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Research Article

Evaluation of insecticidal properties of *Citrus limon* leaf and peel essential oils against rice moth, *Corcyra cephalonica* (Stainton)

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ABSTRACT: The Rice moth, *Corcyra cephalonica* (Lepidoptera: Pyralidae) is a serious pest of stored cereals and processed products causing damage to a variety of food grains. Its larval stage feeds externally on grains and processed products under storage and damages both quantitative and qualitative. For the control of this insect pest, several chemicals of synthetic nature have been used in different forms. Since these synthetic chemicals affect the environment, human health, non-target organisms as well as the quality of air, soil and water, researchers focused on green alternatives. In the present study, essential oil from *Citrus limon* (Family: Rutaceae) leaves and peel was extracted and evaluated to investigate their repellent, toxic, oviposition inhibitory, developmental inhibitory and antifeedant activities on *C. cephalonica*. These two essential oils repelled the adults of *C. cephalonica* in repellency assay and caused acute toxicity in both larvae and adults in fumigant toxicity assays reducing oviposition and interfered with the transformation of larva to adult besides inhibiting the hatching of eggs. In conclusion, these *C. limon* leaves and peel essential oils can be used as the key components in eco-friendly insecticide formulation based on volatile organic chemicals.

KEYWORDS: Antifeedant activity, citrus, essential oils, rice moth, stored grain pests

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INTRODUCTION

Infestation of grain under storage by insects started with the beginning of storage practices leading to both quantitative and qualitative losses. In developing countries that depend on traditional technologies for storing grains, such losses vary between 10-40%. These losses have been estimated at approximately 10% of the total yield at the farm level (Lal, 1988; Shaaya *et al*., 1997). In India, this loss has been estimated up to 10% during storage (Champ & Dyte, 1977; Tooba *et. al*., 2005; Perera *et al.,*, 2021; Kumar *et al*., 2021). These cause spoilage of food as well as raise concerns about security issues, especially in developing countries. In lepidopteran pests, *Corcyra cephalonica* (Stainton) is one of the serious pests under storage conditions found in India and many other parts of the world like Asia, Africa, Brazil, Europe, Indonesia, Myanmar, North America and Thailand (Osman, 1984; Allotey & Azalekor, 2000; Roopa *et al*., 2021). It is an external feeder which damages grains including corn, cotton seeds, groundnuts, pulses, rice, sorghum and jowar. The larval stage of *C. cephalonica* is the feeding stage damaging stored grains and making silken webs (Alam, 1972; Atwal & Dhaliwal, 2008). In case of severe infestation, the whole grains are converted into a webbed mass making the grain unfit for human consumption (Fenemore & Prakash, 1992; Samanta & Yadav 2021).

To manage these losses by insect pests, several chemicals like organophosphates, organochlorines and phosphine were synthesized and used indiscriminately, but besides achieving success in reducing its population, these insecticides have led to resistance development (Elzen & Hardee, 2003; Benhalima *et al*., 2004; Islam & Talukdar, 2005). These synthetic insecticides cause various chromosomal aberrations and the formation of DNA adducts (Le Goff *et al*., 2005; Muniz *et al*., 2008; Simoniello *et al*., 2008). These insecticides cause various environmental problems like thinning of the ozone layer, contamination of soil, air and water, high persistence in the environment, toxic effects in non-target organisms like beneficial insects and a variety of health issues like neurotoxicity, carcinogenicity and teratogenicity (WMO, 1991; Lu, 1995; UNEP, 2000; Beckel *et al*., 2002; Regnault-Roger *et al*., 1997).

These serious concerns lead to reduce the use of these synthetic products and the exploration of new green

and ecologically safe alternative methods. Essential oils are nowadays considered as alternatives to synthetic insecticides to protect stored products from insect infestation. The lemon (*Citrus limon*), an evergreen tree belonging to the Rutaceae family, is native to Asia and found mainly in northern areas like Assam Myanmar and China. Citrus peels have several antioxidant components which have been known to have a variety of biological activities reported by different workers (Akarca & Sevik, 2021; Farida *et al*., 2023). The essential oil extracted from peel contains forty-five volatile constituents representing 99.7% of total essential oil with limonene (60.7%) as a major constituent (Kacaniova *et al*., 2024). Citrus leaf oil contains twenty-seven compounds and linalool is found in maximum quantities of 30.62% (Hojjati & Barzegar, 2017). The citrus extracts are reported for their tumour growth inhibitor activity (Miwa *et al*., 2005). The essential oils of citrus have been reported for their antimicrobial properties that are responsible for ingredient leakage and cell death-induced lysis of bacterial cell walls (Taktak *et al*., 2021, Farida *et al*., 2023). Due to the resistant behaviour of insects, and recently increased interest in developing plant-origin insecticides as an alternative to chemical insecticides the finding of the present work, can be concluded the essential oils from *Citrus limon* (Family: Rutaceae) leaves and peel were extracted and evaluated to investigate their repellent, toxic, oviposition inhibitory, developmental inhibitory and antifeedant activities on *C. cephalonica*.

MATERIALS AND METHODS

Plant collection

Leaves and peels of *Citrus limon* were collected from local area of Madhepura district, Bihar. The harvested materials were dried in the absence of sunlight at room temperature (20-25°C) for 5-7 days.

Essential oil extraction

The essential oil was extracted by hydro-distillation methods using a Clevenger-type apparatus for 4 h. The anhydrous sodium sulphate was used for drying it and stored at 4-5°C in eppendorff tubes.

Insects

Lepidopteran pest, rice moth, *C. cephalonica* was reared in the laboratory in a glass jar (30 cm height, 20 cm diameter). Insects were fed crushed rice grain mixed with 5% (w/w) and kept at a rearing room temperature of 28±1ºC, with RH of 65±5% and a photoperiod of 12 h (L:D). 2-3 days old newly adults were used for the further experimental process.

Repellent activity

The repellency assay was carried out in a Y-shaped glass tube (each arm with a diameter of 2 cm and 10 cm in length). Five grams of crushed rice mixed with different concentrations of *C. limon* leaf and peel oils were placed in Y-tube-like paired arms in which one (experimental) arm and the other (Control) arm contained only crushed rice. 20 numbers of insects of *C. cephalonica* were introduced through the median arm of the Y-tube. The open ends of the median arm were plugged with cotton and the experimental set-up was kept for observation.

The number of insects present in the experimental, control and median arms was counted after 3h. Each concentration was replicated six times. Per cent Repellency (PR) was calculated using the formula:

$$PR = [(N_{UT} - N_T / N_{UT} + N_T] \, 100$$

where, N_{UT} = number of insects in control and N_T = number of insects in experimental.

Fumigant toxicity

The essential oils of the leaf and peels of *Citrus limon* were used for testing their insecticidal activities in a solution made of acetone. 10 adults and third instar larvae of *C. cephalonica* collected from laboratory culture placed in a glass jar (15 cm height 10cm diameter) floored by Whatman filter paper No. 1. A paper strip (2 cm diameter) treated with different concentrations was pasted on the inner surface of the glass cover of each glass jar. The treated filter was covered with wire mesh to avoid contact of the treated filter with the test. Finally, the glass jar was covered by a glass cover and sealed with parafilm. During 24 h of the experiment, the six replicates of each concentration of glass were kept in the dark and after this the treated adults were transferred to a fresh glass jar of similar measurement. After 24 h and 48 h of exposure, mortality in adults and larvae was recorded.

Oviposition inhibition

Oviposition inhibitory activity *C. limon* leaf and peel oils were tested against *C. cephalonica* by fumigation. Ten pairs of 1-2 old adults were placed in a glass jar (15 cm height 10 cm diameter) floored by Whatman filter paper No. 1. A paper strip (2 cm diameter) treated with different sub-lethal concentrations viz. 40 and 80% of 24h-LC_{50} were pasted on the inner surface of the glass cover of each glass jar. Finally, the glass jar was covered by a glass cover and sealed. During 24 h of the experiment, the six replicates of each concentration of glass were kept in the dark. After 24 h of exposure, the experimental adults were transferred to a new glass jar of similar measurement. After four days of treatment, the adults were removed and discarded. The number of eggs was collected and counted for the treated as well as for control groups. The % ODI (Oviposition Deterrence Index) was

calculated using the formula:

$$\%ODI = [(C-T)/(C+T)]100$$

where, C = Number of eggs in control group, T = Number of eggs in experiment group

Ovicidal assay

In the ovicidal assay, twenty-five freshly laid eggs were placed on Whatman filter paper No. 1. The filter paper containing eggs was then placed in the bottom of a glass Petri dish (10 cm in diameter and 1.0 cm in height). These eggs were fumigated with test solutions prepared with acetone by diluting *C. limon* leaf and peel oils with acetone. The test solution (100 µl) was pasted on a filter paper strip (2.5 cm diameter) and evaporated for 5 minutes. The coated paper strips were pasted to the inner surface of the glass Petri dish and incubated for 72 h in conditions maintained for insect culture. After completion of fumigation, number of eggs hatched was recorded. Six replicates of three concentrations of each oil were set for the Per cent Hatching Inhibition Rate. %HIR was calculated using the formula:

$$\%HIR = [(C-T)/C]\ 100.$$

Where, C = Adults in the control group, T = Adults in the test group

Developmental inhibition

Developmental inhibitory activity of *C. limon* leaf and peel oil was tested against newly emerged 3rd instar larvae of *C. cephalonica*. Twenty larvae were fumigated with different sub-lethal concentrations *viz.* 40 and 80% of 48h-LC_{50} of volatile oil in a Petri dish for experimental periods like larvicidal assay and then the treated larvae were transferred to new glass jars and supplied with crushed rice with 5% (w/w) yeast powder. The number of pupae transformed emerged adults from pupae was recorded. Six replicates were set for each concentration of oil as well as control.

Antifeedant activity

The antifeedant activity of *C. limon* leaf and peel oils was tested in *C. cephalonica* larvae. For this assay, food was prepared by crushing 10 gm of rice grains and mixing 5% (w/w) yeast powder in it. Now, three different mixtures of food were prepared by mixing thoroughly 0.3µl/5gm, 0.6µl/gm and 1.2µl/gm volatile oils of *C. limon* leaf and peel. Now ten 3rd instar *C. cephalonica* larvae were placed on Whatman filter paper No. 1. The filter paper containing larvae was then placed in the bottom of a glass Petri dish (10 cm in diameter and 1.0 cm in height). Now, 10 gm of food prepared was spread around the larvae, covered in the Petri dish and kept in laboratory conditions applied for insect rearing. The antifeedant activity was calculated after the end of the larval life by using a formula:

$$AFA = [C-T/C] \times 100$$

where, C = consumption in the control group, and T = consumption in the treated group.

Data analysis

The POLO programme was used for the calculation of LC_{50} (Russel *et al.* 1977). To define all dose-response relationships correlation and linear regression analysis were conducted (Sokal & Rohlf, 1973). For the equality of the regression coefficient, ANOVA was performed (Sokal & Rohlf, 1973).

RESULTS

Repellency

Results of the repellency assay indicated that essential oils of *C. limon* leaf and peel were repellent to C. *cephalonica* adults. The Per cent Repellency (PR) was recorded at 33.33, 57.62 and 96.55%, and 23, 58.97 and 91.30 at 2, 4 and 8µl of *C. limon* leaf and peel essential oil respectively (Table 1).

Fumigant toxicity

In adults, median lethal concentrations were recorded at 128.32 and 84.47 µl/L, and 149.17 and 89.35 µl/L air against *C. cephalonica* adult for *C. limon* leaf and peel oils after 24h and 48h exposure periods, respectively (Table 2). On the other hand, median lethal concentrations were 89.78 and 52.69 µl/L, and 96.34 and 59.28 µl/L air against *C. cephalonica* larvae for *C. limon* leaf and peel oils after 24h and 48h exposure periods respectively (Table 2). The significance of potency estimation, the g-value less than 0.5 indicates the mean value is within the limits. The t-ratio indicates the significance of regression that has more than 1.6 values. The heterogeneity factor of less than 1 showed model

Table 1. Repellent effect of *C. limon* leaf and peel oils on *C. cephalonica*

Concentration (vol:vol)	Leaf oils	Peel oils
	Per cent repellency (PR) Mean±SE	
2	33.33±1.23	23.00±0.85
4	57.63±2.34	58.97±2.58
8	96.55±2.96	91.30±3.05
16	100±0.00	100±0.00

The repellent activity was calculated by using the formula:

$PR = [(N_{UT} - N_T / N_{UT}+N_T]\ 100,$

where, N_{UT} = number of insects in the control area and N_T = number of insects in the experimental area.

fits the data adequately. The regression analysis reveals the concentration-dependent toxicity in adults and larvae of *C. cephalonoca.* (Table 2).

Oviposition inhibition

The oviposition inhibitory activity of *C. cephalonica* reduced significantly after was decreased significantly when fumigated with the *C. limon* leaf and peel oils. The oviposition was reduced to 55.30 and 34.53%; and 57.33 and 34.53% after fumigation of *C. cephalonica* adults with 40 and 80% of 48h-LC_{50} of *C. limon* leaf and peel oils respectively (For *C. limon* leaf oil F = 31.82; and for *C. limon* peel oil F = 33.22; p<0.01; Table 3).

Ovicidal activity

The percentage of egg hatching decreased significantly after *C. limon* leaf and peel oils activity. Egg hatching was reduced to 80.13, 58.85 and 44.68%; and 80.85, 61.70 and 46.08% of the control when eggs were fumigated with 25, 50 and 75 µl/L of *C. limon* leaf and peel oils respectively (For *C. limon* leaf oil F = 146.16; and for *C. limon* peel oil F = 130.00; p<0.01; Table 4).

Developmental inhibition

The larval transformation into the pupa and adult emergence in *C. cephalonica* was decreased significantly with an increase in the concentration of *C. limon* leaf and peel oils. The pupal transformation was reduced to 70.71 and 50.85%; 73.97 and 52.61% of the control when larvae were fumigated with a sub-lethal concentration of essential oils (40 and 80%) of 48h-LC_{50} values of *C. limon* leaf and peel oils, respectively (for *C. limon* leaf oil F = 105.42; and for *C. limon* peel oil F = 108.33; p<0.01; Table 5). Adult emergence from the pupa was reduced to 69.54 and 31.42%; and 68.57 and 36.37% of the control when larvae were fumigated with 40 and 80% of 48h-LC_{50} of *C. limon* leaf and peel oils respectively (for *C. limon* leaf oil F = 164.03; and for *C. limon* peel oil F = 148.98; p<0.01; Table 5).

Antifeedant assay

Citrus limon leaf and peel oils reduced the consumption of food by *C. cephalonica* as antifeedant activity was found to increase with the increase in oil concentration. Consumption by 3rd instar larva was significantly reduced to

Table 2. Fumigant toxicity of *C. limon* leaf and peel oils on *C. cephalonica*

Oil	Parameter	Exposure period	LC_{50} (µl/L)	g-value	t-ratio	Heterogeneity	Regression equation	Correlation coefficient
C. limon leaf oil	Adult mortality	24h	128.32	0.26	3.74	0.33	Y = -3.21+1.45X	0.98
		48h	84.47	0.29	3.23	0.32	Y = -5.95+3.63X	0.99
	Larval mortality	24h	89.78	0.28	4.56	0.34	Y = -3.87+5.32X	0.99
		48h	52.69	0.25	3.49	0.33	Y = 2.66+4.85X	0.98
C. limon peel oils	Adult mortality	24h	149.17	0.26	3.87	0.37	Y = 3.34+1.96X	0.98
		48h	89.35	0.27	3.62	0.39	Y = -2.97+4.09X	0.99
	Larval mortality	24h	96.34	0.29	4.49	0.35	Y = -2.59+2.61X	0.99
		48h	59.28	0.27	3.78	0.36	Y = 3.21+2.97X	0.98

Table 3. Effect of *C. limon* leaf and peel oils on oviposition potential of *C. cephalonica*

Oil	Concentration	Number of larvae emerged/adult (Mean±SE)	%ODI*	F-value** (df=2,15)
Control	-	73.83±4.07 (100)	-	-
C. limon leaf oil	40% 48h-LC_{50}	40.83±3.07(63.97)	28.79	31.82
	80% 48h-LC_{50}	25.50±1.95 (36.33)	48.65	
C. limon peel oil	40% 48h-LC_{50}	42.33±2.45 (70.18)	27.12	33.22
	80% 48h-LC_{50}	27.17±1.40 (41.29)	46.19	

Values in parentheses indicate per cent change with respect to the control group
*% ODI was calculated by
% ODI = [(C-T)/(C+T)]100.
where, C = Number of eggs in control, T = Number of eggs in test,
**Significant at p<0.01

Table 4. Effect of *C. limon* leaf and peel oils on viability of *C. cephalonica* eggs

Oil	Concentration (µl/L)	Number of larvae emerged (Mean±SE)	%HIR	F-value*
Control	-	23.50±0.36(100)	-	-
C. limon leaf oil	25	18.83±0.49(80.13)	11.03	146.16
	50	13.83±0.61(58.85)	25.09	
	75	10.50±0.81(44.68)	35.29	
C. limon peel oil	25	19.00±0.42(80.85)	10.58	130.00
	50	14.50±0.63(61.70)	23.68	
	75	10.83±0.59(446.08)	36.99	

Values in parentheses indicate per cent change with respect to the control group, hatching inhibition rate (%HIR) was calculated as: %HIR = [(C-T)/C]X100,
where, C = Adults in control group, T = Adults in experimental group
*Significant at p<0.01

Table 5. Effect of *C. limon* leaf and peel oils on the development of *C. cephalonica*

Oil	Dose	Number of pupae transformed (Mean±SE)	F-value*	Number of adults emerged (Mean±SE)	F-value* (df=2,15)
Control		19.33±0.22(100)		17.50±0.23(100)	-
C. limon leaf oil	40% 48h-LC_{50}	13.67±0.32(70.71)	105.42	12.17±0.24(69.54)	164.03
	80% 48h-LC_{50}	9.83±0.26(50.85)		5.0±0.26(31.42)	
C. limon peel oil	40% 48h-LC_{50}	14.33±0.31(73.97)	108.33	12.00±0.28(68.57)	148.98
	80% 48h-LC_{50}	10.17±0.29(52.61)		6.33±0.31(36.37)	

Values in parentheses indicate per cent change with respect to the control group
*Significant at $p<0.01$

Table 6. Effect of *C. limon* leaf and peel oils on food consumption by *C. cephalonica*

Oil	Concentration (µl/gm)	Food consumed (gm) (Mean±SE)	AFA	F-value** (df=3,20)
Control	-	8.52±0.65 (100)	-	-
C. limon leaf oil	0.3	6.81±0.34 (79.92)	20.07	69.66
	0.6	5.50±0.31 (64.55)	35.45	
	1.2	3.50±0.28 (40.08)	59.92	
C. limon peel oil	0.3	6.54±0.54 (76.94)	23.04	106.38
	0.6	5.36±0.32 (62.91)	37.09	
	1.2	3.33±0.28 (39.08)	60.92	

Six replicates were set for each concentration of essential oil and control,
Values in parentheses indicate per cent change with respect to the control group
Antifeedant activity (AFA) = [C-T/C] × 100,
where, C = consumption in control group, T = consumption in experimental group,
**Significant at $p<0.01$

79.92, 64.55 and 40.08%, and 76.94, 62.91 and 39.08% of the control at 0.3, 0.6 and 1.2 µl/gm of *C. limon* leaf and peel oil respectively (For *C. limon* leaf oil F = 69.66; and for *C. limon* peel oil F = 106.38; $p<0.01$; Table 6).

DISCUSSION

In early attempts several botanical products in the form of botanical pesticides have been studied previously for their different insecticidal activities against a variety of insect pests of stored grains and products. In the present study, *C. limon* leaf and peel oils repelled adults and caused acute toxicity in adults as well as larvae of *C. cephalonica*. The repellent and rapid toxicity of the essential oils are caused due to vapour action showing their low persistence in the environment and probable neurotoxicity. Several essential oils have been known for their neurotoxicity in insect pests (Chaubey, 2012; Rani, 2012; Kumar & Tiwari, 2018; Ebadollahi *et al*., 2022). These oils interfere with neuromodulator octopamine or GABA-gated chloride channels and break the nervous system of insects by disrupting its activity (Hollingworth *et al.*, 1984; Enan, 2005; Tong & Coats, 2012).

The *C. limon* leaf and peel oils inhibit oviposition and egg hatching by vapour action in *C. cephalonica.* The essential oils of Apiaceae, Piperaceae, Myrtaceae, Poaceae, Geraniaceae, and Lamiaceae family produce similar effects on eggs (Sowmya *et al*., 2023). Different combinations of *Cedrus deodara*, *Cinnamomum camphora*, *Eucalyptus globulus*, *Cymbopogon flexuosus*, *Mentha piperita* and *Citrus aurantium* essential oils have been reported for ovicidal and developmental inhibitory effects via contact application (Jacob & Qamar, 2013). The mode of action of these volatile chemicals has not yet been established but it appears that due to suffocation and inhibition in different biosynthetic processes of insects the oviposition and developmental inhibitory activity were recorded (Don-Perdo, 1989). In a study some essential oils have been reported to reduce total protein, glycogen, and lipid contents and digestive amylase and protease enzyme activities as well as consumption index, relative consumption rate and relative growth rate in insects (Ebadollahi *et al*., 2022). *Citrus limon* leaf and peel oils reduce food consumption by larvae of *C. cephalonica.* This reflects that essential oils reduce damage to grains by feeding action, thus, reducing quantitative and qualitative losses. The

damage to grains causes deterioration and contamination in damaged grains due to microbial action as well as a reduction in protein and carbohydrate levels.

CONCLUSION

In conclusion, *C. limon* leaves and peel essential oils showed repellent, toxic, oviposition inhibitory, developmental inhibitory and antifeedant activities on rice moth, *C. cephalonica*. Since these two volatile oils are of botanical origin and are parts of the human diet, they are safe for humans. Their high fumigant action showed their low persistence in the environment, thus, eliminating residual properties. So, these *C. limon* leaves and peel essential oils can be used in development of eco-friendly formulation based on volatile organic chemicals for the management of stored grain pests.

REFERENCES

Akarca, G., and Sevik, R. 2021. Biological activities of *Citrus limon* L. and *Citrus sinensis* L. peel essential oil. *J Essent Oil-Bear Plants*, **24**(6): 1415-1427. https://doi.org/10.1080/0972060X.2021.2022000

Alam, M. Z. 1972. Pests of stored grains and other stored products and their control. *Agric Inf Res*.

Allotey, J., and Azalekor, W. 2000. Some aspects of the biology and control using botanicals of the rice moth, *Corcyra cephalonica* (Stainton), on some pulses. *J Stored Prod Res*, **36**(3): 235-243. https://doi.org/10.1016/S0022-474X(99)00045-4 PMid:10758262

Atwal, A. S., and Dhaliwal, G. S. 2008. Agricultural pests of South Asia and their management. Kalyani Publishers, New Delhi, India

Beckel, H., Lorini, I., and Lazzari, S. M. N. 2002. Resistência de *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) a inseticidas piretróides e organofosforados usados em trigo armazenado. Resumos e Atas do III Seminário Técnico do Trigo/XVII Reunião da Comissão Centro-sul Brasileira de Pesquisa de Trigo 44.

Benhalima, H., Chaudhry, M. Q., Mills, K. A., and Price, N. R. 2004. Phosphine resistance in stored-products insects collected from various grain storage facilities in Morocco. *J Stored Prod Res*, **40**: 241-249. https://doi.org/10.1016/S0022-474X(03)00012-2

Champ, B. R., and Dyte, C. E. 1977. FAO global survey of pesticide susceptibility of stored grain pests. *Bull Phytosanit de la FAO (FAO)*, **22**(2): 49-67.

Chaubey, M. K. 2012. Biological effects of essential oils against Rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). Journal of Essential Oil Bearing Plants. 15(5): 809-815. https://doi.org/10.1080/0972060X.2012.10644124

Don-Perdo, K. M. 1996. Investigation of single and joint fumigant insecticidal action of citrus peel oil components. *Pest Sci*, **46**: 79-84. https://doi.org/10.1002/(SICI)1096-9063(199601)46:1<79::AID-PS319>3.0.CO;2-8

Ebadollahi, A., Naseri, B., Abedi, Z., Setzer, W. N., and Changbunjong, T. 2022. Promising insecticidal efficiency of essential oils isolated from four cultivated eucalyptus species in Iran against the lesser grain borer, *Rhyzopertha dominica* (F.). Insects, **13**(6): Article 517. https://doi.org/10.3390/insects13060517 PMid:35735854 PMCid:PMC9224839

Elzen, G. W., and Hardee, D. D. 2003. United States Department of Agriculture-Agricultural Research Service research on managing insect resistance to insecticides. *Pest Manag Sci*, **59**: 770-776. https://doi.org/10.1002/ps.659 PMid:12846328

Enan, E. E. 2005. Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils. *Arch Insect Biochem Physiol*, **159**: 161-171. https://doi.org/10.1002/arch.20076 PMid:15986384

Farida, K., Loucif, C., Louiza, H., and Malika, B. 2023. Antimicrobial and antioxidant activities of citrus limon peel essential oils and their application as a natural preservative in fresh cream: Effects on oxidative and sensory properties. Acta Univer Cibinien Series E: Food Technol, **XXVII**(1). https://doi.org/10.2478/aucft-2023-0001

Fenemore, P. G., and Prakash, A. 1992. Applied entomology. Wiley Eastern Limited, New Delhi, India.

Hojjati, M., and Barzegar, H. 2017. Chemical composition and biological activities of Lemon (*Citrus limon*) leaf essential oil. *Nutr Food Sci Res*, **4**(4): 15-24. https://doi.org/10.29252/nfsr.4.4.3

Hollingworth, R. M., Johnstone, E. M., and Wright, N. 1984. Pesticide synthesis through rational approaches. ACS Symposium Series No. 255, American Chemical Society, Washington, DC. https://doi.org/10.1021/bk-1984-0255.ch007

Islam, M. S., and Talukder, F. A. 2005. Toxic and residual effects of *Azadirachta indica*, *Tagetes erecta* and *Cynodon dactylon* extracts against *Tribolium castaneum*. *J Plant Disease Protect*, **112**: 594-601. https://doi.org/10.1007/BF03356157

Jacob, P., and Qamar, A. 2013. Reproductive impairment and lethal effects of selected combinations of some essential oils against the rice moth, *Corcyra cecphalonica*. *Euro J Exp Bio*, **3**(3): 409-415.

Kacaniova, M., Cmikova, N., Vukovic, N. L., Veresova, A., Bianchi, A., Garzoli, S., Saad, R.B., Hsouna, A.B., Ban, Z., Vukic, M. D. 2024. *Citrus limon* essential oil: Chemical composition and selected biological properties focusing on the antimicrobial (*in vitro, in situ*), antibiofilm, insecticidal activity and preservative effect against *Salmonella enterica* inoculated in carrot. *Plants*, **13**(4): Article 524. https://doi.org/10.3390/plants13040524 PMid:38498554 PMCid:PMC10893099

Kumar, R., and Tiwari, S. N. 2018. Fumigant toxicity of essential oils against *Corcyra cephalonica* and *Sitotroga cerealella*. *Environ Ecol*, **36**(1): 33-37.

Kumar, R. R., Bhargava, D. V., Pandit, K., Goswami, S., Mukesh Shankar, S., Singh, S. P., Rai, G. K., Tara Satyavathi, C., and Praveen, S. 2021. Lipase - The fascinating dynamics of enzyme in seed storage and germination - A real challenge to pearl millet. *Food Chem*, **361**: Article 130031. https://doi.org/10.1016/j.foodchem.2021.130031 PMid:34058661

Lal, S. 1988. Saving grain after harvest. The Hindu Survey of Indian Agriculture (pp. 246-248). National Press. Madras, India.

Le Goff, André, V., Lebailly, P., Pottier, D., Périn, F., Perin, O., and Gauduchon, P. 2005. Seasonal variations of DNA-adduct patterns in open field farmers handling pesticides. *Mutat Res*, **587**(1-2): 90-102. https://doi.org/10.1016/j.mrgentox.2005.05.013 PMid:16140568

Lu, F. C. 1995. A review of the acceptable daily intakes of pesticides assessed by the World Health Organization. *Reg Toxicol Pharmacol*, **21**: 351-364. https://doi.org/10.1006/rtph.1995.1049 PMid:7480888

Miwa, Y., Mitsuzumi, H., Sunayama, T., Yamada, M., Okada, K., Kubota, M., …, Kibata, M. 2005. Glucosyl hesperidin lowers serum triglyceride level in hypertriglyceridemic subjects through the improvement of very low-density lipoprotein metabolic abnormality. *J Nutr Sci Vitaminol*. **51**(6): 460-470. https://doi.org/10.3177/jnsv.51.460 PMid:16521708

Muniz, J. A., McCauley, L., Scherer, J., Lasarev, M. R., Koshy, M., Kow, Y. W., Valle Nazar-Stewart, and Kisby, G. E. 2008. Biomarkers of oxidative stress and DNA damage in agricultural workers: a pilot study. *Toxicol Appl Pharmacol*, **227**(1): 97-107. https://doi.org/10.1016/j.taap.2007.10.027 PMid:18086483

Osman, N. 1984. Assessment of damage by the rice moth *Corcyra cephalonica* (St.) on different grains at four levels of moisture content. 1984. In Proc. 7th ASEAN Tech. Seminar on Grain Post Harvest Technol, 55-61pp.

Perera, A. G. W. U., Karunaratne, M. M. S. C., and S.D.M. Chinthaka. 2021. Insecticidal activity of bis (methylthio) methane based volatile extract of *Olax zeylanica* (L.) against *Sitophilus zeamais* (L.) and *Corcyra cephalonica* (Stainton). *Ind Crop Prod*, **169**: Article 113635. https://doi.org/10.1016/j.indcrop.2021.113635

Rani, P. U. 2012. Fumigant and contact toxic potential of essential oils from plant extracts against stored product pests. *J Biopest*, **5**(2): 120-128. https://doi.org/10.57182/jbiopestic.5.2.120-128

Regnault-Roger, C. 1997. The potential of botanical essential oils for insect pest control. *Integr Pest Manag Rev*, **2**: 25-34. https://doi.org/10.1023/A:1018472227889

Roopa, M. S., Rhetso, T., Shubharani, R., and Sivaram, V. 2021. Insecticidal potentials of dry powder and solvent extracts of *Tithonia diversifolia* (Hemsl.) A. gray flower against rice meal moth, *Corcyra cephalonica* (Stainton). *Acta fytotechn zootechn*, **24**(2): 94-100. https://doi.org/10.15414/afz.2021.24.02.94-100

Russel, R. M., Robertson, J. L., and Savin, S. A. 1977. POLO: A new computer programme for probit analysis. *Bull Entomol Soc Ame*, **23:** 209-213. https://doi.org/10.1093/besa/23.3.209

Samanta, S., and Yadav, U. 2021. Efficacy of indigenous plant products on *Corcyra cephalonica* (Stainton) in stored rice grain. *Pharm. Innov*, **10**(7): 97-103.

Shaaya, E., Kostjukovski, M., Eilberg, J., and Sukprakarn, C. 1997. Plant oils as fumigants and contact insecticides for the control of stored-product insects. *J Stored Prod Res*, **33**: 7-15. https://doi.org/10.1016/S0022-474X(96)00032-X

Simoniello, M. F., Kleinsorge, E. C., Scagnetti, J. A., Grigolato, R. A., Poletta, G. L., and Carballo, M. A. 2008. DNA damage in workers occupationally exposed to pesticide mixtures. *J Appl Toxicol*, **28**(8): 957-965. https://doi.org/10.1002/jat.1361 PMid:18636400

Sokal, R. R., and Rohlf, F. J. 1973. Introduction to biostatistics (pp. 165, 231, 289). Freeman WH, San Francisco.

Sowmya, M., Bindhu, O. S., Subaharan, K., Vinay, K. T. M., Senthoorraja, R., Varshney, R., and Chalapathi, R. N. B. V. 2023. Toxicity, Ovipositional behaviour and electrophysiological response of rice moth, *Corcyra cephalonica* (Stainton) adults to essential Oils. *Indian J Entomol*.

Taktak, O., Ameur, R. B., Youssef, S. B., Pieters, L., Foubert, K., and Allouche, N. 2021. Chemical composition and biological activities of essential oils and organic extracts from fresh and sun-dried *Citrus limon* peels. *Chem Africa*, **4**(1): 51-62. https://doi.org/10.1007/s42250-020-00212-w

Tong, F., and Coats, J. R. 2012. Quantitative structure-activity relationship of monoterpenoid binding activities to the house flies GABA receptor. *Pest Manag Sci*, **68**: 1122-1129. https://doi.org/10.1002/ps.3280 PMid:22461383

Tooba, H., Usmani, N. F., and Abbas, T. 2005. Screening of plant leaves as grain protectants against *Tribolium castaneum* during storage. *Pak J Bot*, **37**(1): 149-153.

UNEP. 2000. The Montreal Protocol on substances that deplete the ozone layer. Nairobi (Kenya): United Nations Environment Programme.

WMO. 1991. Scientific assessment of ozone depletion: World Meteorological Organization Report No. 25, World Meteorological Organization of the United Nations, Geneva.