FUMIGANT EFFICACY OF 1,8-CINEOLE AND EUGENOL ON THE PUPAL STAGE OF TRIBOLIUM CASTANEUM (HERBST) (INSECTA: COLEOPTERA: TENEBRIONIDAE)

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SUMMARY

The fumigant efficacy of 1,8-cineole and eugenol compounds was tested on the pupal stage of the red flour beetle Tribolium castaneum (Herbst). Effects of those compounds were determined as mortality as well as impact on development of treated male and female pupae. Also differences in sensitivity to the tested compounds between sexes of T. castaneum pupae were assessed. Compounds were tested at 3 doses rate 0.34, 0.86 and 1.71 ml L^{-1}vol. at 30±1°C and 70±10% r.h. during 48 h. Compounds toxicity was expressed in two action modes: lethal, and as an impediment to normal metamorphosis of pupae into adult stage, forming "adultoids" and deformed adults (at both sexes). Male pupae were generally more sensitive to both tested compounds. Overall, better efficiency was performed with 1,8-cineole, while eugenol had not accomplished promising effect on the tested pupae.

Keywords: fumigation; 1,8-cineole; eugenol; Tribolium castaneum; pupae

INTRODUCTION

The red flour beetle *Tribolium castaneum* (Herbst) is a polyphagous, cosmopolitan pest (Coleoptera: Tenebrionidae). Besides cereals, it can infest a huge range of stored products including sunflower, oil cake, flour, legumes, peanut, coffee, dry fruit, cocoa, chocolate, powdered milk, spices, as well as herbarium collections in museums (Mason, 2003). Fumigation plays a significant role For *T. castaneum* control, as well as for all other stored-product pests. However, in 1992 methyl bromide, a fumigant with the widest range of effectiveness, was defined as ozone depleting substance and since then its usage has been banned in developing countries by the stipulation of Montreal Protocol; by the year 2015 it will be completely banned in the rest of the world (Montreal Protocol, 1995). Therefore there is a need for alternatives in all applications of methyl bromide. As a direct alternative only two fumigants have been left, phosphine and sulphuryl fluoride, according to Ducom (2012).

The reasons of phosphine restriction to become complete replacement of methyl bromide are exposure time and temperature (Ducom, 2012), as well as increasing resistant populations among storage pests (Mahroof and Hagstrum, 2015).

The other possible alternative is sulphuryl fluoride. However, there are also limitations, first and foremost lower activity at the insect egg stage and psocids (Athanassiou et al., 2012) including problems of residues in food (Ducom, 2012). All the things considered, there is an urgent need for new cognition of pest control methods which would be adequately efficient and similarly reduce adverse effect of synthetic substances in stored products protection. Besides, there is a strong interest in the research into plant products efficiency apropos of essential oils and their compounds for stored pest control. Botanical insecticides show different effects on pests which could diminish cross-resistance (Isman, 2008); moreover, they are relevant part of integrated protection within organic production (Ebadollahi, 2013). It has been found out that essential oils and/or their compounds have different effect on pests likewise con-

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tact, repellent, antifeedant, and fumigant or inhibitory to eggs laying (Arabi et al., 2008; Benzi et al., 2009). Besides, they have neurotoxic effect inducing symptoms similar to those produced by organophosphates and carbamate-based insecticides (Isman, 2000).

Monoterpenoid 1,8-cineole have a promising potential for use as a fumigant inducing very good results in the control of stored products insects (Lee et al., 2003). Authors Guo et al. (2015) reported that 1,8-cineole along with some other essential oil components of *Etlingera yunnanensis* rhizomes exhibited stronger contact toxicity than β-caryophyllene against *T. castaneum* adults. Since in our previous study (Liška et al., 2010) 1,8-cineole was far the most effective compound followed by camphor and eugenol against *T. castaneum* adults, we selected 1,8-cineole and eugenol for testing their efficacy on the immature stage of *T. castaneum*.

With this experiment a fumigant efficacy of 1,8-cineole and eugenol compounds were tested against the pupal stage of the red flour beetle. Also differences in sensitivity between sexes of *T. castaneum* pupae to the tested compounds were determined.

MATERIAL AND METHODS

Essential oil compounds

Used compounds: 1,8-cineole 93% (GC) and eugenol 99% (GC) were purchased from the producers „Sigma-Aldrich" (Germany) and „Fluka" (SG Switzerland).

Insects rearing

Test insects of *T. castaneum* species were reared under the controlled conditions at 30±1°C; 70-80% relative humidity (r.h.); in darkness on a mixture of hard wheat flour and dry yeast at the ratio 10:1 (Liu and Ho, 1999). Sexing pupae (Lyon, 2000) was performed with stereozoom loupe with digital camera and software Olympus SZX12 when the pupae were 1-3 days old.

Fumigant toxicity of 1,8-cineole and eugenol

Fumigation was performed in the glass jars of 350 ml volume filled with wheat grain occupying 50% of the jars volume. Twenty sexed pupae were put into the silk mesh cages, and altogether placed in jars in four repetitions. Compounds (1,8-cineole and eugenol) were applied with "Kartell" micropipette on filter paper attached to the lids of the glass containers - tightly sealed and kept under controlled conditions at 30±1°C; 70-80% r.h. in darkness for 48 hours. The compounds were tested at 3 dose rates (0.34, 0.86 and 1.71 ml L^{-1}vol.). The control was carried out under the same conditions only without oil application. In order to assess fumigant efficacy of the tested compounds on the pupal stage, insect mortality and growth activity have been determined following the modified scale according to Mandava (1985). By that scale, a number of dead units in the pupal stage (developmental stage 0), a number of adultoids (developmental stage 1, live and dead), deformed adults (developmental stage 2) developed from the treated survived pupae, and a number of normally developed adults (developmental stage 3) without deformations were defined. Intermediate form or "adultoid" has a characteristic appearance with the front part of the body likewise adult and is pigmented with widespread forewings and hindwings (if developed), while abdomen has a typical appearance of pupae and is non-pigmented.

Data analysis

Fumigant efficacy data were processed by statistical analysis system (SAS/STAT Software 9.3 2013-2014). In order to determine distribution deviations, a Kolmogorov-Smirnov test was used in module SAS Interactive Data Analysis. One-way analysis of variance of the tested variables was subjected to SAS Analyst module and a procedure ANOVA was used. Tukey's Studentized Range (HSD) test was used to detect differences between means at the 0.05 significance level.

RESULTS

Compound toxicity on male sex pupae

Compound toxicity on male sex pupae was expressed in two modes. First, lethal for the treated pupae; in consequence their further development was disabled. The percentage of dead pupae at the stage 0 was ranged from 1.25% to 30.00%, depending on the compound and doses (Table 1). As another mode of action, interference to normal metamorphosis of pupae into adults was detected, forming "adultoid" units and deformed adults developed from treated survived pupae. The percentage of "adultoids" at the stage 1 was ranged from 2.50% to 37.50% (dead), while percentage of deformed units at the stage 2 was ranged from 0% to 22.50% (live), respectively 2.50% to 12.50% (dead) in regard to the compound and dose. These deformities were less or more expressed on elytra developed adults. With increasing 1,8-cineole dose (from 0.34 to 0.86 and 1.71 ml L^{-1}vol.) percentage of normally developed live adults (stage 3), which developed from survived treated pupae, has been significantly decreased (56.25%; 31.25% and 18.75%; $F=25.0$; $df=3$; $P<0.05$). A significant efficacy of eugenol, in regard to the control was detected only at the highest dose expressed with significantly higher percentage of dead units at the stage 2. Since this percentage was relatively low (12.5%) but significant mortality of treated pupae has not been reached and percentage of normally developed live adults has not been significantly different from the control, it could be concluded that eugenol, in this experiment, is not effective against *T. castaneum* male pupae.

Table 1. Fumigant efficacy of 1,8-cineole and eugenol to the *Tribolium castaneum* (Herbst) male sex pupae (scale according to Mandava, 1985)

Tablica 1. Fumigantna učinkovitost 1,8-cineola i eugenola na muške kukuljice vrste Tribolium castaneum (Herbst) (skala prema Mandavi, 1985.)

Oil *Ulje*	Dose ml L^{-1} *Doza ml L^{-1}vol.*	Units of ***Tribolium castaneum*** ♂ **by growth stages (%)*** *Muške jedinke Tribolium castaneum prema stadiju rasta (%)**						
		Growth stage / *Stadij rasta*						
		Stage 0 *Stadij 0*	**Stage 1** *Stadij 1*		**Stage 2** *Stadij 2*		**Stage 3** *Stadij 3*	
		Dead** *Uginuli*** **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***
1,8-cineole *1,8-cineol*	0.34	30.00±3.53a	0.00±0.00a	6.25±3.14b	3.75±2.39b	3.75±3.75a	56.25±5.15b	0.00±0.00a
	0.86	23.75±3.75a	0.00±0.00a	12.50±3.22b	22.50±3.22a	6.25±1.25a	31.25±2.39c	3.75±2.39a
	1.71	27.50±5.20a	0.00±0.00a	37.50±7.21a	6.25±1.25b	8.75±2.39a	18.75±5.90c	1.25±1.25a
	0	3.75±2.39b	3.75±2.39a	3.75±2.39b	7.50±3.22b	0.00±0.00a	81.25±7.46a	0.00±0.00a
Eugenol *Eugenol*	0.34	2.50±2.50a	0.00±0.00a	16.25±1.25a	0.00±0.00a	2.50±2.5ba	78.75±3.75a	0.00±0.00a
	0.86	3.75±2.39a	0.00±0.00a	11.25±4.26ba	2.50±1.44a	2.50±2.50ba	80.00±2.04a	0.00±0.00a
	1.71	1.25±1.25a	0.00±0.00a	2.50±2.50b	3.75±2.39a	12.50±4.78a	80.00±7.07a	0.00±0.00a
	0	3.75±2.39a	3.75±2.39a	3.75±2.39b	7.50±3.22a	0.00±0.00b	81.25±7.46a	0.00±0.00a

* Means in the same column followed by the same letters in superscript are not significantly different $P<0.05$; comparison is for each dose by columns – *Prosječne vrijednosti u kolonama s istim slovom nisu statistički značajne P<0,05; usporedbe za svaku dozu su prema kolonama*

**All units at the stage 0 represent dead pupae only – *Sve jedinke u fazi 0 predstavljaju mrtve kukuljice*

Compound toxicity on female sex pupae

T. castaneum female pupae have shown different sensitivity depending on the applied compound and dose. In comparison of the results (Tukey's test, $\alpha=0.05$) among compounds and control without oil application (Table 2), it is noticeable that 1,8-cineole showed significant efficiency for female pupae control with significantly more dead units at the stage 0 (31.25% - at dose of 1.71 ml L^{-1}vol.) ($F=5.88$, $df=3$, $P=0.0105$) along with significantly lower percentage of normally developed live adults (units at the stage 3) ($F=18.57$, $df=3$, $P<0.05$). Increasing doses from 0.34 to 1.71 ml L^{-1}vol. had no influence on significant increase of eugenol efficacy against *T. castaneum* female pupae.

Table 2. Fumigant efficacy of 1,8-cineole and eugenol to the *Tribolium castaneum* (Herbst) female sex pupae (scale according to Mandava, 1985)

Tablica 2. Fumigantna učinkovitost 1,8-cineola i eugenola na ženske kukuljice vrste Tribolium castaneum (Herbst) (skala prema Mandavi, 1985.)

Oil *Ulje*	Dose ml L^{-1} *Doza ml L^{-1}vol.*	Units of ***Tribolium castaneum*** ♀ **by growth stage (%)*** *Ženske jedinke Tribolium castaneum prema stadiju rasta (%)**						
		Growth stage / *Stadij rasta*						
		Stage 0 *Stadij 0*	**Stage 1** *Stadij 1*		**Stage 2** *Stadij 2*		**Stage 3** *Stadij 3*	
		Dead** *Uginuli*** **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***	**Live** *Živi* **Mean±*SE***	**Dead** *Uginuli* **Mean±*SE***
1,8-cineole *1,8-cineol*	0.34	18.75±5.15ba	1.25±1.25a	7.50±2.50a	3.75±1.25a	3.75±3.75b	63.75±7.46b	1.25±1.25a
	0.86	18.75±5.90ba	0.00±0.00a	8.75±2.39a	10.00±3.53a	6.25±3.75ba	55.0±7.35b	1.25±1.25a
	1.71	31.25±7.18a	0.00±0.00a	11.25±3.75a	8.75±3.75a	17.50±3.22a	28.75±6.25c	0.00±0.00a
	0	0.00±0.00b	0.00±0.00a	2.50±2.50a	3.75±2.39a	0.00±0.00b	93.75±9.39a	0.00±0.00a
Eugenol *Eugenol*	0.34	10.00±2.04a	0.00±0.00a	7.50±1.44a	1.25±1.25a	1.25±1.25a	81.25±3.14b	0.00±0.00a
	0.86	8.75±4.26ba	0.00±0.00a	5.00±2.04a	3.75±1.25a	0.00±0.00b	83.75±1.25ba	0.00±0.00a
	1.71	0.00±0.00b	0.00±0.00a	3.75±3.75a	3.75±2.39a	8.75±3.14a	83.75±4.26ba	0.00±0.00a
	0	0.00±0.00b	0.00±0.00a	2.50±2.50a	3.75±2.39a	0.00±0.00b	93.75±2.39a	0.00±0.00a

* Means in the same column followed by the same letters in superscript are not significantly different $P<0.05$; comparison is for each dose by columns – *Prosječne vrijednosti u kolonama s istim slovom nisu statistički značajne P<0,05; usporedbe za svaku dozu su prema kolonama*

**All units at the stage 0 represent dead pupae only – *Sve jedinke u fazi 0 predstavljaju mrtve kukuljice*

Comparison of compounds efficacy between pupae sex

After the fumigation treatment, *T. castaneum* pupae showed different sensitivity to the tested compounds depending on sex. With 1,8-cineole significant differences in sensitivity between sexes were observed at higher doses (Table 3). Thus, at the dose of 0.86 ml L^{-1} vol., there were more deformed live units of male sex at the stage 2, than females (22.50%, respectively 10.00% F=6.82; *df*=1; *P*=0.040). Additionally, at the same dose of 1,8-cineole for male sex there was a significantly lower percentage of live adults developed from the treated survived pupae (31.25% - live male units at the stage 3; respectively 55.00% - live female units at the stage 3; F=9.42; *df*=1; *P*=0.0220), accordingly pointing to the better survival of female pupae, in general. Male sex was at 1,8-cineole dose of 1.71 ml L^{-1}vol. more sensitive, which is noticeable through a higher percentage of "adultoids" at the stage 1 (37.50% - male units, respectively 11.25% - female units; F=10.42; *df*=1; *P*=0.0180).

Table 3. Fumigant efficacy of 1,8-cineole between *Tribolium castaneum* (Herbst) pupae sex (scale according to Mandava, 1985)

Tablica 3. Fumigantna učinkovitost 1,8-cineola i eugenola između spolova kukuljica Tribolium castaneum (Herbst) (skala prema Mandavi, 1985.)

Sex *Spol*	Units of ***Tribolium castaneum*** by growth stage (%)* *Jedinke Tribolium castaneum prema stadiju rasta (%)**						
	Growth stage / *Stadij rasta*						
	Stage 0 *Stadij 0*	**Stage 1** *Stadij 1*		**Stage 2** *Stadij 2*		**Stage 3** *Stadij 3*	
	Dead** *Uginuli***	**Live** *Živi*	**Dead** *Uginuli*	**Live** *Živi*	**Dead** *Uginuli*	**Live** *Živi*	**Dead** *Uginuli*
	Dose 0.34 ml L^{-1}vol. / *Doza 0,34 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	30.00±3.53a	0.00±0.00a	6.25±3.14a	3.75±2.39a	3.75±3.75a	56.25±5.15a	0.00±0.00a
♀	18.75±5.15a	1.25±1.25a	7.50±2.50a	3.75±1.25a	3.75±3.75a	63.75±7.46a	1.25±1.25a
	Dose 0.86 ml L^{-1}vol. / *Doza 0,86 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	23.75±3.75a	0.00±0.00a	12.50±3.22a	22.50±3.22a	6.25±1.25a	31.25±2.39b	3.75±2.39a
♀	18.75±5.90a	0.00±0.00a	8.75±2.39a	10.00±3.53b	6.25±3.75a	55.00±7.35a	1.25±1.25a
	Dose 1.71 ml L^{-1}vol. / *Doza 1,71 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	27.50±5.20a	0.00±0.00a	37.50±7.21a	8.75±3.75a	8.75±2.39a	18.75±5.90a	1.25±1.25a
♀	31.25±7.18a	0.00±0.00a	11.25±3.75b	6.25±1.25a	17.5±3.22a	28.75±6.25a	0.00±0.00a

* Means in the same column followed by the same letters in superscript are not significantly different *P*<0.05; comparison is for each dose by columns – *Prosječne vrijednosti u kolonama s istim slovom nisu statistički značajne P<0,05; usporedbe za svaku dozu su prema kolonama*

**All units at the stage 0 represent dead pupae only – *Sve jedinke u fazi 0 predstavljaju mrtve kukuljice*

Difference in efficacy depending on pupae sex was less expressed in the treatment with eugenol (Table 4). Only at the lowest dose (0.34 ml L^{-1}vol.) male sex was more sensitive which was expressed as significantly higher percentage of dead "adultoids" with regard to the female sex (16.25%; respectively 7.50% F=21.0; *df*=1; *P*=0.0038). At higher doses of eugenol (0.86 and 1.71 ml L^{-1}vol.) pupae of both sexes were equally sensitive. Also in growth stages between sexes no significant differences were observed (Tukey's test, α=0.05).

Table 4. Fumigant efficacy of eugenol between *Tribolium castaneum* (Herbst) pupae sex (scale according to Mandava, 1985)

Tablica 4. Fumigantna učinkovitost eugenola na spolove kukuljica Tribolium castaneum (Herbst) (skala prema Mandavi, 1985.)

Sex *Spol*	Units of *Tribolium castaneum* by growth stage (%)* *Jedinke Tribolium castaneum prema stadiju rasta (%)**						
	Growth stage / *Stadij rasta*						
	Stage 0 *Stadij 0*	**Stage 1** *Stadij 1*		**Stage 2** *Stadij 2*		**Stage 3** *Stadij 3*	
	Dead** *Uginuli***	**Live** *Živi*	**Dead** *Uginuli*	**Live** *Živi*	**Dead** *Uginuli*	**Live** *Živi*	**Dead** *Uginuli*
	Dose 0.34 ml L^{-1}vol. / *Doza 0,34 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	2.50±2.50a	0.00±0.00a	16.25±1.25a	0.00±0.00a	2.50±2.50a	78.75±3.75a	0.00±0.00a
♀	10.00±2.04a	0.00±0.00a	7.50±1.44b	1.25±1.25a	1.25±1.25a	81.25±3.14a	0.00±0.00a
	Dose 0.86 ml L^{-1}vol. / *Doza 0,86 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	3.75±3.75a	0.00±0.00a	11.25±4.26a	2.50±1.44a	2.50±2.50a	80.00±2.04a	0.00±0.00a
♀	8.75±4.26a	0.00±0.00a	5.00±2.04a	3.75±1.25a	0.00±0.00a	83.75±1.25a	0.00±0.00a
	Dose 1.71 ml L^{-1}vol. / *Doza 1,71 ml L^{-1} vol.*						
	Mean±*SE*	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***	**Mean±*SE***
♂	1.25±1.25a	0.00±0.00a	2.50±2.50a	3.75±2.39a	12.50±4.78a	80.00±7.07a	0.00±0.00a
♀	0.00±0.00a	0.00±0.00a	3.75±3.75a	3.75±2.39a	8.75±3.14a	83.75±4.26a	0.00±0.00a

* Means in the same column followed by the same letters in superscript are not significantly different $P<0.05$; comparison is for each dose by columns

**All units at the stage 0 represent dead pupae only

DISCUSSION

The fumigant effectiveness of 1,8-cineole and eugenol against *T. castaneum* pupae was expressed in two action modes: lethal, and as an impediment to normal metamorphosis of pupae into adult stage, forming "adultoids" and deformed adults (at both sexes). These deformities were more or less expressed on adult elytra. Among deformed adults there were also alive units, although there is an assumption that thus deformed adults have weaker reproduction in comparison to normally developed adults. In support of that, Fathpour et al. (2007) while testing influence of juvenile hormone pyriproxyfen against cockroaches indicated strong positive correlation between morphogenetic anomalies on adult wings and their sterility. In addition, morphologic abnormalities on *T. castaneum* were noticed by Santos et al. (2011), especially on adults after the treatment with allyl isothiocyanate, the main component of mustard oil, on larvae and pupae, suggesting that mono-isothiocynates could also interfere with growth and insect development. Altogether, a better activity was recorded with 1,8-cineole, while a satisfactory effect on tested pupae has not been achieved with eugenol. In our previous study (Liška et al., 2011), at the same dose (0.34 ml L^{-1}vol.) 1,8-cineole had a significant higher lethal effect on treated pupae (male and female) when applied in empty glass containers (70.0% and 27.5% respectively) regarding of application in containers filled with wheat (30.0% and 18.75% respectively). Between sexes, significant differences in efficacy of tested components were noticed. These differences were most expressed by 1,8-cineole. Concerning female sex, 1,8-cineole affected higher percentage of deformed units at the adult stage, in contrast to the male sex. Difference in compound efficacy between sexes was less expressed by the compound eugenol. The same effect of monoterpenoids (terpinen-4-ol, 1,8-cineole, linalool, *R*-(+)-limonene and geraniol) was detected by Stamopoulos et al. (2007) on the pupae of akin species *Tribolium confusum* (Jacquelin du Val), pointing out as well to the appearance of "adultoids" and deformed adults. Our results are partly in accordance with previously mentioned investigation, and that is the fact that toxicity of monoterpenoids has properties acting as juvenile hormones. In other words, metamorphosis postponement at the pupal stage along with occurrence of "adultoids" and deformed adults could be elucidated by the hypothesis of direct influence on hormonal system (Bowers, 1969) similar to influence of insect growth regulators.

CONCLUSION

The fact that the tested monoterpenoids from our research have a growth regulators feature should not be neglected. However, it could represent a base for further investigation in terms of combination of a few essential oils' compounds with different activity, lethal and as a growth regulator, all aiming to have more effective pest control, or moreover, a possible synergism among compounds.

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FUMIGANTNA UČINKOVITOST 1,8-CINEOLA I EUGENOLA NA STADIJ KUKULJICE KESTENJASTOG BRAŠNARA *TRIBOLIUM CASTANEUM* (HERBST) (INSECTA: COLEOPTERA: TENEBRIONIDAE)

SAŽETAK

Fumigantna učinkovitost komponenata 1,8-cineola i eugenola testirana je na stadij kukuljice kestenjastoga brašnara Tribolium castaneum (Herbst). Određen je mortalitet i aktivnost rasta kukuljica oba spola, kao i razlike u osjetljivosti između spolova kukuljica T. castaneum na ispitivane komponente. Komponente su testirane u 3 koncentracije, 0,34, 0,86 i 1,71 ml $^{-1}$vol. u kontroliranim uvjetima na 30±1°C; 70-80% rvz, u tami tijekom 48 sati. Toksičnost komponenata bila je izražena kroz dva načina djelovanja: letalno te kao ometanje normalne preobrazbe kukuljice u odrasli stadij, formirajući „adultoid" i deformirane odrasle jedinke (kod oba spola). Kukuljice muškoga spola općenito su senzibilnije na obje testirane komponente. Sveukupno, bolje je djelovanje ostvareno s 1,8-cineolom, dok s eugenolom nije postignut zadovoljavajući učinak na testirane kukuljice.

Ključne riječi: fumigacija; 1,8-cineol; eugenol; Tribolium castaneum; kukuljice

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