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ORIGINAL RESEARCH ARTICLE

Repellency of *Ferulago angulata* (Schlecht.) Boiss essential oil on two major stored-product insect pests without effect on wheat germination

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Abstract

There has been an increasing demand among agricultural researchers and producers for bio-insecticides due to the threats of the related chemicals leading to human health problems, environmental contamination, pest resistance, and secondary pest outbreaks. In this regard, the repellent effects of the essential oil extracted from *Ferulago angulata* (Schlecht.) Boiss as a well-known medicinal plant were measured against the red flour beetle (*Tribolium castaneum* (Herbst)) and lesser grain borer (*Rhyzopertha dominica* (F.)) using the three different techniques of filter paper, leaky glass, and olfactometry. The experiments were conducted at the concentrations of 30, 52, 93, 165, and 300 ppm under controllable conditions. The maximum Percent Repellency (PR) rates of the essential oil at the concentration of 300 ppm were found to be 59.01, 54.12, and 43.21% for *T. castaneum* and 48.84, 50.52, and 42.73% for *R. dominica* based on the mentioned methods, respectively. By enhancing the essential oil concentrations and exposure times, the PR rates increased. Furthermore, the essential oil effects of *F. angulata* on wheat germination were evaluated and no decreases in the germination of the treated wheat seeds were found at the tested concentrations. According to the results of the present study, the essential oil of *F. angulata* could be used for reducing *T. castaneum* and *R. dominica* populations.

Keywords Germination · *Ferulago angulata* · Olfactometer · Repellency · Stored pest

Introduction

Stored pests are major destroyers of stored products and cause the loss of about 10–40% of the stored grains annually (Parveen et al. 2013). The red flour beetle (*Tribolium castaneum* (Herbst) (Col., Tenebrionidae)) is one of the major insect pests of cereal (Chaubey 2007). This pest is one of the most widespread and destructive stored-product pests throughout the world as it produces up to several generations per year (Liu and Ho 1999). The lesser grain borer (*Rhyzopertha dominica* (F.) (Col., Bostrichidae)) is the primary pest of stored grains in many regions of the world. The insect is injurious to cereals, breeds in corn, rice, and wheat and in other substrates containing starch (Edde 2012). The control of these pests is based on the use of chemical insecticides and fumigants. However, their widespread applications have led to some serious problems, such as the developments of resistant insect strains to insecticides (Jbilou et al. 2006; Ribeiro et al. 2003).

Among higher plants, there are 17,500 aromatic species distributed throughout a limited number of families, including the families of Asteraceae, Apiaceae, Poaceae, etc. (Chaubey 2012). Generally, essential oils play an important role in protecting plants and damaging pests. Moreover, they may attract some insects to disperse pollens and seeds via their odours (Bakkali et al. 2008). Essential oil products can vary in quality, quantity, and composition based on their plant organs, ages, and vegetative cycle stages, as well as the compositions of the soils and climates, in which the plants are grown (Chaubey 2012). Essential oils are natural complex secondary metabolites characterized by a strong odour and generally have a lower density than water (Bakkali et al. 2008). The concerns about human health and environmental problems induced by chemical insecticides have led to making numerous efforts to find safe, suitable, and executable alternatives (Tapondjou et al. 2005). Plant-Based Insecticides (PBIs) can be less toxic to man and suitable for use by small-scale

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farmers, while being capable of protecting crops from attacks by a wide range of insect pests (Udo 2011). Essential oils do not have adverse environmental effects besides being safe and eco-friendly agents with high potential for insect pest management (Regnault-Roger et al. 2012; Isman and Grieneisen 2014).

Ferulago angulata (Schlecht.) Boiss (Apiaceae) species growing in different Iranian regions serves as a medicinal and aromatic plant. It has been used to treat intestinal worms, headache, spleen diseases, skin wound infections, and snake bites (Sefidkon and Omidbaigi 2004; Shahbazi 2016). The essential oil isolated from *F. angulata* has exhibited several valuable bio-effects, such as antioxidant, antimicrobial, insecticidal, cytotoxic, and AChE inhibitory impacts (Taran et al. 2011; Tavakoli et al. 2017). Many researchers in the literature reported that *Ferulago* species essential oil could be used against different plant pathogenic microorganisms (Moghaddam et al. 2018), on different infectious microbes (Taran et al. 2011), against the main malaria vector, *Anopheles stephensi* (Khanavi et al. 2016; Tavakoli et al. 2017), and as antioxidant agents (Bagci et al. 2016). Moreover, *F. angulata* essential oil has several biological activities such as tonic, food-digestive (Lorigooini et al. 2019), food preventative (Ghasempour et al. 2007), antioxidant in metal toxicity, and absorbent the heavy metals including Cd, Zn, and Ni (Asgari and Rafieian-Kopaei 2015; Jallilian and Ziarati 2016).

Therefore, the current study aimed to investigate the repellency impacts of *F. angulate* essential oil against *T. castaneum* and *R. dominica* using three laboratory techniques filter paper, leaky glass, and olfactometry, hoping it candidates as a novel potential alternative to the synthetic chemicals. The other objective was to assess the side-effect of the essential oil on wheat grain germination for possible application on storage grains.

Materials and methods

Plant material collection and essential oil extraction

The fresh plant materials (leaf and stem) of *F. angulata* species were collected from the mountains of Kouhrang County in Chahar Mahal va Bakhtiari Province, Iran (50°N 32°E). The plant materials were dried at room temperature for 3 days and ground with an electric grinder. Then, 100 g of the materials plus 400 ml of water were tested through the hydro-distillation process by using a Clevenger apparatus for 3 h. The obtained essential oil was weighted to calculate the extraction yield, and dehydrated with anhydrous sodium sulphate (Na_2SO_4). Approximately 3 ml of essential oil was produced from every 100 g of the plant powder. The essential oil was poured into small vials, plugged with cotton, covered by foil, and kept in the refrigerator at 4 °C until used.

Insect collection and rearing

The heterogeneous samples of *T. castaneum* and *R. dominica* were collected from various stored food and grain markets located in the eastern district of Tehran (Pakdasht County) to be then reared in the laboratory. The homogenous population of the red flour beetle (*T. castaneum*) and lesser grain borer (*R. dominica*) were maintained in an incubator at the temperature of 25 ± 2 °C, 60 ± 5% RH, and a photoperiod of 16:8 h (D: L) under controllable conditions. The homogenous adults were obtained from laboratory cultures and maintained at the condition of no exposure to any insecticides. Twenty pairs of each of *T. castaneum* and *R. dominica* adults were selected randomly and placed in jar bottles (Height: 15 cm; Diameter: 5 cm). *T. castaneum* was reared on wheat flour mixed with yeast as 10:1 (w: w) (Khattak et al. 2002; Wang et al. 2006), while *R. dominica* was reared on the whole wheat at 60% moisture (Ukeh and Umoetok 2011). The jars were covered with net cloth and placed on a stand to protect them from pests in the laboratory. After three generations, the sufficient populations of synchronized insects were received, and 2–4 old days adults were selected for bioassays. All the experiments were conducted in the Toxicology Laboratory, Department of Entomology and Plant Pathology, College of Aburaihan, University of Tehran.

Bioassay

The repellent activities of *F. angulata* against the two insects were assessed with the help of the three mentioned methods as follows:

Filter paper bioassay method

By implementing the preliminary tests to determine the concentration range, the main experiments on the adults of *T. castaneum* and *R. dominica* were done at 5 concentrations in 4 replicates. The repellency assays of the essential oil were carried out in 8-cm glass Petri dishes via filter paper (Ajayi and Olonisakin 2011; Tapondjou et al. 2005). The solutions were prepared by dissolving different volumes of the essential oil in acetone at the concentrations of 30, 52, 93, 165, and 300 ppm, while acetone alone was considered as the baseline control. Whitman's filter paper was cut into two halves of 8-cm discs, to each half of which each oil solution was applied as uniform as possible using a micropipette. The other halves of the filter paper were treated with acetone alone. Afterwards, both the treated and untreated halves were attached by using adhesive tape and placed at the bottom of the Petri dishes. Then, 20 adults of *T. castaneum* and *R. dominica* were released at the center of the filter paper discs and the Petri dishes were covered and kept in a dark place. 4 replicates were set for each concentration of the essential oil. The numbers of the insects on both the treated and untreated halves were recorded after 12, 24, 48, and 72 h under soft lighting conditions.

Leaky glass bioassay method

In this technique, leaky plastic glasses with equal pores were utilized to only allow the insects to pass through them and not the grains. Different concentrations (30, 52, 93, 165, and 300 ppm) of *F. angulata* were applied to the wheat. After 10 min of air-drying, the wheat grains were put into the glasses and 20 insects of each *T. castaneum* and *R. dominica* species were placed at top of the plastic glasses. The glasses were covered with a muslin cloth and then put into some other glasses. The wheat control group (concentration of 0) treated with acetone was maintained to record the natural movement. All the experiments were conducted under room conditions. The number of the trapped insects was determined at 4 different intervals (12, 24, 48, and 72 h) after the introduction of the insects. There were 4 replicates per each treatment (Jahromi et al. 2014; Mohan and Fields 2002).

Y-Tube olfactometer bioassay technique

In this experiment, we employed a Y-tube olfactometer with 3 arms of 10-cm length and 1-cm diameter via air vacuum, while its end was blocked with muslin cloth (Jahromi et al. 2014; Paranagaw et al. 2004). First, 100 g of the wheat was mixed with each solution. Then, 20 adults of *T. castaneum* and *R. dominica* were introduced into the olfactometer. Finally, the numbers of the insects that were moved into the essential oil- and acetone-treated wheat were recorded at 6 different intervals (1, 2, 4, 8, 12, and 24 h). For each treatment, 4 replicates were applied.

PR was calculated using each of the 3 methods as follows:

$$PR = (C - T)/(C + T) \times 100$$

Where, C and T are the numbers of the insects on the untreated and treated areas, respectively (Kumar et al. 2004; Mohammed 2013; Tapondjou et al. 2005).

The mean repellency value of each phytochemical was measured and assigned to the repellency classes of 0 to V (Mohammed 2013; Parveen et al. 2013, Udo 2011): Class 0 (PR < 0.1%), Class I (0.1–20%), Class II (20.1–40%), Class III (40.1–60%), Class IV (60.1–80%), and Class V (80.1–100%).

Wheat germination

Germination tests were conducted according to the principle described in the International Seed Testing Association method (ISTA 1999). Fifty wheat grains were used for each treatment. The grains treated with the essential oil concentrations of 30, 52, 93, 165, and 300 ppm at the 4 replicates were poured onto the sterilized filter paper in the Petri dishes of 8-cm diameters. Acetone was utilized as the solvent in the control group. After 3 days, the germination rates of all the treatments were recorded.

Statistical analysis

The PR data were analysed using by the analysis of variance (one-way ANOVA) after being transformed by arcsine$\sqrt{x}$. All the negative PR values were treated as zero (Udo 2005, 2011). The data were subjected to the univariate analysis using SPSS19 software. The experimental data were analysed through a completely randomized design by using the factorial arrangements of the treatments (4 replicates for each treatment). The data analysis was performed based on each dependent variable and the treatments were compared for significance using ANOVA. The comparisons of the means were carried out using Tukey's post-hoc test with the significance level of 0.05 for all the statistical tests. The RC_{50} values were calculated by using Probit analysis.

Results and discussion

The results revealed that the F-values of the essential oil concentrations and the exposure times were significant for *R. dominica* and *T. castaneum* in the filter paper technique (Table 1). However, the interactions between the concentrations and times were not significant for either of the insects. Moreover, the highest repellency of *F. angulata* was observed at the concentration of 300 ppm and time of 72 h in this method.

Table 1 further showed that the F-values of the concentrations and times are significant for *R. dominica* and *T. castaneum* based on the leaky glass technique. Nevertheless, the interactions between the concentrations and times were significant for none of the insects. Also, the highest repellences for *R. dominica* and *T. castaneum* were observed at the concentrations of 300 and 300 ppm and times of 72 and 48 h based on this technique, respectively.

Table 1 reveals that the F-values of the concentrations and times are significant for both insects, while the F-values of the interactions between them are not significant in the olfactometry technique. The highest repellency of *F. angulata* for *R. dominica* in the olfactometry technique was observed at the concentration of 300 ppm and time of 72 h.

Tables 2 and 3 show that the adults of *T. castaneum* are more susceptible to *F. angulata* than those of *R. dominica* because of the higher PR rates for *T. castaneum* at the mentioned concentrations and times under similar conditions. According to Table 2, the PR values of *F. angulata* are 59.01, 54.12, and 43.21% for *T. castaneum* and 48.84, 50.52, and 42.73% for *R. dominica* based on the above-mentioned techniques, respectively. The highest and lowest PR values for the mentioned species occurred at the concentrations of 300 ppm and 30 ppm, respectively (Table 2). In all the 3 methods, the mean repellency was increased by

Table 1 Variance analysis of different treatments of the two experimented insect repellency in three techniques

Technique	Source values	*df*	*T. castaneum*		*R. dominica*	
			F	*P*	F	*P*
Filter paper	Concentration	4	61.48	0.0001**	49.86	0.0001**
	Time	3	50.59	0.0001**	93.02	0.001**
	Concentration × Time	12	1.11	0.371[n.s]	1.56	0.127[n.s]
Leaky glass	Concentration	4	25.05	0.0001**	37.09	0.0001**
	Time	3	36.87	0.0001**	64.70	0.0001**
	Concentration × Time	12	1.21	0.298[n.s]	1.64	0.104[n.s]
Olfactometer	Concentration	4	28.47	0.0001**	36.95	0.0001**
	Time	5	63.61	0.0001**	79.45	0.001**
	Concentration × Time	20	0.88	0.610[n.s]	0.77	0.734[n.s]

[n.s] *P* is not significant; ** *P* is significant at 0.05 levels

enhancing the concentrations; however, the results were not accurate for the times. For instance, in the olfactometry technique, the PR values obtained for the time of 12 h were higher than those achieved for the time of 24 h but had no statistically significant difference (Tables 2 and 3). Excessive increases in the essential oil concentrations and saturation of olfactometer could confuse the insect and diminished its sensitivity.

Estimated repellency concentrations (RC_{50}) of *F. angulata* essential oil on stored product insect pests by three techniques were revealed in Table 4. The coefficient R^2 values indicate a good correlation between essential oil concentrations and tested population response. Based on the results, RC_{50} of *F. angulata* essential oil in the olfactometer technique on both insect pests (*T. castaneum and R. dominica*) was significantly lower than filter paper and leaky glass techniques (Table 4). Moreover, there were no statistically significant diffrences between filter paper and leaky glass techniques on both insect pests.

The repellency classes of I-III for this essential oil against the two insect species were not significant at the concentration of 300 ppm based on either of the 3 techniques as the PR values were between 40.1 and 60% (Table 5).

The output of current research revealed that essential oil yield of leaves and stems *F. angulata* extracted by hydrodistillation method was 1.95%. Akhlaghi (2008) reported that yield of *F. angulata* essential oil isolated from flowers, stems, and leaves were 0.66%, 0.54%, and 0.43%, respectively. In other studies, the yields of essential oil extraction from aerial parts of *F. angulata* were 2.50% (Rustaiyan et al. 2002), and 2.65% (Mollaei et al. 2019). These differences may be due to the differences in the endo- and exogenous factors such as growing conditions, extraction methods, and genetic makeup (Sefidkon et al. 2006; Shahbazi 2016).

Gas Chromatography Mass-Spectrometry (GC-MS) analysis of *F. angulata* essential oil revealed that α-phellandrene (24.2%), β-phellandrene (14.9%), α-pinene (14.7%) and p-cymene (10.3%) were the main compoents (Akhlaghi 2008).

Table 2 Repellency mean (± SE) of *F. angulata* on two adult insects at different concentrations with three methods at 24 h

Insect pest	Technique	Concentration (ppm)				
		30	52	93	165	300
T. castaneum	Filter paper	16.44 ± 2.5[e]	26.67 ± 2.4[d]	38.93 ± 3.1[c]	47.95 ± 3.3[b]	59.01 ± 3.1[a]
	Leaky glass	20.21 ± 3.1[c]	26.16 ± 2.9[bc]	32.63 ± 2.9[b]	45.77 ± 4.1[a]	54.12 ± 5.9[a]
	Olfactometer	20.15 ± 2.3[d]	28.92 ± 2.8[c]	32.63 ± 3.2[bc]	36.47 ± 3.5[b]	43.21 ± 3.4[a]
R. dominica	Filter paper	18.33 ± 2.87[d]	23.91 ± 3.4[d]	32.23 ± 4.3[c]	40.88 ± 3.9[b]	48.84 ± 4.4[a]
	Leaky glass	19.42 ± 2.84[d]	24.99 ± 2.3 [cd]	31.48 ± 4.2[c]	40.02 ± 3.5[b]	50.52 ± 5.2[a]
	Olfactometer	18.24 ± 2.68[d]	26.46 ± 3.4[c]	29.89 ± 3.1[bc]	33.88 ± 3.2[b]	42.73 ± 3.4[a]

The means in the same rows for each insect are statistically significant with different letters (at p < 0.05 by Tukey's test)

Table 3 The results of repellency mean (± SE) of *F. angulata* on two insect adults at different times with three techniques at 300 ppm

Insect pest	Technique	Time (h)							
		1	2	4	8	12	24	48	72
T. castaneum	Filter paper	-	-	-	-	21.00 ± 2.91^{c}	59.01 ± 3.1^{a}	42.56 ± 3.80^{b}	52.85 ± 4.46^{a}
	Leaky glass	-	-	-	-	16.48 ± 2.43^{c}	54.12 ± 5.9^{a}	45.65 ± 3.80^{b}	49.85 ± 4.32^{ab}
	Olfactometer	14.97 ± 2.14^{d}	18.23 ± 2.45^{d}	28.62 ± 1.97^{c}	37.11 ± 2.02^{b}	48.46 ± 2.78^{a}	43.21 ± 3.4^{a}	-	-
R. dominica	Filter paper	-	-	-	-	15.22 ± 1.91^{c}	48.84 ± 4.4^{a}	37.38 ± 2.90^{b}	50.49 ± 3.83^{a}
	Leaky glass	-	-	-	-	16.72 ± 2.22^{c}	50.52 ± 5.2^{a}	38.36 ± 3.09^{b}	50.16 ± 2.18^{a}
	Olfactometer	13.47 ± 1.73^{d}	18.71 ± 1.99 cd	22.36 ± 2.43^{c}	33.36 ± 2.65^{b}	42.92 ± 1.30^{a}	42.73 ± 3.4^{a}	-	-

The means in the same rows for each insect are statistically significant with different letters ($p < 0.05$, Tukey's test)

In the study of Shahbazi et al. (2015), α-pinene (28.43%), (Z)-β-ocimene (20.12%), bornyl acetate (7.92%), γ-terpinene (5.72%), germacrene D (5.63%), myrcene (4.67%), and p-cymene (2.17%) were identified as main components. Limonene, α-pinene, β-phellandrene, α-phellandrene, and terpinolene were also introduced in the *F. angulata* essential oil by Mollaei et al. (2019). Therefore, the monoterpenes were reported as dominant components of *F. angulata* essential oils (Khanahmadi and Janfeshan 2006; Taran et al. 2011; Azarbani et al. 2014). Terpenes can influence treated insect pests through contact or vapour exposer including hyperactivity and tremors (Coats et al. 1991). Likewise, the toxic and repellent properties of monoterpenes against stored product pests such as *Cryptolestes pusillus* Schonher, *R. dominica*, and *Sitophilus oryzae* L. have been investigated in the recent studies; Ngoh et al. (1998), García et al. (2005), Abdelgaleil et al. (2009), and López and Pascual-Villalobos (2010). All these researchers represented that monoterpenes' insecticidal modes of action are inhibition of acetylcholinesterase (AChE). Isman (2000) stated that the action of essential oils on insects could be neurotoxic giving symptoms similar to those produced by organophosphates and carbamates insecticides. Therefore, it can be concluded that *F. angulata* essential oil affected on the adults of *T. castaneum* and *R. dominica* thorough same neurotoxic ways in the present study.

The germination rates of wheat grain after exposure to the essential oil of *F. angulata* are presented in Table 6. As can be seen, the concentrations of 30, 52, 93, 165, and 300 ppm have no significant effects on the germination potentials compared to the untreated seeds of the control group. On the other hand, this essential oil has no negative effects on the seed germination.

The lethal and sub-lethal impacts of the essential oils isolated from some *Ferulago* species have been recently evidenced. For example, the high larvicidal activities of *F. trifida* Boiss. and *F. carduchorum* Boiss. & Hausskn against malaria vector *Anopheles stephensi* were reported by Khanavi et al. (2016) and Tavakoli et al. (2017). In some other studies, the anti-nutritional effects of *F. angulate* against the red flour beetle *T. castaneum* were documented (Atashi et al. 2015). In the present research, the repellent impacts of *F. angulate* against the two major Coleopteran insect pests of *T. castaneum* and *R. dominica* were reported for a first time.

The current results are consistent with those of the studies conducted by Zapata and Smagghe (2010) and Wang et al. (2006), who reported the augmented PR values of the essential oils of several plants against *T. castaneum* by elevating their applied concentrations and times. Also, Liu and Ho (1999) reported the bioactivities of the essential oil extracted from *Evodia rutaecarpa* on *T. castaneum*. Bakkali et al. (2008) assessed the effects of several essential oils on *R. dominica* and *T. castaneum*. Similar to our findings, the results reported

Table 4 Estimated repellency concentration of *F. angulata* essential oil on two stored product insect pests by three different techniques at 24 h

Insect	Technique	df	$RC_{50\ (ppm)}$; 95% CL	Slop ± SE	χ^2	R^2
T. castaneum	Filter paper	4	309.34 (172.04–1242.15)	1.37 ± 0.61	2.64	0.75
	Leaky glass	4	303.69 (160.08–1165.10)	0.98 ± 0.07	3.41	0.81
	Olfactometer	4	163.34 (104.42–406.36)	0.76 ± 0.06	3.30	0.85
R. dominica	Filter paper	4	298.20 (194.59–751.27)	1.09 ± 0.07	2.08	0.65
	Leaky glass	4	480.43 (261.50–1371.91)	0.88 ± 0.09	1.43	0.68
	Olfactometer	4	92.95 (88.65–431.37)	0.41 ± 0.05	2.67	0.87

RC: Repellency Concentrations, CL: Confidence Limit

Table 5 The repellency classes of *F. angulata* on two adult insects at different concentrations with three techniques at 24 h

Insect pest	Technique	Concentration (ppm)				
		30	52	93	165	300
T. castaneum	Filter paper		п	П	ш	ш
	Leaky glass	п	п	П	ш	ш
	Olfactometer	п	п	П	п	ш
R. dominica	Filter paper		п	П	ш	ш
	Leaky glass		п	П	п	ш
	Olfactometer	п	п	П	п	ш

by Parveen et al. (2013), Tapondjou et al. (2005), Wang et al. (2006), and Zapata and Smagghe (2010) were indicative of high PR rates induced by high essential oil concentrations. The PR values obtained for *T. castaneum* at the concentration of 300 ppm via all the three technique employed in this study were mostly compatible with the reports of Ajayi and Olonisakin (2011), Jbilou et al. (2006), Liu and Ho (1999), and Sagheer et al. (2011). In addition, Ogendo et al. (2008) reported the repellency and fumigant impacts of the essential oil of *Ocimum gratissimum* on *T. castaneum* and *R. dominica* and found the former species more tolerant than the latter one.

Our results revealed an increase in the repellency effects of *F. angulata* with the passage of time as compared to the reports of Liu and Ho (1999) showing a decrease in the repellency power of the essential oil of *E. rutaecarpa* after 5 h. Zapata and Smagghe (2010) demonstrated the PR rate of up to 90% obtained for the effect of *Laurelia sempervirens* on *T. castaneum* within 4 h.

According to the results of the current investigation, the adults of *T. castaneum* were repelled by the essential oil of *F. angulata* even at low concentrations. The main reason for this great repellency seemed to be its higher movement ability than the other stored product pests (Liu and Ho 1999; Tripathi et al. 2000). Therefore, the adults of these insects were susceptible to the essential oil of *F. angulata*.

Table 6 The mean of wheat grain germination treated with different concentration after three days

Time (h)	Concentration (ppm)					
	0	30	52	93	165	300
24	25.00^{a}	25.75^{a}	25.00^{a}	24.00^{a}	21.25^{a}	20.75^{a}
48	37.25^{a}	37.75^{a}	37.75^{a}	37.25^{a}	36.75^{a}	35.25^{a}
72	99.00^{a}	99.5^{a}	99.2^{a}	99.1^{a}	99.00^{a}	99.00^{a}

The means in the same rows for each concentration are statistically significant with different letters ($p < 0.05$, Tukey's test)

These findings indicated the effectively and suitably repellent activity of the essential oil of *F. angulata* in the control of stored wheat insect pests without any negative effects on its seed vigour. Hence, *F. angulata* can be integrated into any other effective control options for the management of *R. dominica* and *T. castaneum* since having no environmentally destructive effects, unfavourable impacts on seed germination, and undesirable influences on humans besides being capable of reducing insect pest resistance and resurgence and environmental pollution.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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