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Insecticidal Activity of Radish, *Raphanus sativus* Linn. (Brassicaceae) Roots Extracts.

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ABSTRACT

Chemical constituents of *Raphanus sativus* Linn. roots were extracted and tested for their toxicity against adults and second instar nymphs of *A. gossypii* under laboratory conditions. The most effective fraction against both adults and nymphs was methylene chloride fraction with LC_{50} values of 386.63 and 309.43 ppm, followed by ethyl acetate fraction with LC_{50} values of 394.9 and 334.37 ppm then petroleum ether fraction with LC_{50} values of 636.2 and 424.56 ppm, for adults and nymphs, respectively. Also, the volatile components of each fraction were qualitatively and quantitatively identified and characterized by GC/MS technique. Moreover, the impact of the sub-lethal concentrations of *R. sativus* roots extracts on transaminases and alkaline phosphatase of *A. gossypii* was studied. Great inhibition of all tested enzymes activity was observed. This suggested the high potency of *R. sativus* roots extracts as environmentally friendly alternatives of traditional insecticides.

Keywords: *Raphanus sativus*, insecticidal activity, *Aphis gossypii*, transaminases and alkaline phosphatase

INTRODUCTION

Raphanus sativus is a common vegetable reputed to possess diverse medicinal properties. All parts of the plant are used in medicines (Ahmad *et al*., 2012). It possesses antimicrobial, anticancer, antidiabetic, diuretic, hypertensive, nephroprotective, gastroprotective, hepatoprotective property, and jaundice (Agarwal and Varma, 2014). *R. sativus* contains diverse chemical constituents of nitrogen compounds, alkaloids, enzymes, glucosinolates, flavonoids, saponins, gibberellins, organic acids, Sulphur compounds, tannins, carbohygrates, proteins, amino acids, brassinosteroids and polyphenols (Gutierrez and Perez, 2004, Aruna, 2012 and Sham *et al*. 2013). Many chemical constituents of *R. sativus* were isolated such as 4-methylthio-3-butenyl isothiocyanate or raphasatin, 4-(methylthio) butyl isothiocyanate, β- sitosterol and unsaturated triglycerides which were isolated from roots (Ragasa *et al*., 2015). Also, two phytosterols, stigmast-5-en-3-ol (β-sitosterol) and stigmasta-5,22E-dien-3β-ol (stigmasterol) and two flavonoid glycosides, quercetin 3-O-α-L-arabinopyranosyl-7-O-α-L-rhamnopyranosid and kaempferol 3-O-α-L-arabinopyranosyl-7-O-α-L-rhamnopyranoside were isolated from R. sativus leaves (Ibrahim and Abdel-Mogib, 2019). *R. sativus* is a wealthy resource of ingredients which can be used in drug development. Besides, why not use its extract as secure alternatives to the widest spread synthetic insecticides?

Cotton aphid, *A. gossypii* (Glov.) was considered an ideal insect pest for testing the insecticidal activity of radish extracts. *A. gossypii* is extremely polyphagous serious pest infecting many economically important crops, including cotton, melon, okra, peppers, potato, squash, sesame, citrus, coffee and cucurbits. It causes serious damage either directly by sucking plant juice or indirectly by excretion of honeydew or acting as virus diseases vectors. *A. gossypii* transmits over 50 plant viruses (Blackman. and Eastop , 2000). In cotton, it transmits cotton anthocyanosis virus, cotton curliness virus, cotton blue disease, cotton leaf roll and purple wilt (Kennedy *et al*., 1962 and Brown, 1992). Also, it transmits watermelon mosaic virus 2 (WMV-2), zucchini yellow mosaic virus (ZYMV) and celery mosaic virus (CeMV).

The objective of the present study was to investigate the phytochemistry and the insecticidal activity of *R. sativus* roots extracts against the cotton aphid, *A. gossypii*. Also, the effect of *R. sativus* extracts on some biochemical aspects of *A. gossypii* was studied.

MATERIALS AND METHODS

Instruments:

GC perkinelmer Claruss 500 equipped with PerkinElmer Claruss 500 Mass Spectrometer was used for performing GC/MS analysis of the different fractions of the root extracts. Turbomass data system was used for MS identification of the GC components. GC/MS analysis was performed on a Varian GC interfaced to Finnegan SSQ 7000 Mass selective Detector (SMD) with ICIS V2.0 data system for MS identification of the GC components. For biochemical study, Spectrophotometer (Jen Way 6051Colorimeter) was used.

Plant material

Insecticides-free *R. sativus* Linn. roots were collected from faculty of Agriculture farm, Mansoura University and dried at room temperature then grounded to a fine powder.

Extraction and Isolation

The powdered material of *R. sativus* roots were extracted with methanol using a soxhlet apparatus. The total

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methanolic extract was concentrated by rotary evaporation under vacuum, then, it was diluted with water and successively extracted with different organic solvents of different polarities using separating funnel. Petroleum ether, methylene chloride and ethyl acetate fractions were obtained then dried over anhydrous Sodium sulphate and evaporated to dryness. A sample of each fraction was subjected to GC/MS technique for characterization and identification of the volatile constituents.

The tested insect pest

For screening insecticidal activity of *R. sativus* root extracts, cotton aphid, *A. gossypii* was used as a model insect. Aphid strain was reared on cucumber, *Cucumis sativus* (2-3 weeks old) planted in small pots (15 cm3) under laboratory conditions at 27 ± 5oC, 70 ±5 RH and 14hs photoperiod.

Bioassay

Ten adult individuals or newly molted second instar nymphs of *A. gossypii* were transferred to cucumber leaf free from pesticides by using camel hair brush and placed in plastic jar. They were subsequently sprayed with the tested concentrations of the plant extracts containing 0.3% Tween 80 were then the lids with ventilation pores were sealed. Each treatment was replicated three times in addition to another three replicates sprayed only with water containing 0.3% Tween 80 to be considered as control. All treatments were carried out under laboratory conditions at 27 ± 2oC, 70 ± 5 % RH, and 14hs photoperiod. Mortality percentages and observations were recorded at 72hs after treatments.

Biochemical study

- **Preparation of samples for biochemical assay**

For each trial, fifty individuals of alive *A. gossypii* adults treated with LC_{50} of different tested extracts were collected at 1st, 3rd and 5th days after treatment. Untreated samples were served as control. Samples were homogenized in saline solution (0.9% NaCl) using a Teflon homogenizer. Then, the homogenates were centrifuged at 4000 rpm for 15 min. Then, the supernatants were immediately assayed for enzymes activities determination.

- **Determination of transaminases activity**

Determination of glutamine pyruvic transaminase (GPT) and glutamic oxaloacetic transaminase (GOT) were carried out according to the method of Murray, (1984) by using Diamond Diagnostics, DP International, Egypt. The enzymes activity were measured calorimetrically at 550 nm.

- **Determination of Alkaline phosphatase activity**

Alkaline phosphatase was determined according to the method described by Belfield and Goldberg, (1971) by using ABC Diagnostics, Egypt. Alkaline phosphatase was measured, immediately, by spectrophotometer at 510 nm.

Statistical analysis

Mortality percentages of both adults and the 2nd instar nymphs of *A. gossypii* were determined after 72h of initial application of different tested extracts of *R. sativus* roots, then corrected by using Abotts' formula, (1925). The LC50, LC90 and slope values were estimated according to Finney, (1971). Also, toxicity indexes of different tested extracts of *R. sativus* roots were evaluated by comparing it with the most effective one using Sun's equation, (1950).

RESULTS AND DISCUSSION

Chemical constituents of R. sativus roots extracts

Different fractions of *R. sativus* roots were analyzed by GC/MS technique (Table 1). Petroleum ether fraction revealed existence of nine peaks corresponding to nine compounds, while methylene chloride fraction revealed seven compounds. Also, ethyl acetate fraction detected six compounds. These compounds were identified by comparing their mass spectra with those of their analogous reported by Wiley, NIST and Pfleger libraries. The most abundant constituents of Petroleum ether fraction were Hexadecanoic acid (12.86%), Caryophyllene- oxide (11.82%) and oleic acid (1.04%). Methylene chloride fraction mainly consisted of thiocyanate compounds (Allyl thiocyanate (11.22%), Benzyl thiocyanate (12.9%) and 4-(methylthio)-3-butenyl isothiocyanate (19.06%)) in addition to carbamate compound (Squamolone, 16.05%), 1-methylpiperidin-2-one (14.61%), 2-Azetidinecarboxylic acid (9.46%), and Hexadecanoic acid (28.39%). While the major constituents of ethyl acetate fraction were fatty acids (Hexadecanoic acid (28.56%) and Octadecanoic acid (32.11%)), sulfur compounds (Sulfolane (10.73%) and Thiiranebutanenitrile (19.60%)), L-Glutamic acid (16.48%) and Hydrocinnamic acid (15.44%).

Table 1. The GC/MS analysis of different fractions of R. sativus roots

Compound Name	R.T. min	Area %	M.F.	Mol.wt
Pet. ether fraction of *R. sativus* roots				
Methyl dodecanoate (Methyl laurate, 1).	27.69	0.6	$C_{13}H_{26}O_2$	214
Hexadecanoic acid (Palmitic acid, 2).	28.88	12.86	$C_{16}H_{32}O_2$	256
Methyl oleate (3).	30.86	0.42	$C_{19}H_{36}O_2$	296
Caryophyllene- oxide (4)	31.98	11.82	$C_{15}H_{24}O$	220
9-Octadecenoic acid (Z-Oleic acid, 5).	32.28	1.04	$C_{18}H_{34}O_2$	282
Hexadecanedioic acid (Thapsic acid, 6)	35.44	0.28	$C_{16}H_{30}O_4$	286
Nonacosane (7)	41.61	0.2	$C_{29}H_{60}$	408
Triacontane (8)	42.95	0.2	$C_{30}H_{62}$	422
Cholesterol (9)	46.88	0.59	$C_{27}H_{46}O$	386
Methylene chloride fraction of *R. sativus* roots:				
2-Azetidinecarboxylic acid (S-form, 10).	9.46	0.74	$C4H_7NO_2$	101
3-Thiocyanato-1-propene (Allyl thiocyanate, 11).	11.22	76.92	C_4H_5NS	99
Benzyl thiocyanate (Benzyl rhodanide, 12).	12.9	0.59	C_8H_7NS	149
1-methylpiperidin-2-one (13).	14.61	0.27	$C_6H_{11}NO$	113
Squamolone (1-Carbamoyl-2-pyrrolidone,14)	16.05	0.92	$C_5H_8N_2O_2$	128
4-(methylthio)-3-butenyl isothiocyanate (15)	19.06	18.97	C_6H_9NS	159
Hexadecanoic acid (2)	28.39	0.35	$C_{16}H_{32}O_2$	256
Ethyl acetate fraction of *R. sativus* roots:				
Sulfolane (Bondolane A, 16).	10.73	12.31	$C_4H_8O_2S$	120
3-Phenylpropanoic acid (Hydrocinnamic acid, 17)	15.44	20.73	$C_9H_{10}O_2$	150
L-Glutamic acid (18)	16.48	17.3	$C_5H_9NO_4$	147
Thiiranebutanenitrile (3-Cyanopropyl-thiirane, 19)	19.60	12.12	C_6H_9NS	127
Hexadecanoic acid (2)	28.56	2.21	$C_{16}H_{32}O_2$	256
Octadecanoic acid (Stearic acid, 20)	32.11	0.85	$C_{18}H_{36}O_2$	284

Insecticidal activity of radish, *R. sativus* roots extracts

Different fractions of *R. sativus* roots extract were screened for their insecticidal activity against both adults and 2nd instar nymphs of *A. gossypii*. It's clear from data

shown in Table 2 that methylene chloride fraction was the most effective at the LC_{50} and LC_{90} levels, followed by ethyl acetate fraction, then petroleum ether fraction for both nymphs and adults. Methylene chloride fraction suppressed *A. gossypii* adults with LC_{50} value: 386.63 ppm, LC_{90} value: 1860.5 ppm and toxicity index at LC_{50} of 100% followed by ethyl acetate fraction with LC_{50} value: 394.9 ppm, LC_{90} value: 2735.14 ppm and toxicity index at LC_{50} of 97.9% then petroleum ether fraction with LC_{50} value: 636.2 ppm, LC_{90} value: 4066.65 ppm and toxicity index at LC_{50} of 60.77%. In the same vein, methylene chloride fraction was the most effective fraction against the 2nd nymphal instar of *A. gossypii* with LC_{50} value: 309.43 ppm, LC_{90} value: 1440.23 ppm and toxicity index at LC_{50} of 100% followed by ethyl acetate fraction with LC_{50} value: 334.37 ppm, LC_{90} value: 1499.14 ppm and toxicity index at LC_{50} of 92.54% then petroleum ether fraction with LC_{50} value: 424.56 ppm, LC_{90} value: 2112.52 ppm and toxicity index at LC_{50} of 72.88%.

The present results agreed with Khater and Khater (2009) who illustrated the insecticidal activity of *R. sativus* against the third larval instar of the blowfly, *Lucilia sericata* which transmit mycobacterial infections to humans and animals. Also, the current data agreed with Ibrahim and Abdel-Mogib (2019) who confirmed the insecticidal activity of *R. sativus* leaves extracts against third instar nymphs of *Phenacoccus solenopsis*.

The insecticidal property of any natural extract is an obvious reflection of its chemical contents. Taking the same approach, the high insecticidal activity of the methylene chloride fraction may be due to the presence of some components such as the thiocyanate compounds (96.48%). Allyl isothiocyanate (76.92%) showed insecticidal activity against adults of stored product insects (Worfel *et al*., 1997, Tsao *et al*., 2002 and Wu *et al*., 2009) and when it was applied as fumigant against all stages of the red flour beetle, Tribolium castaneum, it revealed high potentiality causing larvae and adult malformations (Santos *et al*., 2011). Also, benzyl thiocyanate showed moderately toxic action on the house fly, Musca domestica inhibiting tyrosinase and phenolase. In addition to acting as insecticide, it synergizes with the carbamate insecticide carbaryl (Bakry *et al*., 1968).

Ethyl acetate fraction revealed moderate mortality, this might be as a result of presence of high percentages of fatty acids, hexadecanoic acid (28.56%) and stearic acid (32.11%) besides other high polar components which were previously investigated such as pyrrolidine, phenethylamine, N-methylphenethylamine, 1, 2-pyrrolidin-tion-3-il-3-acid-carboxilic-1, 2, 3, 4-tetrahydro-β-carboline, and sinapine (Marquardt, 1976, Wan, 1984 and Weilan *et al*., 1987).

Also, the insecticidal activity of the petroleum ether fraction may be due to the presence of some components such as caryophyllene oxide (11.82%) which previously showed insecticidal and antifeedant activities against L. decemlineata (Rodilla *et al*., 2008), Tribolium castaneum (Kim *et al*., 2010) and against both of Sitophilus zeamais and Tribolium castaneum (Liu *et al*., 2012). Moreover, presence of fatty acids, Hexadecanoic acid (12.86%); oleic acid (1.04%) and thapsic acid (0.28%) took a part in potency of this fraction as previously reported against weevil species (Su *et al*., 1972, Su, 1976, Messina and Renwick, 1983 and Abdallah *et al*., 1986) and against *Aedes aegypti* larvae (Tare and Sharma, 1991). Also, this fraction contained methyl oleate (0.42%) which showed killing effects on *Tetranychus cinnabarinus* and inhibitory effects on the growth of the eggs (Du *et al*., 2012).

Table 2. Susceptibility of *A. gossypii* adults and 2nd nymphal instar to different extracts of *R. sativus* roots using spray method under laboratory conditions of 27±2°C, 70 ± 5 % RH, and 14hs photoperiod.

Tested fraction	Adults						2nd instar nymphs					
	LC50 (ppm) and confidence limits at 95%		LC90 (ppm) and confidence limits at 95%		Slope ± SE	X2	Toxicity index*	LC50 (ppm) and confidence limits at 95%		LC90 (ppm) and confidence limits at 95%		Slope ± SE	X2	Toxicity index*
Pet. ether fraction	636.2		4066.65		1.59± 0.37	0.112	60.77	424.56		2112.52		1.84± 0.39	0.11	72.88
	422.26	916.56	2176.47	19346.8				264.99	578.26	1348.02	5614.48			
Methylene chllride fraction	386.63		1860.5		1.88± 0.4	0.64	100	309.43		1440.23		1.92± 0.43	0.45	100
	234.55	527.2	1215.54	4633.29				188.71	421.7	931.75	3805.74			
Ethyl acetate fraction	394.9		2735.14		1.52± 0.38	0.36	97.9	334.37		1499.14		1.97± 0.44	0.02	92.54
	203.47	570.06	1551.74	11968.43				192.25	458.62	1000.4	3640.5			

Biochemical studies

• Determination of transaminases activity

Insects have an unusually high concentration of free amino acids in both of haemolymph and tissues reaching 50 to 300 times higher than their level in human blood (Auclair, 1953 and Florkin, 1959). Such high concentration of amino acids may be to fulfill number of specific functions aside from serving as substrates for protein synthesis to regulation of the osmotic pressure, detoxication of waste products, acting as energy sources under special conditions and participation in a variety of morphogenetic and reproductive processes (Chen, 1966 and Chen, 1971). Aminotransferases are the responsible for maintenance of "amino acid pool" balance in the insect body (Meister, 1957). Also, the amino-transferases, especially glutamine pyruvic transaminase (GPT) act as catalytic agents in the metabolism of carbohydrates (Katunuma, 1968). It was found that insecticides have a great impact on enzymes catalyzing amino acids metabolism in insects (Kamina and Handler, 1957). So, the current study aimed to investigate the effect of the tested fractions of *R. sativus* extract on GPT and GOT in *A. gossypii* to confirm their insecticidal potency.

Data arranged in Table 3&4 indicated that all treatments at sub-lethal concentration (LC_{50}) revealed a great decrease in GPT and GOT activities comparing with

the untreated control. Methylene chloride fraction showed the highest declination of GPT and GOT enzymes activity at 5th day post treatment to reach: -62.7 and -53.96%, respectively. Also, petroleum ether fraction inhibited both enzymes activity to reach: -51.03 and -52.06%, respectively at the 5th day post treatment. Ethyl acetate fraction revealed relatively slight increase of GPT and GOT activity (14.52 and 16.88%, respectively) at the first day after treatment, then the gradual decrease of both enzymes activity was observed to reach -36.95 and -37.93%, respectively at 5th day after treatment compared with control.

The present results was in accordance with Younes *et al*. (2011) who indicated the decrease of GPT and GOT in 4th instar larvae of *Tribolium granarium* after rearing on diet treated with some plant oils. Also, the inhibitory effect of *Fagonia bruguieri* extracts against the desert locust *Schistocerca gregaria* had been recorded as inhibitors for ACP activity (Basiouny *et al*., 2010).

Table 3. GPT activity (U/L) in *A. gossypii* treated with LC_{50} of the tested *R. sativus* roots extracts

Treatment	GPT activity at different times post treatment					
	1st day		3rd day		5th day	
	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %
Pet. ether fraction	51.17 ± 9.49	-10.02	40.6 ± 5.38	-25.82	27. 7 ± 2.71	-51.03
Methylene chloride fraction	45.53 ± 7.53	-19.94	31.87 ± 5.42	-41.77	21.1 ± 4.98	-62.7
Ethyl acetate fraction	65.13 ± 6.46	14.52	49.17 ± 7.53	-10.16	35.67 ± 7.5	-36.95
Control	56.87 ± 4.8	-----	54.73 ± 4.89	-----	56.57 ± 13.31	-----

Table 4. GOT activity (U/L) in *A. gossypii* treated with LC_{50} of the tested *R. sativus* roots extracts

Treatment	GOT activity at different times post treatment					
	1st day		3rd day		5th day	
	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %
Pet. ether fraction	54.27 ± 5.52	-15.16	42.63 ± 6.71	-33.91	30.33 ± 4.47	-52.06
Methylene chloride fraction	50.93 ± 5.12	-20.38	39.6 ± 4.98	-38.6	29.13 ± 3.97	-53.96
Ethyl acetate fraction	74.77 ± 6.62	16.88	59.97 ± 4.92	-7.02	39.27 ± 3.52	-37.93
Control	63.97 ± 5.6	-----	64.5 ± 8.84	-----	63.27 ± 9.72	-----

- **Determination of Alkaline phosphatase activity**

Data presented in Table 5 demonstrated the effect of different fractions of *R. sativus* extract on *A. gossypii* AlP activity. All treatments exhibited great inhibition of ALP activity along the experimental period. Methylene chloride caused the most inhibition of AlP activity followed by Petroleum ether fraction, then ethyl acetate fraction with inhibition percentages values: -62.49, -55.45 and -52.31%, respectively. The current results agreed with previous studies (Miao, 2002 and Zera and Zhao, 2004) stated that different stress, disease and toxic chemicals causes considerable decrease in the activity of ALP. Also, it was coincide with previous results (Al-Dali, 2007 and Younes *et al*. 2011) which illustrated inhibitory effects of some plant oils on ALP and ACP in treated khapra beetle, *Trogoderma ranarium* larvae and grasshopper, *Euprepocnemis plorans* nymphs, respectively.

Table 5. AlP activity (U/L) in *A. gossypii* treated with LC_{50} of the tested *R. sativus* roots extracts

Treatment	AlP activity at different times post treatment					
	1st day		3rd day		5th day	
	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %	mean ± SD (U/L)	Change %
Pet. ether fraction	34.13 ± 6.05	-7.58	22.6 ± 5.33	-36.57	16.07 ± 3.83	-55.45
Methylene chloride fraction	24.83 ± 5.32	-32.76	17.27 ± 3.65	-51.53	13.53 ± 1.4	-62.49
Ethyl acetate fraction	33.13 ± 4.61	-10.29	22.93 ± 4.89	-35.64	17.2 ± 3.14	-52.31
Control	36.93 ± 8.18	-----	35.63 ± 6.31	-----	36.07 ± 2.34	-----

The phosphatases and transaminases usually show the greatest diagnostic potential as a result of their vital roles in many functions within the insect body. They are concerned with the synthesis of nutrition, fibrous protein, development and egg maturation of insects (Sridhara and Bhat, 1963). The current study illustrated the disturbance of transaminases, GPT, GOT and AlP activities. Great inhibition of all tested enzymes activity of *A. gossypii* treated with the sub-lethal concentrations of different fractions of *R. sativus* extracts was observed. This means that different physiological functions, such as growth, development, reproduction, in the insect body have been inhibited and ultimately lead to death. According previous studies reported that the use of insecticides may cause multiple sub-lethal effects on the enzyme activities in insect pests (Singh and Marwaha, 2000 and Sabri *et al*. 2017). It was suggested, therefore, that all tested fraction of *R. sativus* extracts have promising insecticidal activity.

CONCLUSION

The insecticidal activity of different fractions of *R. sativus* roots extract against *A. gossypii* were studied. The most active fraction was the methylene chloride followed by ethyl acetate fraction then petroleum ether fraction. The major volatile components of the tested fractions were characterized by GC/MS technique. Also, the impact of R. sativus roots extracts on transaminases and alkaline phosphatase of *A. gossypii* was studied. It was found that all tested fractions of the plant extract caused dramatic declination of both transaminases and alkaline phosphatase. This suggested the high potency of *R. sativus* roots extracts as environmentally friendly alternatives of traditional insecticides.

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مستخلصات جذور نبات الفجل كمبيدات حشرية

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تم استخلاص المكونات الكيميائية لجذور الفجل واختبار كفاءتها الابادية على الأطوار الكاملة والعمر الثاني لحوريات من القطن في الظروف المعملية. ولقد كان مستخلص الميثيلين كلوريد هو الأعلى كفاءة على كل من الاطوار البالغة والحوريات مظهرة تركيزات نصف مميتة : 386.63 و 309.43 جزء في المليون لكل منهما على التوالي، يليه مستخلص خلات الايثيل حيث كان LC50: 394.9 و 334.37 جزء في المليون، ثم مستخلص الايثير البترولي مظهرة تركيزات نصف مميتة: 636.2 و 424.56 جزء في المليون على كل من الاطوار البالغة والحوريات على التوالي. أيضاً تم تعريف المركبات المتطايرة في المستخلصات المختلفة لجذور الفجل باستخدام تقنية كروماتوجرافيا الغاز/ طيف الكتلة. أيضاً تم دراسة بيوكيميائية لأثر مستخلصات جذور الفجل على نشاط الانزيمات الناقلة للأمين Aminotransferases و انزيم الفوسفاتيز القاعدي في حشرات المن المعاملة وقد لوحظ انهيار شديد في نشاط جميع الانزيمات محل الدراسة مما يؤكد كفاءة مستخلصات جذور الفجل كبدائل آمنة صديقة للبيئة.