] with helium as the carrier gas maintained with a pressure of 3 kg · cm^{-3} was used. The oven temperature was programmed at 60°C for 5 min and then 3°C/min to 285°C after which the oven temperature was maintained isothermally at 285°C for 8 min. The detector and injector temperature were set at 280°C. Injection was done in split mode with 1 : 100 GC-MS. Analysis was carried out with a Varian 3,400 interfaced with a mass spectrometer (model) using Saturn software fitted with a HP-5 column [10 m × 0.1 mm (0.4 mm film thickness)]. The oven temperature was programmed at 40°C for 5 min and then 4°C/min to 285°C. The thermal degree of the injection shield was 260°C. The transfer line temperature was 270°C. Mass spectra were recorded at 70 ev under EI conditions with 1 scan/sec. The identification of individual compounds was based on the comparison of their relative retention index with those of the original samples on a capillary column (Adams 2001).

Results

The adults of *R. dominica* and *O. surinamensis* were very susceptible to the *E. dundasii* essential oil in the evaluation of fumigant toxicity. For these adults, the LC_{50} values were 41.69 µl · l^{-1} of air and 57.92 µl · l^{-1} of air, respectively (Table 1). Based on the Preisler method (Robertson *et al*. 2007) and comparing the upper and lower confidence limits, because of the overlapping of LC_{50} confidence interval where no significant difference is observed (Table 1). LT_{50} values for concentrations of 100, 200, and 500 µl · l^{-1} of air were 5.54, 3.79, and 2.05 h for *R. dominica*, respectively. While LT_{50} values were 4.81, 3.80, and 3.31 h for *O. surinamensis*, respectively. Comparison of LT_{50} values using the Preisler method and the upper and lower limits of 95% confidence limits, showed that concentrations of 100 and 200 µl · l^{-1} of air performed the same in both insects but the LT_{50} of fumigant toxicity in both insects was not overlapped and was significantly different at 500 µl · l^{-1} of air (Table 2).

The obtained results showed that the essential oil effect declined over time. The durability of *E. dundasii* essential oil at a concentration of 500 µl · l^{-1} of air on *R. dominica* adults was 7 days, and 17 days for *O. surinamensis* adults at the same density. The calculated LT_{50} for essential oil durability was 3.71 days and 9.64 days on *R. dominica* and *O. surinamensis* adults, respectively. Based on the Preisler method and a comparison of the upper and lower limits of LT_{50}, the essential oil in both insects was not overlapped and was significantly different enough to be categorised as different groups (Table 3).

For repellent bioassay, both insects were susceptible to the vapour of *E. dundasii* essential oil and adults were repelled at all concentrations. Based on the repellency-effect comparison of each concentration of *E. dundasii* essential oil on both insects, it was found that the repellent index increased with increases in the essential oil concentration (Table 4). It could be conclude, that essential oil at 70 and 140 µl · l^{-1} of air concentration was equally repellent in both insects. However, there were significant differences in terms of repellency at 280 µl · l^{-1} of air concentration. As far as the insects go, the *R. dominica* and *O. surinamensis* adults fell into different groups: the essential oil was stronger in terms of repellency on *O. surinamensis* (Table 4).

The results of variance analysis showed the effect of different concentrations of *E. dundasii* essential oil on the RGR of *R. dominica* and *O. surinamensis* adults to be significantly different. Increasing the concentration led

Table 1. The Probit analysis of *Rhyzopertha dominica* and *Oryzaephilus surinamensis* adults affected by the fumigation of *Eucalyptus dundasii* essential oil

Insects	LC_{50} [μl · l^{-1} air][a]	LC_{90} [μl · l^{-1} air][a]	Slope ±SE	Intercept	χ^2 (df = 1)	Comparison using the Preisler method
R. dominica	41.69 (32.84–49.86)	142.61 (108.01–232.55)	5.51±0.88	–8.93	38.76	A*
O. surinamensis	57.92 (41.20–72.53)	320.61 (218.21–676.42)	3.96±0.70	–6.98	31.38	A

[a] 95% lower and upper fiducial limits are shown in parenthesis; *based on the Preisler method and comparing the upper and lower confidence limits, because of the overlapping of LC_{50} confidence interval where no significant difference is observed and same letter (A) is used; SE – standard error

Table 2. LT_{50} values of fumigant toxicity of *Eucalyptus dundasii* essential oil against adult *Rhyzopertha dominica* and *Oryzaephilus surinamensis*

Insects	Concentration [μl · l^{-1} air]	LT_{50} [days][a]	χ^2 (df = 1)	Slope ±SE	Intercept	Comparison using the Preisler method
R. dominica	100	5.54 (5.07–5.92)	94.43	1.03±10.01	–7.44	A*
	200	3.79 (3.31–4.18)	84.22	9.05±0.98	–5.24	A
	500	2.05 (1.58–2.40)	44.44	8.64±1.29	–2.69	A
O. surinamensis	100	4.81 (4.21–5.29)	68.28	8.19±0.99	–5.60	A
	200	3.80 (3.14–4.27)	45.69	9.79±1.44	–5.68	A
	500	3.31 (2.66–3.74)	30.28	12.23±2.22	–6.36	B**

[a] 95% lower and upper fiducial limits are shown in parenthesis; *based on the Preisler method and comparing the upper and lower confidence limits, because of the overlapping of LC_{50} confidence interval where no significant difference is observed and same letter (A) is used; SE – standard error; **based on the Preisler method significant difference is observed and different letter (B) is used

Table 3. Calculated LT_{50} values for the durability of fumigant toxicity in *Eucalyptus dundasii* essential oil at a concentration of 500 μl · l^{-1} of air on adult *Rhyzopertha dominica* and *Oryzaephilus surinamensis*

Insects	Concentration [μl · l^{-1} air]	LT_{50} [days][a]	χ^2 (df = 1)	Slope ±SE	Intercept	Comparison using the Preisler method
R. dominica	500	3.71 (3.28–4.14)	71.74	–7.56±0.89	4.31	A*
O. surinamensis	500	9.64 (8.87–0.44)	144.41	–6.58±0.54	6.48	B*

[a] 95% lower and upper fiducial limits are shown in parenthesis; *based on the Preisler method and comparing the upper and lower confidence limits, because of the overlapping of LC_{50} confidence interval where a significant difference is observed and different letters (A and B) are used; SE – standard error

Table 4. The results of the repellency effect of *Eucalyptus dundasii* essential oil against *Rhyzopertha dominica* and *Oryzaephilus surinamensis* adults

Insects	Concentration [μl · l^{-1} air]	The mean of repellent indexes	Standard deviation of repellent indexes (SD)	1 – SD	1 + SD	Effect	The mean repellent [%] ±SD
R. dominica	70	0.39	0.12	0.87	1.12	repellent	60.24 a ±12.57 IV
	140	0.33	0.03	0.96	1.03	repellent	67.00 b ±3.82 IV
	280	0.25	0.03	0.96	1.03	repellent	74.56 c ±3.10 IV
O. surinamensis	70	0.33	0.27	0.72	1.27	repellent	66.10 a ±27.22 IV
	140	0.38	0.19	0.80	1.19	repellent	61.62 b ±19.51 IV
	280	0.11	0.09	0.90	1.09	repellent	88.15 b ±9.90 V

The mean of percent repellency (PR): Class 0: PR = 0–0.1%, Class I: PR = 0.1–20%, Class II: PR = 20.1–40%, Class III: PR = 40.1–60%, Class IV: PR = 60.1–80%, and Class V: PR = 80.1–100%.
The mean with the same letter for each column are not significant

to a decline in the RGR. There was no significant difference in *R. dominica* at 0.5, 1, 1.5, 2, and 3 μl · l^{-1} of air concentrations, however, there was a significant difference at concentrations in *O. surinamensis* (Table 5). The results of *E. dundasii* essential oil on the RCR of *R. dominica* and *O. surinamensis* adults at different concentrations,

Table 5. The anti-nutritional effects of essential oil from *Eucalyptus dundasii* on the adults of *Rhyzopertha dominica* and *Oryzaephilus surinamensis*

Insects	Concentration [μl · l^{-1} air]	RGR (F = 15.92)	RCR (F = 14.09)	ECI (F = 3.21)	FDI (F = 7.89)
R. dominica	0	0.069 a ±0.002	0.57 a ±0.06	44.91 a ±1.89	–
	12.5	0.015 b ±0.020	0.38 ab ±0.16	12.26 b ±1.87	29.68 a ±31.47
	25.0	0.007 b ±0.01	0.32 b ±0.07	2.28 c ±1.43	40.68 a ±12.25
	37.5	0.007 b ±0.003	0.24 bc ±0.09	1.25 cd ±4.14	53.39 a ±16.36
	50.0	0.000 b ±0.008	0.04 cd ±0.04	0.65 d ±5.06	90.77 b ±4.04
	75.0	–0.001 b ±0.006	0.03 d ±0.008	–0.65 d ±15.09	92.83 b ±2.12
O. surinamensis	0	0.76 a ±0.01	0.432 a ±0.04	18.01 a ±4.46	–
	12.5	0.027 ab ±0.002	0.289 ab ±0.12	13.38 b ±14.83	29.68 a ±31.47
	25.0	0.024 ab ±0.023	0.246 b ±0.02	11.60 bc ±6.75	35.36 ab ±2.59
	37.5	0.014 b ±0.04	0.204 bc ±0.04	11.26 bc ±8.04	48.65 ab ±10.38
	50.0	0.012 b ±0.001	0.153 bc ±0.10	4.36 c ±16.49	59.04 ab ±33.70
	75.0	–0.002 b ±0.032	0.078 c ±0.02	–7.18 d ±36.71	78.48 b ±6.38

RGR – relative growth rate; RCR – relative consumption rate; ECI – efficiency of conversion of ingested food; FDI – feeding deterrence index
Non-similar letters indicate a significant difference at a 5% level of probability in Tukey's test

Table 6. The results obtained for the chemical analysis of essential oil isolated from the leaves of *Eucaliptus dundasii*

Components	Retention index [min]	Percentage [%]
α-thujene	928	11.37
α-pinene	935	0.84
β-pinene	976	0.15
Myrcene	987	0.30
p-cymene	1,023	12.41
1,8-cineole	1,030	54.15
γ-terpinene	1,058	0.67
terpinolene	1,086	0.20
Cis-P-menth-2-en-1-ol	1,118	0.28
Trans pinocarveol	1,136	1.40
Pinocarvone	1,160	0.33
Terpinen-4-ol	1,174	0.30
Cryptone	1,182	0.46
α-terpineol	1,186	0.20
E-caryophyllene	1,420	6.70
α-guaiene	1,435	1.40
Allo-aromadendrene	1,461	0.30
Trans carina-1(6),4-2	1,474	0.53
Bicyclogermacrene	1,496	0.16
Zonarene	1,527	0.45
Longipinanol	1,566	0.90
Globulol	1,578	0.10
Total	–	93.6

were significantly different. An increased density led to a decrease in the relative consumption rate. Concentration differences in the control were considerable. There were significant differences among the densities (Table 5). The results of the variance analysis showed that the effect of *E. dundasii* essential oil at different concentrations on the ECI for *R. dominica* and *O. surinamensis* adults, did not differ significantly (Table 5). The results revealed that *E. dundasii* essence effects on FDI of *R. dominica* and *O. surinamensis* adults, were significantly different. In both insects, an increase in the concentration led to an increase in the FDI. The highest effect was seen in the food deterrence increase. In general, the element of caused effects in RGR and RCR was contributed to the food deterrence index (Table 5).

The results of the chemical analysis are presented in table 6. Twenty-two compounds in *E. dundasii* leaf oil were identified. The major constituents were found to be: 1,8-cineole (54.15%), *p*-cymene (12.41%), *α*-thujene (11.37%), E-caryophyllene (6.7%), trans pinocarveol (1.4%), and *α*-guaiene (1.4%), accounting for 87.43% of the total oil. Total identified components were 93.7% of the essential oil.

Discussion

The results obtained concerning the toxicity of *E. dundasii* essential oil on *R. dominica* and *O. surinamensis* adults indicated that both insects were sensitive to this oil and the estimated LC_{50} increased when the concentration and exposure time increased. The insecticidal effects of *Lavandula angustifolia* Chaix, *Rosmarinus officinalis* L., *Thymus vulgaris* L., and *Laurus nobilis* L. plant essential oils were studied against: *Sitophilus oryzae* (Linnaeus, 1763), *R. dominica*, and *Tribolium castaneum* (Herbst). *Sitophilus oryzae* and *R. dominica* were found to have the maximum sensitivity to essential oil (Rozman *et al*. 2007). Ebadollahi *et al*. (2010) studied the fumigant insecticidal toxicity of *Agastache foeniculum* (Pursh) essential oil. The 24 h-LC_{50} on adults of *O. surinamensis* and *Lasioderma serricorne* (Fabricius) was 18.781 and 21.565 μl · l^{-1} of air, respectively. *Oryzaephilus surinamensis* was more sensitive than *L. serricorne* and the number of deaths increased with an increase in the concentration and with an increase in time. The fumigant toxicity of *Artemisia argyi* H. Lév. & Vaniot essential oil against *O. surinamensis* was studied by Lu *et al.* (2011). The results revealed that the essential oil had a highly insecticidal effect and its lethal effects increased as the concentration increased. The mortality rate exceeded 97% when the concentration was increased to 160 μl · l^{-1} of air.

The results revealed that *E. dundasii* essential oil at a concentration of 70, 140, and 280 μl · l^{-1} of air was repellent against both *R. dominica* and *O. surinamensis*. The repellency increased as the concentration was increased.

The essential oil *E. dundasii* acted stronger in *O. surinamensis* and show a more repellent effect. Also supporting our study on the susceptibility of *R. dominica* and *O. surinamensisi* adults in the repellent assays, was the study by Salvadores *et al*. (2007), who found that clove oil was repellent against *R. dominica*, *S. oryzae*, and *T. castaneum* (Salvadores *et al*. 2007). *Schinus molle* L. essential oil was found to be repellent against the adults of *S. granarius*, *R. dominica*, and *T. castaneum* (Benzi *et al*. 2009). Khemira *et al* (2012) found a strong repellent activity of the essential oil of *Eucalyptus astringens* Maiden against *R. dominica* and *O. surinamensis.* This oil showed a 58.75% repellent activity against *R. dominica* and 55% repellent activity against *O. surinamensis*. The results of all the mentioned studies are similar to the results of our present study.

The present study's results for the nutritional indexes of *E. dundasii* essential oil against *R. dominica* and *O. surinamensis* adults, revealed that RGR, RCR, ECI, and FDI decreased significantly in both insects. In other words, the mentioned oil had the highest inhibitory effect against both insects; however, it does not lead to toxicity when followed by feeding. The effects of plant essential oils and even extracts on the nutritional indexes of insect pests have been studied by various researchers. The antifeedant effects of essential oils from *Eupatorium adenophorum* and *Artemisia nilagricia* against *Rhynchophorous ferrugineus* (Olivier, 1790) was studied by Shukla *et al*. (2012). Their results showed that essential oils were antinutritional in 96 h time intervals, and at 1,000 ppm, nutrition decreased by 52.96%. The antifeedant effects of *Piper nigrum* L. and *Jatropha curcas* L. extracts against *Corcyra cephalonica* (Stainton, 1866) larvae were also studied. Significant antifeedant effects of both extracts increased when the concentration was increased. The extractions of both plants had antifeedant properties at all concentrations as was shown in the FDI evaluation (Khani *et al*. 2013).

Several reports showing the insecticidal activity of *Eucalyptus* species essential oils have been reported (Papachristos and Stamopoulos 2002; Negahban *et al*. 2007; Mishra *et al*. 2012; Izakmehri *et al*. 2013; Shafiei Alavijeh 2014). But the present study is the first to show that essential oil from *E. dundasii* can function as insecticide against *R. dominica and O. surinamensis*. Among the essential components of essential oil, monoterpenoids has contributed the most to fumigation activities against storage product pests (Rajendran and Sriranjini 2008). Several reports indicated that monoterpenoids was lethal to the insects through inhibition of the activity of the acetyl choline esterase (AChE) enzyme (Houghton *et al*. 2006). In the current study, the main compound of *E. dundasii* essential oil was found to be 1,8-cineole, a monoterpenoid, and this finding is supported by many researchers (Sefidkon *et al*. 2007; Fathi and Sefidkon 2012; Zhang *et al*. 2012). The main component of the fumigation toxicity agent in the essential oils against storage pests was found to be 1,8-cineole (Cimanga *et al*. 2002; Lee *et al*. 2004; Rajendran and Sriranjini 2008). It can be concluded, that toxicity of *E. dundasii* essential oil against the mentioned pests is related to the major components, such as 1,8-cineole.

The results of this and of earlier studies indicate that essential oils including, *E. dundasii*, are a bio-source of biologically active vapors which may potentially prove to be efficient insecticides. For the practical application of the essential oils as insecticides, further studies which deal with the development of formulations are necessary to improve efficacy and durability as well as to reduce costs.

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