Bitki Koruma Bülteni / Plant Protection Bulletin

http://dergipark.gov.tr/bitkorb

Original article

Fumigant and contact toxicity of *Ruta chalepensis* l. (Rutaceae) essential oil against five coleopteran stored product pests and its effects on cholinesterases

Ruta chalepensis L. (Rutaceae) uçucu yağının beş coleopteran depo ürün zararlısına karşı fumigant ve kontak toksisitesi ile kolinesterazlar üzerine etkileri

Yasemin Yücel YÜCEL[a,b*], Ömer Cem KARAKOÇ[c], Hüseyin SERVI[d], Salih GÜCEL[e], Ayşe NALBANTSOY[f], Kaan POLATOĞLU[b,g]

[a,b]https://orcid.org/0000-0002-6595-6850, [c]https://orcid.org/0000-0002-1997-5639, [d]https://orcid.org/0000-0002-4683-855X, [e]https://orcid.org/0000-0001-5331-8379, [f]https://orcid.org/0000-0002-3852-1974, [b,g]https://orcid.org/0000-0001-5493-2995

[a]*Altınbaş University, Faculty of Pharmacy, Department of Biochemistry, 34147, Istanbul, Türkiye*

[b]*Altınbaş University, Natural Products Research and Development Center (DUAGEM), 34147, Istanbul, Türkiye*

[c]*Çankırı Karatekin University, Yapraklı Vocational School, Department of Crop and Animal Protection, 18100, Çankırı, Türkiye*

[d]*Istanbul Yeniyuzyıl University, Faculty of Pharmacy, Department of Pharmacognosy and Phytotherapy, 34010, Istanbul, Türkiye*

[e]*Near East University, Institute of Environmental Sciences, 10, Mersin, Nicosia, Türkiye*

[f]*Ege University, Faculty of Engineering, Department of Bioengineering, 35100, Bornova İzmir, Türkiye*

[g]*Altınbaş University, Faculty of Pharmacy, Department of Analytical Chemistry, 34147, Istanbul, Türkiye*

ARTICLE INFO

Article history:

DOI:10.16955/bitkorb.1374633

Received : 11-10-2023

Accepted : 04-12-2023

Keywords:

Ruta chalepensis, essential oil composition, stored product pests, acetylcholinesterase, butyrylcholinesterase, enzyme inhibition

* Corresponding author: Yasemin Yücel YÜCEL

yasemin.yucel@altinbas.edu.tr

ABSTRACT

The essential oil composition of aerial parts of *Ruta chalepensis* L. was analyzed with GC-MS. Seventy-nine compounds were detected representing 85.93 ± 1.08% (n = 3) of the essential oil. The major components of the essential oil were 2-undecanone 21.52 ± 0.21%, 2-nonanone 18.31 ± 0.27%, and 2-nonyl acetate 13.22%. The highest insecticidal contact toxicity of the oil was observed against *Rhyzopertha dominica* F. with 0.018 µl/insect LD50 and 0.039 µl/insect LD90 after 24h. Essential oil also produced considerably low 0.50 and 0.59 µl/insect LD50 values after 24h against *Sitophilus oryzae* L. and *Sitophilus granarius* L. respectively. The lowest contact toxicity was observed against Tribolium castaneum Herbst. and *Tribolium confusum* Jacquelin du Val. 0.138 and 0.078 µl/insect LD50 after 24h respectively. The highest fumigant toxicity was observed against *S. granarius* for the application concentration of 10 µl, 10% oil/acetone (v:v) in a 10 ml chamber which afforded 100.00 ± 0.00% mortality after 48h. The essential oil also produced high fumigant toxicity against *S. oryzae*, *T. castaneum* and *R. dominica* which were 95.47 ± 3.41%, 93.30 ± 5.54%, and 85.47 ± 3.41% mortality at 20 µl application concentration of the oil solution after 48h. The *R. chalepensis* essential oil produced low acetylcholinesterase enzyme 5.29 ± 1.20% (n=3) inhibition and mediocre butyrylcholinesterase enzyme inhibition 42.6 ± 0.71% (n=3). According to the insecticidal activity assays performed, the essential oil *R. chalepensis* seems to be a promising source that could yield natural compounds that could be employed in stored product pest management.

INTRODUCTION

The appropriate storage of agricultural products is very important to reduce product losses. Product loss during storage is caused by many factors, including pests such as insects, rodents, and microorganisms as well as the conditions during storage such as humidity, temperature, etc. (Bouajaj et al. 2014, Chebli et al. 2004, Eisen 2013, Shah et al. 2015, Shaaya et al. 1997, Yazdgerdian et al. 2015). The most significant damage among the factors listed that affect the product is caused by stored product insects. The primary (*S. granarius, S. oryzae, R. dominica*, etc.) and secondary (*T. confusum, T. castaneum, O. surinamensis,* etc.) stored product insect species cause serious damage to the product during the storage (Atay et al. 2023, Polatoğlu and Karakoç 2016, Prakash and Rao 1996, Rajendran and Sriranjini 2008). Unless they are controlled, they can produce serious losses in the product (Çam et al. 2012, Hernandez-Lambraño et al. 2015, Kamanula et al. 2010). Product losses can be between 40% and 100%, particularly if modern storage techniques are not used (Campbell and Sinha 1976, Shaaya et al. 1997, Yıldırım et al. 2001). Currently, synthetic chemical compounds with contact and fumigant activity—often consisting of organic phosphorus—are frequently utilized in large-scale pest control of stored products against insects (Alkan et al. 2023, Çam et al. 2012, Evlice and Alkan 2023, Martin et al. 2015, Udo 2005). Natural pest control methods are becoming more popular as a result of increased environmental and health concerns, as well as new laws implemented to address these issues, such as the European Pesticide Regulation (EC) No. 1107/2009 (Alkan and Atay 2023, Atay and Alkan 2023, Isman 2006, 2008, Villaverde et al. 2014).

Ruta species of Rutaceae is only represented by *Ruta chalepensis* L. in Cyprus (Viney 1994). *Ruta* species are plants native to the Mediterranean and they found many uses in traditional medicine (Pollio et al 2008). These medicinal uses include uses for dropsy, inflamed eyes, colics, spasms, diarrhoea, insect/scorpion/spider bites, snake bites, poisoning, headache, migraine, epilepsy, hysteria, internal parasites, catarrh, common cold, cough, toothache (Lardos 2006). Until now from the *Ruta* species, many different types of secondary metabolites including alkaloids, coumarins, flavonoids, triterpenes, sterols, saponins, and tannins were isolated (Chen et al. 2001, Hnatyszyn et al. 1974). The furocoumarins (psoralens) are specifically observed in the species of Rutaceae, Umbelliferae, Moraceae, Fabaceae, and Apiaceae. Psoralens cause phytophotodermatitis in humans (Pathak et al. 1962). *Ruta* species is also known for its quinolone alkaloids. The essential oils of the *Ruta* species were also investigated comprehensively. However, most of the reports only indicate a few identified substances in the composition of the essential oil except for a couple of comprehensive reports that identify many substances in the composition of the oil (Ulubelen et al. 1986).

The *Ruta* essential oils are characterized with alcohols (2-nonanol), esters (nonyl acetate, 2-methyloctyl acetate), ketones (2-undecanone, 2-dodecanone, 2-decanone, 2-nonanone) of saturated fatty acids (Abbad et al. 2014, Akkari et al. 2015, Rustaiyan et al. 2002, Tounsi et al. 2011, Tzakou and Couladis 2001). Usually, the essential oils of *Ruta* species contain geijerene (2-Isopropenyl-1-methyl-1-vinyl-3-cyclohexane) and moskachan (psoralen) derivatives in minor quantities (Joulain et al. 1991, Stashenko et al. 1995, Stashenko et al. 2000, Yaacob et al. 1989). The *Ruta* essential oils are reported to have herbicidal, molluscicidal, nematicidal, antimicrobial, antibacterial, antifungal, anti-inflammatory, antipyretic, emmenagogue and antihelmintic effects (Bouabidi et al. 2015, Günaydin and Savcı 2005, Haddouchi et al. 2013, Hmamouchi et al. 2000, Iauk et al. 2004, Ntalli et al. 2011,). Additionally, the essential oils of *Ruta* species are known for their considerable insecticidal activity against a broad spectrum of insect species. *R. chalepensis* has already been reported to have larvicidal, repellent and biting deterrent activity against vectors of many diseases namely *Aedes albopictus Skuse*, *Aedes aegypti* (L.), *Culex pipiens pallens Coquillett, Anopheles quadrimaculatus* Say (Diptera: Culicidae) (Ali et al. 2013, Conti et al. 2013, Kim et al. 2002, Perez Lopéz et al. 2015). Furthermore, the essential oils of *Ruta* species were tested against agricultural product insects namely *Orgyia trigotephras* Boisd. (Lepidoptera), *Tribolium confusum* Jacquelin du Val, *T. castaneum* (Herbst) (Coleoptera) and found active against these pests (Abbad et al. 2014, Akkari et al. 2015, Majdoub et al. 2014). The extracts of *Ruta* species were reported to have aphicidal, insecticidal, and nematicidal activity against *Alphitobius diaperinus* Panzer, *Trogoderma granarium* Everts (Coleoptera), *Aphis punicae* Passerini, *Bemisia tabaci* Gennadius (Hemiptera), *Hypsipyla grandella* Zeller (Lepidoptera), *Locusta migratoria* L. (Orthoptera), *Meloidogyne arenaria* Chitwood, *M. hapla* Chitwood, *M. javanica* (Treub) Chitwood, *M. incognita* (Kofoid and White) Chitwood (Tylenchida), *Pediculus humanus* L. (Phthiraptera), *Psammotermes hybostoma* Desneux (Blattodea), *Xiphinema index* Thorne and Allen (Dorylaimida) species (Abdellaoui et al. 2014, Al-mazr'awi and Ateyyat 2009, Alshehry et al. 2014, Jorge et al. 2009, Madkour et al. 2012, Mancebo et al. 2001, Marcomini et al. 2009, Moawad and Al-Barty 2011, Sasanelli 1992, Sasanelli and D'Addabba 1993, Soto Monterrosa et al. 2007). Natural substances isolated from *Ruta* species namely quinoline, quinoline-4-carbaldehyde, quinoline-3-carbaldehyde, and quinolone carboxylic acid derivatives were reported to have fumigant and contact toxicity against *S. oryzae* (Jeon et al. 2013). The 3-(2″,2″-dimethylbutenyl)-

3′-hydroxyl-dihydrofuropsoralen and rutamine isolated from *R. chalepensis* were reported to have larvicidal activity against *Spodoptera littoralis* (Emam et al. 2009). The active essential oil component of *R. graveolens* 2-isopropyl-5-methylphenol and its derivatives namely 5-isopropyl-2-methylphenol, 4-isopropyl-3-methylphenol, 2-methylphenol, 3-methylphenol, 4-methylphenol, 2-isopropylphenol, 3-isopropylphenol and 4-isopropylphenol were tested against *S. oryzae, S. zeamais* and *Lasioderma serricorne* (Fabricius) with fumigant toxicity assay; highest activity was observed for 3-isopropylephenol (Jeon et al. 2015). *R. chalepensis* essential oils were also reported to have antifungal activity against the fungal species that produce damage to agricultural products such as species from *Alternaria, Aspergillus, Botrytis, Fusarium* and *Phytophthora* genus (Bouabidi et al. 2015, Bouajaj et al. 2014, Chebli et al. 2004, Haddouchi et al. 2013). Additionally, *R. chalepensis* essential oil was reported to have seed germination inhibition against *Triticum durum* Desf. and *Phalaris canariensis* L. (Bouajaj et al. 2014, Mejri et al. 2012).

Inhibition of the cholinergic system enzymes is reported to be one of the possible insecticidal action mechanisms of essential oils (Rattan 2010). Essential oil components with inhibitory properties against AChE were reported in the literature (López and Pascual-Villalobos 2010, Miyazawa et al. 1997, Miyazawa and Yamafuji 2005). Previously, AChE inhibitory properties of methanol and water extracts of *Ruta graveolens* L. were reported (Adsersen et al. 2006). Another report shows that hexane extract of the same species inhibits AChE and BChE enzymes better than its methanol extract (Wszelaki et al. 2010). This report also indicates that non-polar substances which include components of the essential oil present in the plant could be responsible for the previously reported insecticidal activity.

A considerable number of reports regarding the insecticidal activity of the *Ruta* species as well as a lack of any reports on the chemical composition of *Ruta chalepensis* from Cyprus presented a high potential for discovering new insecticidal lead compounds from this genus which prompted us to do present research. Herein, it is aimed to determine insecticidal, AChE, and BChE inhibitory activity and essential oil composition of *R. chalepensis* as a part of our phytochemical and insecticidal activity screening study of Cypriot plants.

MATERIALS AND METHODS

Plant materials

Plant samples were collected on 25 May 2015 from St. Hilarion - Kyrenia. The voucher specimen has been placed at the Herbarium of the Near East University of Cyprus' Institute of Environmental Sciences (Voucher number. 6890). Dr. Salih Gücel from the Institute of Environmental Sciences, Near East University, Nicosia, identified the plant materials.

Isolation of the essential oils

Using a Clevenger-style device, aerial parts (100 g) of the air-dried plant were hydro distilled for 3 hours to obtain essential oils with yields of 1.27% (v/w). After being dried over anhydrous Na2SO4, oil was kept in an amber vial at -20 °C until the day it was tested.

Gas chromatography-mass spectrometry analysis

With Agilent 7890B GC and 5977B EI MSD equipment, the GC-MS analysis was carried out. Samples of essential oils were diluted by 1/10 (v/v) in n-hexane. Temperatures were set at 250 ˚C for the MS transfer line and injector. The 50:1 split ratio was chosen. Both GC/MS studies employed an Innowax FSC column (60 m x 0.25 mm, 0.25 m film thickness) and helium as the carrier gas (1 ml/min). The temperature of the oven was set at 60 °C for 10 minutes before being increased to 220 °C at a rate of 4 °C/min. After being held at 220 °C for 10 minutes, the temperature was increased to 240 °C at a rate of 1 °C/min. At 70 eV, mass spectra covering the m/z range of 35 to 425 were captured. The integration of the peaks in MS chromatograms was used to determine the relative percentage quantities of the separated substances. The components of essential oils were identified. The commercial Wiley 8th Ed./NIST 05 Mass Spectra Library, the Adams Essential Oil Mass Spectral Library, and the Pallisade 600K Complete Mass Spectral Library were used for computer matching throughout the mass spectra comparison process. The findings of the analysis were presented as the mean standard deviation after being performed in triplicate. Figure 1 shows the GC-MS chromatogram for the study of *Ruta chalepensis* aerial parts oil.

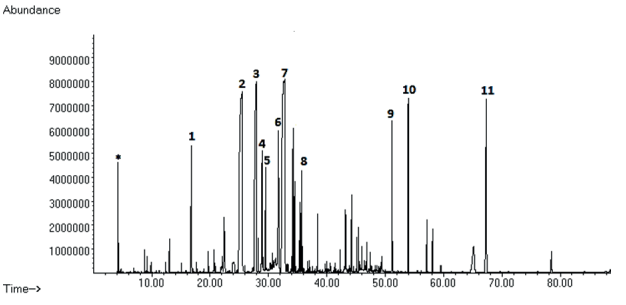

Figure 1. GC/MS Chromatogram of *Ruta chalepensis* aerial parts oil. Compounds: *. Solvent peak (n-hexane); 1. Limonene; 2. 2-Nonanone; 3. 2-Nonyl acetate; 4. 2-Decanone; 5. 2-Nonanol; 6. Pregeijerene; 7. 2-Undecanone; 8. 2-Dodecanone; 9. Moskachan A; 10. Moskachan B; 11. Moskachan D

Stored product insect cultures

Sitophilus oryzae, Sitophilus granarius, Rhyzopertha dominica, Tribolium confusum and *Tribolium castaneum* were collected from the infested stored products in Türkiye. Insect cultures were prepared at Çankırı Karatekin University, Yapraklı Vocational School, in the laboratory of the Animal and Plant Production Department according to the previous methods (Karakoç et al. 2006, Pimentel et al. 2008).

Insecticidal activity assays

Insecticidal contact toxicity assay

To create a 10% (v/v) stock solution, *Ruta chalepensis* essential oil was diluted with acetone. The dorsal side of the thorax of the insects was exposed to a stock solution of oil sample (1 µl) using a 50 µl Hamilton syringe (Gokce et al. 2010). The same volume of acetone was used in the empty controls. Following the sample or blank application, the insects were transferred to 60 mm glass petri plates containing 5 g of either whole wheat (for *S. granarius* and *S. oryzae*) or broken wheat (for *T. castaneum, T. confusum* and *R. dominica*) (n = 10 for each bug species and treatments). For 72h the insects were raised at 50 ± 10% relative humidity and 27 ± 2 °C. At 24, 48, and 72 hours, the samples and controls were observed, and the number of dead insects was noted. Each sample and blank treatment were made at least three times.

Insecticidal fumigant toxicity assay

The fumigant toxicity of *Ruta chalepensis* essential oil against the mentioned insects was determined according to a previous protocol (Çam et al. 2012). At the 48th hour, samples and controls were checked, and the number of dead insects was noted. Each sample and blank treatment were made at least three times.

Acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) inhibitory activity

The previously mentioned technique was used to assess the *Ruta chalepensis* essential oil's inhibitory effect on AChE and BChE (Ellman et al. 1961). AChE (Electric Eel) or BChE was added to the reaction mixture at a concentration of 0.0325 U/ml to initiate reactions. The average and standard deviation of three parallel tests were used to display the experiment's results.

Statistical analysis

In order to calculate the arcsin values, the activity findings from the insecticidal activity assays were converted into % death values (Zar 1996). ANOVA was performed on the arcsin values before Tukey's multiple comparison tests with a $P<0.05$ significance threshold. The software package Minitab Release 14 (McKenzie and Goldman 2005) was used for all of the statistical analyses.

RESULTS

The essential oil composition of aerial parts of *Ruta chalepensis* was given in Table 1. Seventy-nine compounds were detected representing 85.93 ± 1.08 % (n = 3) of *R. chalepensis* aerial parts oil. The essential oil was dominated by the derivatives of n-alkanes. The major components of the essential oil were 2-undecanone 21.52 ± 0.21%, 2-nonanone 18.31 ± 0.27%, and 2-nonyl acetate 13.22%.

However, there were differences in the relative percent amount of the major components of the essential oil as well as the composition of the secondary components of the oil. The essential oil investigated in the present study afforded moskachan derivatives as the components that have a relative percentage in the range of 2-5% very similar to a previous study (Joulain et al. 1991) unlike the other studies.

The insecticidal contact toxicity of the *Ruta chalepensis* oil against *S. granarius, S. oryzae, T. castaneum, T. confusum* and *R. dominica* was given in Table 2. *R. chalepensis* essential oil was active against all the insects with different LD50 and LD90 values. The highest activity of the oil was observed against *R. dominica* with 0.018 µl/insect LD50 and 0.039 µl/insect LD90 after 24h. The highest activity was observed after 24h of application against all insect species except for *R. dominica*. The oil showed the highest activity after 24h against *R. dominica* and there was no change after 48h and 72h of applications. *S. oryzae* and *S. granarius* were also affected considerably with 0.50 and 0.59 µl/insect LD50 after 24h respectively. However, this activity increased with longer exposure times and produced lower LD50 values. The lowest contact toxicity was observed against *T. castaneum* and *T. confusum* at 0.138 and 0.078 µl/insect LD50 after 24h respectively. The contact toxicity of the essential oil slightly increased at longer exposure periods for *T. confusum* and *T. castaneum*.

The fumigant toxicity of the *Ruta chalepensis* oil against *S. granarius, S. oryzae, T. castaneum, T. confusum* and *R. dominica* was given in Table 3. The highest fumigant toxicity was observed against *S. granarius* for the application concentration of 10 µl, 10% oil/acetone (v:v) in a 10 ml chamber which afforded 100.00 ± 0.00% mortality. The toxicity of the oil produced by the oil was decreased to 98.86 ± 3.41% mortality at 5 µl and to 0.00 ± 0.00% mortality at 2.5 µl application of the oil solution for *S. granarius*. The essential oil also produced high fumigant toxicity against *S. oryzae, T. castaneum* and *R. dominica* which were 95.47 ± 3.41%, 93.30 ± 5.54% and 85.47 ± 3.41% mortality at 20 µl

Table 1. The essential oil composition of aerial parts of *Ruta chalepensis*

No	RRI[1]	RRI Lit.[2]	Compound	I[3]	II	III	Ave[4]	SD[5]	IM[6]	Literature
1	1023	1032	α-Pinene	0.24	0.21	0.22	0.22	0.02	RI[7], MS[8]	Başer et al. 2000a)
2	1027	1176	α-Thujene	0.02	0.02	0.02	0.02	0.00	RI, MS	(Tabanca et al. 2011)
3	1033	1035	2-Methyl-3-buten-2-ol	0.18	0.17	0.17	0.17	0.01	RI, MS	(Başer et al. 2000b)
4	1038	1042	Isopropyl butyrate	0.01	0.01	0.01	0.01	0.00	RI, MS	(Narain et al. 2007)
5	1051	1061	Isopropyl-2-methyl butyrate	0.13	0.12	0.13	0.13	0.01	RI, MS	(Başer et al. 2002a)
6	1069	1079	Ethyl isovalerate	0.01	0.01	0.01	0.01	0.00	RI, MS	(Kamatou et al. 2008)
7	1075	1083	Butanoic acid, 3-methyl-1methylethyl ester	0.02	0.02	0.02	0.02	0.00	RI, MS	(Kaya et al. 2003)
8	1087	1093	Hexanal	0.03	0.03	0.03	0.03	0.00	RI, MS	(Başer et al. 2000a)
9	1112	1118	β-Pinene	0.13	0.12	0.12	0.12	0.01	RI, MS	(Başer et al. 2000a)
10	1126	1132	Sabinene	0.4	0.38	0.38	0.39	0.01	RI, MS	(Başer et al. 2000a)
11	1168	1174	Myrcene	0.11	0.11	0.11	0.11	0.00	RI, MS	(Başer et al. 2001)
12	1184	1188	α-Terpinene	0.03	0.03	0.03	0.03	0.00	RI, MS	(Başer et al. 2000a)
13	1186	1192	2-Heptanone	0.03	0.03	0.03	0.03	0.00	RI, MS	(Başer et al. 2004)
14	1205	1203	Limonene	2.49	2.34	2.4	2.41	0.08	RI, MS	(Başer et al. 2000a)
15	1210	1213	1,8-Cineole	0.05	0.05	0.05	0.05	0.00	RI, MS	(Başer et al. 2001)
16	1215	1213	4-Methoxy-2-methyl-2-mercaptobutane	0.01	0.01	0.01	0.01	0.00	RI, MS	(Kumazawa and Masuda 1999).
17	1224	1232	(E)-2-Hexanal	0.11	0.1	0.1	0.10	0.01	RI, MS	(Kırımer et al. 2000)
18	1238	1244	2-Pentylfuran	0.03	0.03	0.03	0.03	0.00	RI, MS	(Başer et al. 2000a)
19	1251	1255	γ-Terpinene	0.06	0.06	0.06	0.06	0.00	RI, MS	(Başer et al. 2000a)
20	1258	1265	(E)-β-Ocimene	0.01	0.01	0.01	0.01	0.00	RI, MS	(Başer et al. 2002b)
21	1277	1278	m-Cymene	0.06	0.01	0.01	0.03	0.03	RI, MS	(Kılıç et al. 2010)
22	1290	1295	2-Octanone	0.3	0.29	0.29	0.29	0.01	RI, MS	(Başer et al. 2006)
23	1294	1296	Octanal	0.14	0.14	0.14	0.14	0.00	RI, MS	(Başer et al. 2001)
24	1318		Geijerene derivative I	0.08	0.08	0.08	0.08	0.00	MS	
25	1332	1338	Geijerene	1.64	1.53	1.72	1.63	0.10	RI, MS	(Tabanca et al. 2007)
26	1344	1348	6-Methyl-5-hepten-2-one	0.01	0.01	0.01	0.01	0.00	RI, MS	(Başer et al. 2000a)
27	1387	1391	(Z)-3-Hexen-1-ol	0.04	0.04	0.03	0.04	0.01	RI, MS	(Kırımer et al. 2000)

28	1410	1398	2-Nonanone	18.58	18.04	18.32	18.31	0.27	RI, MS	(Başer et al. 2006)
29	1423	1426	2-Octanol	0.08	0.08	0.08	0.08	0.00	RI, MS	(Van Vuuren et al. 2006)
30	1479	1470	2-Nonyl acetate	13.41	13.04	13.21	13.22	0.19	RI, MS	(Van Vuuren et al. 2007)
31	1486	1483	Acetic acid octyl ester	0.31	0.31	0.31	0.31	0.00	RI, MS	(Başer et al. 2000c)
32	1501	1493	Isogeijerene c	0.03	0.03	0.03	0.03	0.00	RI, MS	(Tabanca et al. 2007)
33	1505	1491	2-Decanone	2.3	2.21	2.23	2.25	0.05	RI, MS	(Bendimerad et al. 2005)
34	1509	1506	Decanal	0.23	0.24	0.23	0.23	0.01	RI, MS	(Başer et al. 2001)
35	1516	1516	Geyrene	0.06	0.06	0.06	0.06	0.00	RI, MS	(Das 2015)
36	1524	1521	2-Nonanol	1.98	1.93	1.93	1.95	0.03	RI, MS	(Kıvçak et al. 2004)
37	1528		Geijerene derivative II	0.14	0.14	0.14	0.14	0.00	MS	
38	1535		Geijerene derivative III	0.04	0.04	0.04	0.04	0.00	MS	
39	1556		Geijerene derivative IV	0.13	0.14	0.13	0.13	0.01	MS	
40	1577	1572	Pregeijerene B	0.92	0.9	0.88	0.90	0.02	RI, MS	
41	1591	1594	Pregeijerene	3.68	3.61	3.5	3.60	0.09	RI, MS	(Tabanca et al. 2005)
42	1628	1604	2-Undecanone	21.73	21.32	21.51	21.52	0.21	RI, MS	(Kırımer et al. 2000)
43	1635	1651	6-Methyl-1-octanol	0.07	0.07	0.07	0.07	0.00	RI, MS	(Wen et al. 2014)
44	1665	1664	1-Nonanol	0.23	0.23	0.23	0.23	0.00	RI, MS	(Başer et al. 2001)
45	1682	1674	2-Dodecanone	1.19	1.15	1.15	1.16	0.02	RI, MS	(Kawakami and Kobayashi 1991)
46	1688	1687	Decyl acetate	0.07	0.07	0.07	0.07	0.00	RI, MS	(Tabanca et al. 2006)
47	1694	1694	p-Vinylanisole	0.01	0.01	0.01	0.01	0.00	RI, MS	Başer et al. 2002b)
48	1698	1676	1,8-Menthadien-4-ol	0.03	0.03	0.02	0.03	0.01	RI, MS	(Kollmanns-berger et al. 1992)
49	1707	1706	α-Terpineol	0.3	0.29	0.29	0.29	0.01	RI, MS	(Başer et al. 2001)
50	1715	1766	1-Decanol	0.73	0.71	0.71	0.72	0.01	RI, MS	(Kırımer et al. 2000)
51	1719	1719	1-Heptadecene	0.02	0.01	0.01	0.01	0.01	RI, MS	(Kamariah et al. 1999)
52	1724	1722	2-Undecanol	1.36	1.35	1.35	1.35	0.01	RI, MS	(Kırımer et al. 2000)
53	1735	1728	(Z,E)-α-Farnesene	0.05	0.05	0.05	0.05	0.00	RI, MS	(Özek et al. 2010)
54	1758	1758	(E,E)-α-Farnesene (= α-farnesene)	0.12	0.12	0.12	0.12	0.00	RI, MS	(Demirci et al. 2006)
55	1766	1766	1-Decanol	0.04	0.04	0.04	0.04	0.00	RI, MS	(Kırımer et al. 2000)
56	1770		2-Methyl-undecanal	0.11	0.11	0.11	0.11	0.00	MS	

57	1797	1800	Methyl salicylate	0.02	0.02	0.02	0.02	0.00	RI, MS	(Kırımer et al. 2000)
58	1819	1815	2-Tridecanone	0.62	0.67	0.6	0.63	0.04	RI, MS	(Demirci et al. 2006)
59	1837	1835	β-Damascenone	0.01	0.01	0.01	0.01	0.00	RI, MS	(Başer et al. 2000a)
60	1845	1845	trans-Carveol	0.01	0.01	0.01	0.01	0.00	RI, MS	(Başer et al. 2000a)
61	1901	1904	Ethyl dihydrocinnamate	0.1	0.1	0.1	0.10	0.00	RI, MS	(Polatoğlu et al. 2010)
62	1955	1958	(E)-β-Ionone	0.04	0.04	0.04	0.04	0.00	RI, MS	(Demirci et al. 2006)
63	2026	2029	Methyl eugenol	0.04	0.05	0.04	0.04	0.01	RI, MS	(Başer et al. 2001)
64	2093	2099	Hedycaryol	0.4	0.4	0.39	0.40	0.01	RI, MS	(Joichi et al. 2005)
65	2101	2181	Anthranilic acid	0.17	0.17	0.15	0.16	0.01	RI, MS	(Pino et al. 2009)
66	2134	2131	Hexahydrofarnesyl acetone	0.06	0.05	0.07	0.06	0.01	RI, MS	(Başer et al. 2000a)
67	2186	2185	γ-Eudesmol	0.07	0.07	0.06	0.07	0.01	RI, MS	(Başer et al. 2001)
68	2197	2192	τ-Cadinol	0.02	0.02	0.02	0.02	0.00	RI, MS	(Tümen et al.1998)
69	2241	2250	α-Eudesmol	0.06	0.06	0.06	0.06	0.00	RI, MS	(Başer et al. 2001)
70	2251	2257	β-Eudesmol	0.09	0.09	0.08	0.09	0.01	RI, MS	(Demirci et al. 2006)
71	2342		Moskachan A	1.95	1.93	1.91	1.93	0.02	MS	
72	2383	2181	1-Nonadecanol	0.03	0.03	0.03	0.03	0.00	RI, MS	
73	2400	2400	Tetracosane	0.02	0.02	0.02	0.02	0.00	RI, MS, Ac[9]	
74	2449		Moskachan B	2.77	2.75	2.72	2.75	0.03	MS	
75	2504	2500	Pentacosane	0.04	0.04	0.04	0.04	0.00	RI, MS, Ac	
76	2551		4-(3,4-Methylenedioxy-phenyl)-2-butanone	0.77	0.77	0.77	0.77	0.00	MS	
77	2617	2622	Phytol	0.11	0.11	0.11	0.11	0.00	RI, MS	(Kırımer et al. 2000)
78	2700	2700	Heptacosane	0.03	0.02	0.01	0.02	0.01	RI, MS, Ac	
79	2793		Moskachan D	5.38	5.33	5.3	5.34	0.04	MS	
			Monoterpenes	10.27	9.82	9.94	10.01	0.23		
			Oxygenated Monoterpenes	0.44	0.43	0.42	0.43	0.01		
			Sesquiterpenes	0.17	0.17	0.17	0.17	0.00		
			Oxygenated Sesquiterpenes	10.80	10.70	10.61	10.70	0.10		
			Diterpenes	0.11	0.11	0.11	0.11	0.00		
			Others	65.34	63.82	64.36	64.51	0.77		
			Total	87.13	85.05	85.61	85.93	1.08		

[1]Relative retention index; [2]Relative retention index of the compound given in the literature that uses similar methodology; [3]The GC-MS analyses were performed in triplicate and results were given as relative percent amounts calculated from the chromatograms; [4]Average relative percent amounts obtained from the analyses; [5]Standard deviation of the relative percent amounts; [6]Identification method used for the compound; [7]RI: Relative retention index match of the compound with the literature that uses same/similar chromatographic conditions; [8]MS: Mass spectra match of the compound; [9]Ac: Relative retention index and mass spectra similarity of the compound with the authentic compound (co-injection).

Table 2. The contact toxicity of the *Ruta chalepensis* oil given for 24, 48, and 72h periods as LD50 and LD90

Insect Species	24 h				48 h				72 h			
	LD_{50} (µL/insect) (Fiducial limits)	LD90 (µL/insect) (Fiducial limits)	Slope±SE	X^2	LD_{50} (µL/insect) (Fiducial limits)	LD90 (µL/insect) (Fiducial limits)	Slope±SE	X^2	LD_{50} (µL/insect) (Fiducial limits)	LD90 (µL/insect) (Fiducial limits)	Slope±SE	X^2
S. granarius	0.059 (0.052-0.067)	0.107 (0.089-0.141)	5.02±0.77	7.98	0.052 (0.045-0.059)	0.096 (0.081-0.125)	4.76±0.66	11.37	0.052 (0.045-0.059)	0.096 (0.081-0.125)	4.76±0.66	11.37
S. oryzae	0.050 (0.040-0.061)	0.090 (0.072-0.138)	4.97±0.69	22.94	0.046 (0.038-0.053)	0.083 (0.069-0.110)	4.92±0.67	13.94	0.040 (0.034-0.045)	0.071 (0.061-0.088)	5.06±0.68	7.93
T. castaneum	0.138 (0.118-0.162)	0.327 (0.259-0.480)	3.42±0.49	11.65	0.116 (0.092-0.146)	0.316 (0.231-0.559)	2.95±0.39	22.57	0.111 (0.089-0.137)	0.311 (0.230-0.522)	2.86±0.38	19.43
T. confusum	0.078 (0.060-0.099)	0.340 (0.238-0.628)	2.01±0.31	11.90	0.078 (0.060-0.099)	0.340 (0.238-0.628)	2.01±0.31	11.90	0.073 (0.055-0.093)	0.324 (0.227± 0.597)	2.011±0.31	12.48
R. dominica	0.018 (0.011-0.023)	0.039 (0.029-0.066)	3.83±0.59	11.63	0.018 (0.014-0.022)	0.038 (0.029-0.062)	3.92±0.60	11.31	0.018 (0.014-0.022)	0.038 (0.029-0.062)	3.92±0.60	11.31

application concentration of the oil solution in acetone. The fumigant toxicity of the oil was concentration-dependent. According to the results presented in Table 3, the most susceptible insect species was *S. granarius* to the essential oil of *R. chalapensis*. The essential oil did not produce any fumigant toxicity against *T. confusum*.

The contact toxicity study of the essential oil provided a different activity profile than the fumigant toxicity study. The highest contact toxicity was observed for *R. dominica* whereas the highest fumigant toxicity was observed for *S. granarius*. This fact states that active substances were less active in the vapor phase for *R. dominica*. In contact toxicity, this fact could be explained by different cuticle penetration amounts of active substances in different insects.

The AChE and BChE inhibitory activity of the oil was determined at 20 µl application volume of 10 mg/ml oil solution in methanol in the assay mixture. The oil produced 5.29 ± 1.20% inhibition of the AChE and 42.6 ± 0.71% inhibition of BChE. The oil produced very low AChE inhibition and mediocre BChE inhibition, therefore observed insecticidal activity could be related to another mechanism than the action on the cholinergic system.

DISCUSSION

Previously insecticidal activity of 2-undecanone was reported against *Keiferia lycopersicella* (Walsingham) and *Spodoptera exigua* (Hübner) of Lepidoptera (Lin et al. 1987). Additionally, the biting deterrence and larvicidal activity of *R. chalepensis* essential oil, 2-undeacanone, 2-nonanone and 2-nonyl acetate against *Aedes aegypti* L. and *Anopheles quadrimaculatus* Say. were documented in detail (Ali et al. 2013). The insecticidal activity observed for *R. chalepensis* essential oil could be related to the major components namely 2-undeacanone, 2-nonanone, and 2-nonyl acetate.

The essential oil of *Ruta chalepensis* from Cyprus has very high fumigant insecticidal activity against *S. granaries* and

Table 3. The fumigant toxicity of the *Ruta chalepensis* oil given for 48 h period as % mortality

Test insects	Mortality±SD (%)				
	Doses (µl (10% (v/v) oil/acetone)[1]				
	Control[2]	20	10	5	2.5
Sitophilus granarius	0.00±0.00	100.00±0.00	100.00±0.00	98.86±3.41	0.00±0.00
Sitophilus oryzae	0.00±0.00	95.47±3.41	56.69±0.34	25.00±5.54	N.A.
Tribolium castaneum	0.00±0.00	93.30±5.54	80.69±1.66	4.53±3.41	N.A.
Tribolium confusum	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	N.A.
Rhyzopertha dominica	0.00±0.00	85.47±3.41	53.35±1.35	6.70±5.54	N.A.

[1]The volume (µl) of essential oil solution (essential oil is diluted with acetone 10% (v/v)) applied in the fumigant insecticidal activity assay (chamber size is 10 ml). [2]Control (blank) is essential oil-free acetone.

S. oryzae, Ryzopherta dominica and *Tribolium castaneum*. The oil also produced considerably high insecticidal activity against *Ryzopherta dominica, S. granaries,* and *S. oryzae*. The major components of the *Ruta chalepensis* oil namely 2-undeacanone, 2-nonanone, and 2-nonyl acetate were previously reported to have insecticidal and repellent activity against other insect species (Ali et al. 2013, Lin et al. 1987). Consequently, these substances are thought to be the cause of the insecticidal effects seen in the current study on the species under investigation. However, the insecticidal activity of 2-undeacanone, 2-nonanone, and 2-nonyl acetate should be investigated in detail against *S. granarius, S. oryzae, T. castaneum, T. confusum* and *R. dominica* to prove their activity. Additionally, the *R. chalepensis* essential oils from different locations were reported to have seed germination inhibition against *Triticum durum* Desf. and *Phalaris canariensis* L. which contains 2-undeacanone and 2-nonanone major compounds (Bouajaj et al. 2014, Mejri et al. 2012). The inhibitory activity of 2-undecanone and 2-nonanone on germination of radish was reported to be 38% and 30% respectively which could be related to low inhibition values (De Feo et al. 2002). The essential oil of *R. chalepensis* appears to be a promising source from which natural compounds can be extracted that can be used in the pest control of stored product.

ACKNOWLEDGEMENTS

This research was presented at the 47th International Symposium on Essential Oils, Nice, France. The results presented in this poster were obtained using the infrastructure provided by the Republic of Türkiye Ministry of Food, Agriculture and Livestock, General Directorate of Agricultural Research and Policies (Project No: TAGEM/16 ARGE/07).

Author's Contributions

Authors declare the contribution of the authors is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

ÖZET

Ruta chalepensis L.'nin toprak üstü aksamından elde edilen uçucu yağ kompozisyonu GC-MS ile analiz edildi. Uçucu yağın %85.93 ± 1.08 (n = 3)'i temsil eden yetmiş dokuz bileşik tespit edildi. Uçucu yağın ana bileşenleri olarak %21.52 ± 0.21 oranında 2-undekanon, %18.31 ± 0.27 oranında 2-nonanon ve %13.22 oranında da 2-nonil asetat belirlendi. Uçucu yağı en yüksek insektisidal kontak toksisitesi 24 saat sonra 0.018 µl/böcek LD50 ve 0.039 µl/ böcek LD90 değerleri ile *Rhyzopertha dominica* F. üzerinde gözlemlenmiştir. Uçucu yağ, ayrıca *Sitophilus oryzae* L. ve *Sitophillus granarius* L. karşısında 24 saat sonra sırasıyla 0.50 ve 0.59 µl/ böcek değerleriyle oldukça düşük denebilecek LD50 değerlerini gösterdi. En düşük kontak toksisite 24 saat sonra *Tribolium castaneum* Herbst. ve *Triboliom confusum* Jacquelin du Val.'e karşı sırasıyla 0.138 ve 0.078 µl/böcek LD50 değerleri şeklinde gözlemlendi. *S. granarius*'a karşı en yüksek fumigant toksisite 48 saat sonra %100 ölüm oranını sağlayan ve 10 ml'lik haznede uygulanan 10 µl, %10 yağ/aseton (v:v) konsantrasyonunda görüldü. Uçucu yağ ayrıca *S. oryzae, T. castaneum* ve *R. dominica*'ya karşı yüksek fumigant toksisiteyi de ortaya çıkardı. 48 saat sonra 20 µl yağ çözeltisi uygulama konsantrasyonunda ölüm oranı sırasıyla %95.47 ± 3.41, %93.30 ± 5.54 ve %85.47 ± 3.41 idi. *R. chalepensis* uçucu yağı ile %5.29 ± 1.20'lik düşük bir asetilkolinesteraz enzim inhibisyonu ile %42.6 ± 0.71'lik orta derecede bir bütirilkolinesteraz enzim inhibisyonu elde edildi. Yapılan insektisidal aktivite denemelerine göre, *R. chalepensis* uçucu yağının, depo ürün zararlılarına karşı mücadelede kullanılabilecek doğal bileşiklerin elde edilmesi adına umut verici bir kaynak olduğu düşünülmektedir.

Anahtar Kelimeler: *Ruta chalepensis*, uçucu yağ analizi, depo ürün zararlıları, asetlkolinesteraz, bütirilkolinesteraz, enzim inhibisyonu

REFERENCES

Abbad A., Kasrati A., Jamali C.A., Zeroual S., Ba M'hamed T., Spooner-Hart R., Leach D., 2014. Insecticidal properties and chemical composition of essential oils of some aromatic herbs from Morocco. Natural Product Research, 28 (24), 2338-2341.

Abdellaoui K., Bahloul N., Milad M., Marzouk I.B., Chaiier N., Halima-Kamel M.B., 2014. The bioactivity of *Ruta chalepensis* and *Peganum harmala* extracts on the migratory locust *Locusta migratoria* (Orthoptera: Acrididae). Journal of Natural Product and Plant Resources, 4 (2), 62-68.

Adsersen A., Gauguin B., Gudiksen L., Jäger A.K., 2006. Screening of plants used in Danish folk medicine to treat memory dysfunction for acetylcholinesterase inhibitory activity. Journal of Ethnopharmacology 104 (3), 418-422.

Akkari H., Ezzine O., Dhahri S., B'chir F., Rekik M., Hajaji S., Darghouth M.A., Jamâa M.L.B., Gharbi M., 2015. Chemical composition, insecticidal and *in vitro* anthelmintic activities of *Ruta chalepensis* (Rutaceae) essential oil. Industrial Crops and Products, 74, 745-751.

Ali A., Demirci B., Kiyan H.T., Bernier U.R., Tsikolia M., Wedge D.E., Khan I.A., Başer H.C.B., Tabanca N., 2013. Biting deterrence, repellency, and larvicidal activity *of Ruta chalepensis* (Sapindales: Rutaceae) essential oil and its major individual constituents against mosquitoes. Journal of Medical Entomology, 50 (6), 1267-1274.

Alkan M., Atay T., 2023. Insecticidal effects of *Thymus citriodorus* L. (Lamiaceae) essential oil on two important

stored product pests. 3nd International Congress of the Turkish Journal of Agriculture-Food Science and Technology, Turjaf 2023, 13-16 September 2023, p 401.

Alkan M., Kaplan Evlice A., Evlice E., 2023. Chemical composition and potential insecticidal activity of essential oil of *Anthemis tinctoria* (Asteraceae) and *Anthemis austiaca* (Asteraceae). Sivas II. International Conference on Scientific and Innovation Research, 15-17 September-Sivas,Türkiye, 1327-1336.

Atay T., Alkan M., 2023. Biological activity of the *Schinus molle* L. (Anacardiaceae) essential oil on granary weevil, *Sitophilus granarius* (Linnaeus) (Coleoptera: Dryophthoridae). 3nd International Congress of the Turkish Journal of Agriculture-Food Science and Technology, Turjaf 2023, 13-16 September 2023, p. 402.

Atay T., Alkan M., Ertürk S., Toprak U., 2023. Individual and combined effects of α-Pinene and a native diatomaceous earth product on control of stored product beetle pests. Journal of Asia-Pacific Entomology, 26 (4), 102149.

Alshehry A.Z., Zaitoun A.A., Abo-Hassan R.A., 2014. Insecticidal activities of some plant extracts against subterranean termites, *Psammotermes hybostoma* (Desneux) (Isoptera: Rhinotermitidae). International Journal of Agricultural Sciences, 4 (9), 257-260.

Al-mazra'awi S.M., Ateyyat M., 2009. Insecticidal and repellent activities of medicinal plant extracts against the sweet potato whitefly, *Bemisia tabaci* (Hom.: Aleyrodidae) and its parasitoid *Eretmocerus mundus* (Hym.: Aphelinidae). Journal of Pest Science, 82 (2), 149-154.

Başer K.H.C., Özek T., Demirci B., Duman H., 2000a. Composition of the essential oil of *Glaucosciadium cordifolium* (Boiss.) Burtt et Davis from Turkey. Flavour and Fragrance Journal, 15 (1), 45-46.

Başer K.H.C., Özek T., Demirci B., Duman H., 2000b. Composition of the essential oil of Prangos heyniae H. Duman et MF Watson, a new endemic from Turkey. Flavour and Fragrance Journal, 15 (1), 47-49.

Başer K.C., Özek T., Demirci B., Kürkçüoğlu M., Aytac Z., Duman H., 2000c. Composition of the essential oils of *Zosima absinthifolia* (Vent.) Link and *Ferula elaeochytris* Korovin from Turkey. Flavour and Fragrance Journal, 15 (6), 371-372.

Başer K. H. C., Demirci B., Tabanca N., Özek T., Gören N., 2001. Composition of the essential oils of *Tanacetum armenum* (DC.) Schultz Bip., *T. balsamita* L., *T. chiliophyllum* (Fisch. & Mey.) Schultz Bip. var. *chiliophyllum* and *T. haradjani* (Rech. fil.) Grierson and the enantiomeric distribution of camphor and carvone. Flavour and Fragrance Journal, 16 (3), 195-200.

Başer K.H.C., Demirci B., Özek T., Akalin E., Özhatay N., 2002a. Micro-distilled volatile compounds from *Ferulago* species growing in western Turkey. Pharmaceutical Biology, 40 (6), 466-471.

Başer K.H.C., Demirci B., Kirimer N.E., Satil F., Tümen G., 2002b. The essential oils of *Thymus migricus* and *T. fedtschenkoi* var. handelii from Turkey. Flavour And Fragrance Journal, 17 (1), 41-45.

Başer K.H.C., Özek T., Kırımer N., Deliorman D., Ergun F., 2004. Composition of the essential oils of *Galium aparine* L. and *Galium odoratum* (L.) Scop. from Turkey. Journal of Essential Oil Research, 16 (4), 305-307.

Başer K.H.C., Özek G., Özek T., Duran A., Duman H., 2006. Composition of the essential oils of *Rhabdosciadium oligocarpum* (Post ex Boiss.) Hedge et Lamond and *Rhabdosciadium microcalycinum* Hand.-Mazz. Flavour and Fragrance Journal, 21 (4), 650-655.

Bendimerad N., Taleb Bendiab S. A., Benabadji A.B., Fernandez X., Valette L., Lizzani-Cuvelier L., 2005. Composition and antibacterial activity of *Pseudocytisus integrifolius* (Salisb.) essential oil from Algeria. Journal of Agricultural and Food Chemistry, 53 (8), 2947-2952.

Bouabidi W., Hanana M., Gargouri S., Amri I., Fezzani T., Ksontini M., Hamrouni L., 2015. Chemical composition, phytotoxic and antifungal properties of *Ruta chalepensis* L. essential oils. Natural Product Research, 29 (9), 864-868.

Bouajaj S., Romane A., Benyamna A., Amri I., Hanana M., Hamrouni L., Romdhane M., 2014. Essential oil composition, phytotoxic and antifungal activities of Ruta chalepensis L. leaves from High Atlas Mountains (Morocco). Natural Product Research, 28 (21), 1910-1914.

Campbell A., Sinha R.N., 1976. Damage of wheat by feeding of some stored product beetles. Journal of Economic Entomology, 69 (1), 11-13.

Chebli B., Hmamouchi M., Achouri M., Hassani L.I., 2004. Composition and *in vitro* fungitoxic activity of 19 essential oils against two post-harvest pathogens. Journal of Essential Oil Research, 16 (5), 507-511.

Chen C.C., Huang Y.L., Huang F.I., Wang C.W., Ou J.C., 2001. Water-soluble glycosides from *Ruta graveolens*. Journal of Natural Products, 64 (7), 990-992.

Çam H., Karakoç Ö.C., Gökçe A., Telci İ., Demirtaş İ., 2012. Farklı nane türlerine ait klonların uçucu yağlarının buğday biti [*Sitophilus granarius* L. (Coleoptera: Curculionidae)]'ne fumigant etkisi. Türkiye Entomoloji Dergisi, 36 (2), 255-263.

Conti B., Leonardi M., Pistelli L., Profeti R., Ouerghemmi I., Benelli G., 2013. Larvicidal and repellent activity of

essential oils from wild and cultivated *Ruta chalepensis* L. (Rutaceae) against *Aedes albopictus* Skuse (Diptera: Culicidae), an arbovirus vector. Parasitology Research, 112 (3), 991-999.

Das A.K., Suresh Kumar J., Swamy P.S., 2015. Larvicidal activity and leaf essential oil composition of three species of genus *Atalantia* from south India. International Journal of Mosquito Research, 2 (3), 25-29.

De Feo V., De Simone F., Senatore F., 2002. Potential allelochemicals from the essential oil of *Ruta graveolens.* Phytochemistry, 61 (5), 573-578.

Demirci B., Baser K.H.C., Dadandi M.Y., 2006. Composition of the essential oils of *Phlomis rigida* Labill. and *P. samia* L. Journal of Essential Oil Research, 18 (3), 328-331.

Eisen R.J., Enscore R.E., Atiku L.A., Zielinski-Gutierrez E., Mpanga J.T., Kajik E., Andamab V., Mungujakisab C., Tibob E., MacMillana K., Borcherta J.N., Gage K.L., 2013. Evidence that rodent control strategies ought to be improved to enhance food security and reduce the risk of rodent-borne illnesses within subsistence farming villages in the plague-endemic West Nile region, Uganda. International Journal of Pest Management, 59 (4), 259-270.

Elamrani A., Benaissa M., 2010. Chemical composition and antibacterial activity of the essential oil of *Ononis natrix* from Morocco. Journal of Essential Oil Bearing Plants, 13 (4), 477-488.

Ellman G.L., Courtney K.D., Andres Jr, V., Featherstone R.M., 1961. A new and rapid colorimetric determination of acetylcholinesterase activity. Biochemical pharmacology, 7 (2), 88-95.

Emam A.M., Swelam E.S., Megally N.Y., 2009. Furocoumarin and quinolone alkaloid with larvicidal and antifeedant activities isolated from *Ruta chalepensis* leaves. Journal of Natural Products, 2, 10-22.

Evlice E., Alkan M., 2023. Contact insecticidal activity of *Artemisia vulgaris* (Asteraceae) essential oil against two important stored product pests. Sivas II. International Conference on Scientific and Innovation Research, 15-17 September-Sivas, Türkiye, 1312-1320.

Gokce A., Stelinski L.L., Whalon M.E., Gut L.J., 2010. Toxicity and antifeedant activity of selected plant extracts against larval obliquebanded leafroller, *Choristoneura rosaceana* (Harris). The Open Entomology Journal, 4 (1), 30-36.

Günaydin A.K., Savci B.S., 2005. Phytochemical studies on *Ruta chalepensis* (LAM.) Lamarck. Natural Product Research, 19 (3), 203-210.

Haddouchi F., Chaouche T.M., Zaouali Y., Ksouri R., Attou A., Benmansour A., 2013. Chemical composition and antimicrobial activity of the essential oils from four *Ruta* species growing in Algeria. Food Chemistry, 141 (1), 253-258.

Hernandez-Lambrano R., Pajaro-Castro N., Caballero-Gallardo K., Stashenko E., Olivero-Verbel J., 2015. Essential oils from plants of the genus *Cymbopogon* as natural insecticides to control stored product pests. Journal of Stored Products Research, 62, 81-83.

Hmamouchi M., Lahlou M., Agoumi A., 2000. Molluscicidal activity of some Moroccan medicinal plants. Fitoterapia, 71 (3), 308-314.

Hnatyszyn O., Arenas P., Moreno A.R., Rondina R., Coussio J.D., 1974. Plantas reguladoras de la fecundidad segun la medicina folklorica. Revista de la Sociedad Científica, 14, 37.

Iauk L., Mangano K., Rapisarda A., Ragusa S., Maiolino L., Musumeci R., Costanzoa R., Serra A., Speciale A., 2004. Protection against murine endotoxemia by treatment with *Ruta chalepensis* L., a plant with anti-inflammatory properties. Journal of Ethnopharmacology, 90 (2-3), 267-272.

Isman M.B., 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annual Review of Entomology, 51, 45-66.

Isman M.B., 2008. Perspective, botanical insecticides: for richer, for poorer. Pest Management Science: Formerly Pesticide Science, 64 (1), 8-11.

Jeon J.H., Kim M.G., Lee H.S., 2013. Insecticidal activities of *Ruta chalepensis* leaves isolated constituent and structure-relationships of its analogues against *Sitophilus oryzae.* Journal of The Korean Society for Applied Biological Chemistry, 56 (5), 591-596.

Jeon J.H., Lee S.G., Lee H.S., 2015. Isolation of insecticidal constituent from *Ruta graveolens* and structure-activity relationship studies against stored-food pests (Coleoptera). Journal of Food Protection, 78 (8), 1536-1540.

Joichi A., Yomogida K., Awano K.I., Ueda Y., 2005. Volatile components of tea-scented modern roses and ancient Chinese roses. Flavour and Fragrance Journal, 20 (2), 152-157.

Joulain D., Laurent R., Fourniol J.P., Yaacob K.B., 1991. Novel moskachan related compounds in the essential oil of *Ruta angustifolia* Pers. from Malaysia. Journal of Essential Oil Research, 3 (5), 355-357.

Jorge T.C., Lenartovicz V., Andrade M.W., Bonafin T., Giordani M.A., Bueno N.B., Schneider D.S.L.G., 2009.

Pediculicidal activity of hydroethanolic extracts of *Ruta graveolens, Melia azedarach* and *Sambucus australis*. Latin American Journal of Pharmacy, 28 (3), 457-459.

Kamanula J., Sileshi G.W., Belmain S.R., Sola P., Mvumi B.M., Nyirenda G.K., Stevenson P.C., 2010. Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa. International Journal of Pest Management, 57 (1), 41-49.

Kamatou G.P.P., Viljoen A.M., Özek T., Başer K.H.C., 2008. Head-space volatiles of *Gethyllis afra* and *G. ciliaris* fruits ("kukumakranka"). South African Journal of Botany, 74 (4), 768-770.

Kamariah A.S., Lim L.B., Baser K.H.C., Ozek T., Demirci B., 1999. Composition of the essential oil of *Plumeria obtusa* L. Flavour and Fragrance Journal, 14 (4), 237-240.

Karakoç Ö.C., Gökçe A., Telci I., 2006. Fumigant activity of some plant essential oils against *Sitophilus oryzae* L., *Sitophilus granarius* L. (Col.: Curculionidae) and *Acanthoscelides obtectus* Say. (Col.: Bruchidae). Turkish Journal of Entomology, 30 (2), 123-135.

Kawakami M., Kobayashi A., 1991. Volatile constituents of green mate and roasted mate. Journal of Agricultural and Food Chemistry, 39 (7), 1275-1279.

Kaya A., Demirci B., Başer K.H.C., 2003. The essential oil of *Seseli tortuosum* L. growing in Turkey. Flavour and Fragrance Journal, 18 (2), 159-161.

Kılıç C.S., Coşkun M., Duman H., Demirci B., Başer K.H., 2010. Comparison of the essential oils from fruits and roots of *Prangos denticulata* Fisch. et Mey. growing in Turkey. Journal of Essential Oil Research, 22 (2), 170-173.

Kim M.K., Jang Y.S., Ahn Y.J., Lee D.K., Lee H.S., 2002. Larvicidal activity of Australian and Mexican plant extracts against *Aedes aegypti* and *Culex pipiens* pallens (Diptera: Culicidae). Journal of Asia-Pacific Entomology, 5 (2), 227-231.

Kırımer N., Tabanca N., Özek T., Tümen G., Baser K.H.C., 2000. Essential oils of annual *Sideritis* species growing in Turkey. Pharmaceutical Biology, 38 (2), 106-111.

Kıvçak B., Akay S., Demirci B., Başer K., 2004. Chemical composition of essential oils from leaves and twigs of *Pistacia lentiscus, Pistacia lentiscus* var. *chia*, and P*istacia terebinthus* from Turkey. Pharmaceutical Biology, 42 (4-5), 360-366.

Kollmannsberger H., Nitz S., Drawert F., 1992. Über die Aromastoffzusammensetzung von Hochdruckextrakten. Zeitschrift fur Lebensmittel-Untersuchung und Forschung, 194 (6), 545-551.

Kumazawa K., Masuda H., 1999. Identification of potent odorants in Japanese green tea (Sen-cha). Journal of Agricultural and Food Chemistry, 47 (12), 5169-5172.

Lardos A., 2006. The botanical materia medica of the Iatrosophikon—a collection of prescriptions from a monastery in Cyprus. Journal of Ethnopharmacology, 104 (3), 387-406.

Lin S.Y., Trumble J.T., Kumamoto J., 1987. Activity of volatile compounds in glandular trichomes of *Lycopersicon* species against two insect herbivores. Journal of Chemical Ecology, 13 (4), 837-850.

López M.D., Pascual-Villalobos M.J., 2010. Mode of inhibition of acetylcholinesterase by monoterpenoids and implications for pest control. Industrial Crops and Products, 31 (2), 284-288.

Madkour M.H., Zaitoun A.A., Singer F.A., 2012. Efficacy of three plant species extracts in the control of *Trogoderma granarium* Everts (Coleoptera: Dermestidae). Journal of Food, Agriculture & Environment, 10 (2 part 3), 1200-1203.

Majdoub O., Dhen N., Souguir S., Haouas D., Baouandi M., Laarif A., Chaieb I., 2014. Chemical composition of *Ruta chalepensis* essential oils and their insecticidal activity against *Tribolium castaneum*. Tunisian Journal of Plant Protection, 9 (1), 83-90.

Mancebo F., Hilje L., Mora G.A., Castro V.H., Salazar R., 2001. Biological activity of *Ruta chalepensis* (Rutaceae) and *Sechium pittieri* (Cucurbitaceae) extracts on *Hypsipyla grandella* (Lepidoptera: Pyralidae) larvae. Revista de Biología Tropical, 49 (2), 501-508.

Marcomini A.M., Alves L.F.A., Bonini A.K., Mertz N.R., Santos J.D., 2009. Atividade inseticida de extratos vegetais e do óleo de nim sobre adultos de *Alphitobius diaperinus* Panzer (Coleoptera, Tenebrionidae). Arquivos do Instituto Biológico, 76 (3), 409-416.

Martin D.T., Baributsa D., Huesing J.E., Williams S.B., Murdock L.L., 2015. PICS bags protect wheat grain, *Triticum aestivum* (L.), against rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). Journal of Stored Products Research, 63, 22-30.

Mckenzie J.D., Goldman R., 2005. The Student guide to MINITAB release 14 Manual. Pearson Education, Boston, MA.

Mejri J., Bouajila J., Ali S.B.S., Abderrabba M., Mejri M., 2012. *Ruta chalepensis* L. essential oil: chemical composition and phytotoxic activity. Journal of Biologically Active Products from Nature, 2 (6), 341-352.

Miyazawa M., Watanabe H., Kameoka H., 1997. Inhibition of acetylcholinesterase activity by monoterpenoids with

ap-menthane skeleton. Journal of Agricultural and Food Chemistry, 45 (3), 677-679.

Miyazawa M., Yamafuji C., 2005. Inhibition of acetylcholinesterase activity by bicyclic monoterpenoids. Journal of Agricultural and Food Chemistry, 53 (5), 1765-1768.

Moawad S.S., Al-Barty A.M., 2011. Evaluation of some medicinal and ornamental plant extracts toward pomegranate aphid, *Aphis punicae* (Passerini) under laboratory conditions. African Journal of Agricultural Research, 6 (10), 2425-2429.

Narain N., Galvão M.D.S., Ferreira D.D.S., Navarro D.M., 2007. Flavor biogeneration in Mangaba (*Hancornia speciosa* Gomes) fruit. Revista Brasileira de Engenharia de Biossistemas, 1 (1), 25-31.

Ntalli N.G., Manconi F., Leonti M., Maxia A., Caboni P., 2011. Aliphatic ketones from *Ruta chalepensis* (Rutaceae) induce paralysis on root knot nematodes. Journal of Agricultural and Food Chemistry, 59 (13), 7098-7103.

Özek G., Demirci F., Özek T., Tabanca N., Wedge D.E., Khan S.I., Başer K.H.C., Duran A., Hamzaoglu E., 2010. Gas chromatographic–mass spectrometric analysis of volatiles obtained by four different techniques from *Salvia rosifolia* Sm., and evaluation for biological activity. Journal of Chromatography A, 1217 (5), 741-748.

Prakash A., Rao J., 1996. Botanical pesticides in agriculture. CRC Press, Lewis Publishers, Boca Raton, Florida, 476 pp.

Pathak M.A., Daniels Jr, F., Fitzpatrick T.B., 1962. The presently known distribution of furocoumarins (psoralens) in plants. Journal of Investigative Dermatology, 39 (3), 225-239.

Perez López L.A., de la Torre Y.C., Cirio A.T., de Torres N.W., Flores Suárez A.E., Aranda R.S., 2015. Essential oils from *Zanthoxylum fagar* a wild lime, *Ruta chalepensis* L. and *Thymus vulgaris* L.: composition and activity against Aedes aegypti larvae. Pakistan Journal of Pharmaceutical Sciences, 28, 1911-1915.Pimentel M.A.G., Faroni L.R.D.A., Batista M.D., Silva F.H.D., 2008. Resistance of stored-product insects to phosphine. Pesquisa Agropecuária Brasileira, 43, 1671-1676.

Pino J.A., Márquez E., Castro D., 2009. Volatile and non-volatile acids of noni (*Morinda citrifolia* L.) fruit. Journal of the Science of Food and Agriculture, 89 (7), 1247-1249.

Polatoğlu K., Karakoç Ö.C., 2016. Biologically active essential oils against stored product pests. Essential Oils in Food Preservation, Flavor and Safety, Chapter 5, Elsevier Inc., 39-59. http://dx.doi.org/10.1016/B978-0-12-416641-7.00005-5

Polatoğlu K., Demirci F., Demirci B., Gören N., Baser K.H.C., 2010. Antimicrobial activity and essential oil composition of a new *T. argyrophyllum* (C. Koch) Tvzel var. *argyrophyllum* chemotype. Journal of Oleo Science, 59 (6), 307-313.

Pollio A., De Natale A., Appetiti E., Aliotta G., Touwaide A., 2008. Continuity and change in the Mediterranean medical tradition: *Ruta* spp.(Rutaceae) in hippocratic medicine and present practices. Journal of Ethnopharmacology, 116 (3), 469-482.

Rajendran S., Sriranjini V., 2008. Plant products as fumigants for stored-product insect control. Journal of Stored Products Research, 44 (2), 126-135.

Rattan R.S., 2010. Mechanism of action of insecticidal secondary metabolites of plant origin. Crop Protection, 29 (9), 913-920.

Rustaiyan A., Khossravi M., Sultani-Lotfabadi F., Yari M., Masoudi S., Monfared A., 2002. Constituents of the essential oil of *Ruta chalepensis* L. from Iran. Journal of Essential Oil Research, 14 (5), 378-379.

Sasanelli N., 1992. Nematicidal activity of aqueous extracts from leaves of *Ruta* graveolens on *Xiphinema index*. Nematologia Mediterranea, 20 (1), 53-55.

Sasanelli N., D'Addabbo T., 1993. Effect of *Cineraria maritima, Ruta graveolens* and *Tagetes erecta* leaf and root extracts on Italian populations of *Meloidogyne* species. Nematologia Mediterranea, 21 (1), 21-25.

Shah T.B., Saeed M., Khan I., Khan A., Khan G.Z., Farid A., Khan S.M., 2015. Repellency evaluation of selected indigenous medicinal plant materials against *Rhyzopertha dominica* (Herbst) (Coleoptera: Tenebrionidae). Journal of Entomology and Zoology Studies, 3, 65-68.

Shaaya E., Kostjukovski M., Eilberg J. E., Sukprakarn C., 1997. Plant oils as fumigants and contact insecticides for the control of stored-product insects. Journal of Stored Products Research, 33 (1), 7-15.

Soto-Monterrosa F., Hilje-Quirós L., Mora-López G.A., Aguilar-Vega M.E., Carballo-Vargas M., 2007. Systemic activity of plant extracts in *Cedrela odorata* (Meliaceae) seedlings and their biological activity on *Hypsipyla grandella* (Lepidoptera: Pyralidae) larvae. Actividad sistémica de extractos vegetales en plántulas de *Cedrela odorata* (Meliaceae) y su actividad biológica sobre larvas de Hypsipyla grandella (Lepidoptera: Pyralidae). Agricultural and Forest Entomology, 9, 221-226.

Stashenko E.E., Villa H.S., Combariza M.Y., 1995. Comparative study of Colombian rue oils by high resolution gas chromatography using different detection systems. Journal of Microcolumn Separations, 7 (2), 117-122.

Stashenko E.E., Acosta R., Martinez J.R., 2000. High-resolution gas-chromatographic analysis of the secondary metabolites obtained by subcritical-fluid extraction from Colombian rue (*Ruta graveolens* L.). Journal of Biochemical and Biophysical Methods, 43 (1), 379-390.

Tabanca N., Demirci B., Gürbüz İ., Demirci F., Becnel J.J., Wedge D.E., Can Başer K.H., 2011. Essential oil composition of five collections of *Achillea biebersteinii* from central Turkey and their antifungal and insecticidal activity. Natural Product Communications, 6 (5), 701-706.

Tabanca N., Demirci B., Baser K.H.C., Mincsovics E., Khan S.I., Jacob M.R., Wedge D.E., 2007. Characterization of volatile constituents of *Scaligeria tripartita* and studies on the antifungal activity against phytopathogenic fungi. Journal of Chromatography B, 850 (1-2), 221-229.

Tabanca N., Demirci B., Baser K.H.C., Aytac Z., Ekici M., Khan S.I., Jacob M.R., Wedge D.E., 2006. Chemical composition and antifungal activity of *Salvia macrochlamys* and *Salvia recognita* essential oils. Journal of Agricultural and Food Chemistry, 54 (18), 6593-6597.

Tabanca N., Demirci B., Kirimer N., Baser K.H.C., Bedir E., Khan I.A., Wedge D.E., 2005. Gas chromatographic–mass spectrometric analysis of essential oils from *Pimpinella aurea, Pimpinella corymbosa*, *Pimpinella peregrina* and Pimpinella puberula gathered from Eastern and Southern Turkey. Journal of Chromatography A, 1097 (1-2), 192-198.

Tounsi M.S., Wannes W.A., Ouerghemmi I., Msaada K., Smaoui A., Marzouk B., 2011. Variation in essential oil and fatty acid composition in different organs of cultivated and growing wild *Ruta chalepensis* L. Industrial Crops And Products, 33 (3), 617-623.

Tümen G., Başer K.H.C., Demirci B., Ermin N., 1998. The essential oils of *Satureja coerulea* Janka and *Thymus aznavourii* Velen. Flavour and Fragrance Journal, 13 (1), 65-67.

Tzakou O., Couladis M., 2001. Essential oil of *Ruta chalepensis* L. from Greece. Journal of Essential Oil Research, 13 (4), 258-259.

Udo I.O., 2005. Evaluation of the potential of some local spices as stored grain protectants against the maize weevil *Sitophilus zeamais* Mots (Coleoptera: Curculionidae). Journal of Applied Sciences and Environmental Management, 9 (1), 165 – 168.

Ulubelen A., Terem B., Tuzlaci E., Cheng K.F., Kong Y.C.,1986. Alkaloids and coumarins from *Ruta chalepensis.* Phytochemistry, 25 (11), 2692-2693.

Van Vuuren S.F., Viljoen A.M., Őzek T., Demirci B., Başer K.H.C., 2007. Seasonal and geographical variation of *Heteropyxis natalensis* essential oil and the effect thereof on the antimicrobial activity. South African Journal of Botany, 73 (3), 441-448.

Van Vuuren S.F., Viljoen A.M., Van Zyl R.L., Van Heerden F.R., Başer K.H.C., 2006. The antimicrobial, antimalarial and toxicity profiles of helihumulone, leaf essential oil and extracts of *Helichrysum cymosum* (L.) D. Don subsp. *cymosum.* South African Journal of Botany, 72 (2), 287-290.

Villaverde J.J., Sevilla-Morán B., Sandín-España P., López-Goti C., Alonso-Prados J.L., 2014. Biopesticides in the framework of the European Pesticide Regulation (EC) No. 1107/2009. Pest Management Science, 70 (1), 2-5.

Viney D.E., 1994. An illustrated flora of north Cyprus. Koenigstein, Germany, Koeltz Scientific Books, 697 pp.

Wen Y.Q., He F., Zhu B.Q., Lan Y.B., Pan Q.H., Li C.Y., Reeves M.J., Wang J., 2014. Free and glycosidically bound aroma compounds in cherry (*Prunus avium* L.). Food Chemistry, 152, 29-36.

Wszelaki N., Kuciun A., Kiss A., 2010. Screening of traditional European herbal medicines for acetylcholinesterase and butyrylcholinesterase inhibitory activity. Acta Pharmaceutica, 60 (1), 119.

Yaacob K.B., Abdullah C.M., Joulain D., 1989. Essential oil of *Ruta graveolens* L. Journal of Essential Oil Research, 1 (5), 203-207.

Yazdgerdian A.R., Akhtar Y., Isman M.B., 2015. Insecticidal effects of essential oils against woolly beech aphid, *Phyllaphis fagi* (Hemiptera: Aphididae) and rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). Journal of Entomology and Zoology Studies, 3 (3), 265-271.

Yıldırım E., Ozbek H., Alan I., 2001. Depolanmış ürün zararlıları, Atatürk Üniversitesi Ziraat Fakültesi Yayınları, No: 191, Erzurum, 117.

Zar J.H., 1996. Biostatistical Analysis. 3rd Edition, Prentice Hall, Upper Saddle River, 662 p.

Cite this article: Yücel, Y. Y., Karakoç, Ö. C., Servi, H., Gücel, S., vd. (2023). Fumigant and contact toxicity of *Ruta chalepensis* l. (Rutaceae) essential oil against five coleopteran stored product pests and its effects on cholinesterases. Plant Protection Bulletin, 63-4. DOI: 10.16955/bitkorb.1374633

Atıf için: Yücel, Y. Y., Karakoç, Ö. C., Servi, H., Gücel, S., vd. (2023). *Ruta chalepensis* L. (Rutaceae) uçucu yağının beş coleopteran depo ürün zararlısına karşı fumigant ve kontak toksisitesi ile kolinesterazlar üzerine etkileri. Bitki Koruma Bülteni, 63-4. DOI: 10.16955/bitkorb.1374633