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Long-term efficacy of nineteen essential oils against Corcyra cephalonica (Stainton), Sitotroga cerealella (Olivier) and Callosobruchus chinensis (Linnaeus)

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ABSTRACT: Experiments were conducted to study the long- term bio-efficacy and fumigant toxicity of nineteen essential oils of *Curcuma longa, Cymbopogon flexuosus, Cymbopogon martini, Cymbopogon winterianus, Eucalyptus citriodora, Eucalyptus globulus, Ferula asafoetida, Lavandula angustifolia, Lippia alba, Mentha arvensis, Mentha cardiaca, Mentha citrata, Mentha piperita, Mentha spicata, Pelargonium graveolens, Pinus roxburghii, Ocimum basilicum, Salvia officinalis and Tanacetum cinerariifolium against Corcyra cephalonica (Stainton), Sitotroga cerealella (Olivier) and Callosobruchus chinensis (Linnaeus) at the concentration of 0.1, 0.2, 0.3, and 0.4 percent (v/w). The study revealed that all the essential oils were highly effective against target insect pests of stored grains and they can be utilized for its protection. The essential oils of <i>M. arvensis, F. asafoetida* and *L. angustifolia* were highly effective against *C. cephalonica* at all the concentrations. The oils of *M. arvensis, M. spicata, M. piperita, C. winterianus, T. cinerariifolium, O. basilicum* and *L. alba* were also highly effective against *S. cerealella*. All the essential oils showed high efficacy against *C. chinensis* at all concentration as they caused 100 per cent mortality of it. The fumigant toxicity of some oils persisted for 263, 234 and 175 days against *C. cephalonica, S. cerealella* and *C. chinensis,* respectively. The findings suggest that all these essential oils may be exploited to prevent the post-harvest infestation of stored grains.

Key words: Bio-efficacy, Callosobruchus chinensis, Corcyra cephalonica, essential oils, , fumigant toxicity, Sitotroga cerealella

Insect pests are known to cause extensive qualitative and quantitative losses to grain during storage. On the basis of severity of damage, they are classified as major and minor pests which can be further divided into primary and secondary pest. Among these, major primary pests are of great concern as they are capable to initiate infestation in whole grains which paves the way for feeding by secondary pests. In majority of storage system, Sitophilus oryzae (rice weevil), Rhyzopertha dominica (lesser grain borer), Corcyra cephalonica (rice moth), Sitotroga cerealella (Angoumois grain moth) and Callosobruchus chinensis (pulse beetle) have been recognized to be major primary pest. Several types of traditional and scientific methods are employed in different countries to prevent the losses from these insect pests. However, most of the techniques fail to provide adequate protection in long term storage. Presently insecticides and fumigants are being used

at different level as prophylactic and curative measures, but their efficacy is not so encouraging due to development of resistance and other factors. It has also been widely recognized that these chemical methods of control have certain drawbacks and adverse effect on the environment and health of the consumers due to their faulty application and residual toxicity. Under such condition it is very important to investigate effective non-pesticidal control measures which are safe to environment and human health.

In the last five decades it has been proved beyond doubt that secondary metabolites and volatiles present in plants of family Lamiaceae, Brassicaceae, Zingiberaceae, Compositae, Meliaceae, Myrtaceae, Pinaceae, Lauraceae, Rutaceae, Poaceae, Labiatae and Piperaceae etc., are very effective against insect pests of stored grain and several species including *Mentha* spp., *Syzygium aromaticum, Thymus vulgaris, Curcuma longa, Acorus calamus, Allium sativum, Azadirachta indica, Cedrus deodara, Chenopodium ambrosioides, Cinnamomum*

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camphora, Cymbopogon citratus, Cymbopogon nardus, Cymbopogon winterianus, Salvia bracteata, Pogostemon patchouli, Rosmarinus officinalis, Piper nigrum, Lantana camara, Pinus longifolia, Ocimum basilicum, Murraya koenigii, Tanacetum cinerariifolium etc. have adequate potential for protection of stored grain (Singh et al., 1989;1995; Shaaya et al., 1990, 1997; Tunc et al., 2000; Tripathi et al., 2002; Lee et al., 2002, 2004; Ngamo et al., 2007; Rajendran and Sriranjini, 2008; Tewari and Tiwari, 2008; Geetanjly et al., 2016; Gangwar and Tiwari, 2017; Kumar and Tiwari, 2017; 2018a; 2018b; Joshi and Tiwari, 2019; Sharma and Tiwari, 2021b; Tewari and Tiwari, 2021a; 2021b; Kumari and Tiwari, 2022). The mode of action of these oils are known to vary. These oils may be toxic (Don-Pedro, 1996; Koul and Dhaliwal, 2001; Clemente et al., 2003), repellant (Pascual and Ballesta, 2003), antifeedant, ovicidal, or oviposition inhibitors against insect pest. The pesticidal properties in these plants have found to be due to presence of certain compounds such as cyanohydrins in *M. esculenta*, monoterpenoids (Coats et al., 1991), sulphur compounds, thiocyanates, 1,8-cineole in the essential oil of Eucalyptus spp., borneol in L. nobilis, linalool in Ocimum spp., eugenol in clove oil (S. *aromaticum*), thymol in garden thyme (*T. vulgaris*) and menthol in various species of mint (Mentha species), limonene in *Citrus* spp., myrcene in *C*. longa, carvone in C. carvi, asarone in A. calamus, glucosinolates in plants belonging to Brassicaceae, thiosulfinates in Allium spp., methyl salicylate in Securidaca longipedunculata and carvacrol as well as β-thujaplicin in *T. dolabrata*. (Behal, 1998; Isman, 1999; Baskaran and Janarthanan, 2000; Verma et al., 2001; Bhargava et al., 2005; Ghosal et al., 2005; Gangwar and Tiwari, 2017; Sharma and Tiwari, 2021a). Although, pest control properties of abovementioned plants have been investigated in various studies, we do not have much information on their long-term efficacy which is prerequisite for their use in grain protection. Also, their efficacy is not well known against all the major primary and secondary pests of stored grain which is very much desirable in many storage systems. Very recently, Kumari and Tiwari, 2022 studied the long-term bio-efficacy and fumigant toxicity of essential oils extracted from M.

cardiaca, T. cinerariifolium, O. basilicum, L. alba, F. asafoetida, S. officinalis and L. angustifolia against R. dominica, S.oryzae and T. castaneum at 0.1, 0.2, 0.3, and 0.4 percent (v/w) concentration and reported that essential oils of M. cardiaca and O. basilicum completely checked the progeny production of S.oryzae for 180 days at all four concentrations while such pronounced effect was exhibited by T.cinerariifolium at 0.2-0.4 per cent; L. angustifolia at 0.3-0.4 per cent and L. alba at 0.4 per cent only. In case of *R. dominica*, the oils of *M*. cardiaca, T. cinerariifolium, O. basilicum and F. asafoetida completely checked the F1 progeny for 220 days at all four concentrations while complete inhibition was achieved by L. angustifolia at 0.2-0.4 percent and L. alba and S. officinalis at 0.3-0.4 percent. On the other hand, O. basilicum completely checked the reproduction of T. castaneum at 0.1-0.4 percent for 90 days while such high efficacy was shown by M. cardiaca at 0.2-0.4 per cent and T. cinerariifolium and L. angustifolia at 0.4 per cent. The long-term efficacy of above-mentioned oils is not known against other major primary pest of stored grain due to which present investigation was undertaken to study their efficacy against C. cephalonica, S. cerealella and C. chinensis along with some other essential oils.

MATERIALS AND METHODS

The experiments were conducted in Post-Harvest Entomology Laboratory of Department of Entomology, G.B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar (Uttarakhand).

Culture of Insects

Pure culture of test insects was developed in the control room maintained at $27^{\circ}C\pm 1$ temperature and $70\pm 5\%$ relative humidity. Plastic jars of about 1.0 kg capacity were used for rearing purpose. At the center of the lid a hole of 1.8 cm diameter was made and covered with 30 mesh copper wire net to facilitate aeration in the jar. Rice moth,*C. cephalonica* was cultured on broken maize, while paddy and gram were used to rear *S. cerealella* and *C. chinensis*, respectively. Before use, grains were disinfected in the oven at 60°C for 12 hrs. After disinfestation the moisture content of the grain was measured and raised to 13.5 per cent by mixing water in the grain. The quantity of water required to raise the moisture content was calculated by using following formula as described by Pixton (1967).

Quantit Where,	y of w	vater to l	be added = $\frac{W_1(M_2 - M_1)}{100 - M_2}$
	W_1	=	Initial weight of grains
	M_1	=	Initial moisture content
	$\dot{M_2}$	=	Final moisture content

After mixing the water in grain it was kept in closed polythene bags for a week so that moisture content of grain could equilibrate. The grain was then filled in plastic jar and 100 adults were released in each jar after which it was kept in incubator. To prepare the culture medium of *C. cephalonica*, maize grains were grounded to 3-4 pieces. These broken pieces were disinfected at 100°C for 30 min and then treated with 1% formalin and 5g yeast powder was mixed in it. The medium was filled in plastic jars and adults were released in it. First generation adults (0-7 days old) were used for experimental purpose.

Procurement of Oils

In order to ensure the purity of the oils selected for

the study they were procured from the Medicinal and Aromatic Plants Research and Development Centre, Haldi (Pantnagar) and Central Institute of Medicinal and Aromatic Plants, Field Station, Nagla and Central Institute of Medicinal and Aromatic Plants, Lucknow. The common and scientific name of plants, the oils of which were used in the experiment is provided in Table1.

Preparation of Grain

All fumigation experiments on *C. cephalonica* and *S. cerealella*, were conducted on untreated graded seed of wheat variety PBW-343. Before use, the grains were disinfested by keeping them in the oven at 60°C for 12 hrs. After disinfestation the moisture content of grain was measured and raised to 13.5 per cent by adding water in the required quantity to the grain. To ensure the even distribution of water, the grain was spread on a platform and water was sprayed on it using hand sprayer. The grain was then mixed thoroughly and closed in polythene bags for a week for equilibration of moisture content of grain. The grain (50g) was then filled in 100ml capacity plastic vials to perform experiment.

Details of Experiment Conducted

The experiment was conducted on *C. cephalonica,S. cerealella* and *C. chinensis* to evaluate the efficacy

 Table1: Common and scientific name of plants the essential oil of which was used to study fumigant toxicity

Sl. No.	Scientific name	Common name	Family	Concentrations % (v/w)
1	Curcuma longa Linn.	Turmeric	Zingiberaceae	0.1, 0.2, 0.3, 0.4
2	Cymbopogon flexuosus (DC)Stapf.	Lemongrass	Poaceae	0.1, 0.2, 0.3, 0.4
3	Cymbopogon martini (Roxb.) Wats.	Palmarosa	Poaceae	0.1, 0.2, 0.3, 0.4
4	Cymbopogon winterianus Jowitt	Citronella	Poaceae	0.1, 0.2, 0.3, 0.4
5	Eucalyptus citriodora Hook.	Nilgiri	Myrtaceae	0.1, 0.2, 0.3, 0.4
6	Eucalyptus globulus Labill.	Eucalyptus	Myrtaceae	0.1, 0.2, 0.3, 0.4
7	Ferula asafoetida Linn.	Ferula	Apiaceae	0.1, 0.2, 0.3, 0.4
8	Lavandula angustifoliaMill.	Lavender	Lamiaceae	0.1, 0.2, 0.3, 0.4
9	Lippia alba	Bushymatgrass	Verbenaceae	0.1, 0.2, 0.3, 0.4
10	Mentha arvensis Linn.	Mint	Lamiaceae	0.1, 0.2, 0.3, 0.4
11	Mentha cardiaca (S.F. Gray) Bak.)	Scotch spearmint	Lamiaceae	0.1, 0.2, 0.3, 0.4
12	Mentha citrata Ehrh.	Bergamot mint	Lamiaceae	0.1, 0.2, 0.3, 0.4
13	Mentha piperita Linn.	Peppermint	Lamiaceae	0.1, 0.2, 0.3, 0.4
14	Mentha spicata Linn.	Spearmint	Lamiaceae	0.1, 0.2, 0.3, 0.4
15	Pelargonium graveolens L' Heritier	Geranium	Geraniaceae	0.1, 0.2, 0.3, 0.4
16	Pinus roxburghii Sarg.	Pine	Pinaceae	0.1, 0.2, 0.3, 0.4
17.	Ocimum basilicumLinn.	Tulsi	Lamiaceae	0.1, 0.2, 0.3, 0.4
18.	Salvia officinalis Linn.	Common sage	Lamiaceae	0.1, 0.2, 0.3, 0.4
19	Tanacetum cinerariifoliumSch.Bip.	Tanacetum	Asteraceae	0.1, 0.2, 0.3, 0.4

of essential oils at different concentrations of 0.1, 0.2, 0.3 and 0.4 percent as mentioned in Table1. The experiment was conducted under controlled conditions at $27+1^{\circ}$ C temperature and 70+5 per cent relative humidity. Fifty-gram wheat grains of variety PBW-343 (moisture content 13.5 per cent) was filled in each plastic vial. In case of C. chinensis gram (Cajanus cajan) was filled in vials. Each treatment was replicated 3 times. Untreated grain was used as control. Different set was prepared for each insect. Ten adults of C. cephalonica, S. cerealella or C. chinensis (0-7 days old) were released in each vial. After 24 hrs. of releasing the insects measured quantity of oil was poured on the absorbing mat, which was then placed inside the vial between the grains. Screw cap of vials was then tightly closed. In case of C. cephalonica and S. cerealella, oil treated mat was inserted inside the vial before releasing the insects.

Insects were then allowed to feed and breed on the treated grain. The insects emerging in the vial were counted after appearance of visible symptoms of infestation. The experiments were performed twice in preliminary and confirmatory test to confirm the bio-efficacy of essential oils. The last observations in case of preliminary and confirmatory tests were recorded at 263 and 150, 234 and 100 and 102 and 175 days after fumigation in case of *C. cephalonica,S. cerealella* and *C. chinensis,* respectively, after which the experiment was terminated.

RESULTS AND DISCUSSION

The bio-efficacy of different plant oils against *C. cephalonica* is presented in Table 2 which indicates that the oil of *M. arvensis*, *F. asafoetida* and *L. angustifolia* were highly effective against this insect at 0.1-0.4 percent as no adult emerged from grain treated with these oils in both the tests.Similar efficacy was also exhibited by oils of *M. spicata*, *M. piperita*, *M. cardiaca*, *M. citrata*, *P. graveolens*, *T. cinerariifolium*, *L. alba* at this level in confirmatory test. The essential oils of *F. asafoetida* and *L. angustifolia* have also been reported to have similar efficacy against *R. dominica* at 0.1-0.4 and 0.2-0.4 percent, respectively (Kumari and Tiwari,

2022). In the same study, the oil of L. angustifolia was also very effective against S. oryzae at 0.3 and 0.4 and T. castaneum at 0.4 percent. In the present investigation, the essential oils of M. citrata, T. cinerariifolium, L. alba and S. officinalis showed very high efficacy at 0.2-0.4 percent in both the studies. Kumari and Tiwari (2022) have reported that the oil of L. alba and S. officinalis is also effective against R. dominica at 0.3 and 0.4 percent. In the present study, the oils of M. spicata, M. piperita, P. roxburghii and E. globulus completely inhibited the progeny production of C. cephalonica in both the studies at 0.3-0.4 percent. Detrimental effect of E. globulus oil on egg hatchability was also reported by Pathak and Krishna (1991). Present study revealed that the essential oil of M. cardiaca was highly effective against this insect at 0.2 and 0.4 percent. This oil was also reported to be highly effective against S. oryzae, R. dominica and T. castaneum at 0.1, 0.2, 0.3 and 0.4 percent (Kumari and Tiwari, 2022). The essential oil of C. flexuosus was highly effective at 0.4 percent in the present study. Bhargava et al. (2005) found feeding deterrent activity of C. *flexuosus* oils on sorghum seeds at 1.0ml/100g seeds for 72hrs. Similarly, Michaelraj et al. (2006) observed maximum inhibition of hatching of eggs of C. cephalonica at 250ppm and 96.6 percent mortality of C. cephalonica at 2.5ml/ kg on stored maize. The oils of *M. spicata*, *M.* piperita, M. cardiaca, M. citrata, P. graveolens, T. cinerariifolium, L. alba completely checked progeny production in confirmatory test at 0.1-0.4 percent while E. citriodora showed efficacy at 0.4 percent. Insecticidal activity of E. citriodora was also reported by Ngamo et al., 2004.

The bio-efficacy of essential oils against *S. cerealella* is presented in Table 3. which indicates that oils of *M. arvensis*, *M. spicata*, *M. piperita*, *C. winterianus*, *T. cinerariifolium*, *O. basilicum*, *L. alba* were highly effective at 0.1-0.4 percent as no adult emerged from these treatments. The essential oils of *M. arvensis*, *M. spicata* and *M. piperita* were also reported to be highly effective against *R. dominica* (Tewari and Tiwari, 2021b). Kumari and Tiwari (2022) reported that the oil of *O. basilicum* was effective against *S. oryzae*, *R. dominica and T. castaneum* while *T.*

Essential oils	Dose		Preliminar	v test	Confirmatory test		
	(%) v/w	Number	Davs	Number	0/0	Davs	
	()0) ////	of adults	Inhibition	after	of adults	Inhibition	after
		emerged		fumigation	emerged		fumigation
M. arvensis	0.1	0.0±0.0	100	263	0.0±0.0	100	150
M. arvensis	0.2	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. arvensis	0.3	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. arvensis	0.4	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. spicata	0.1	2.3±1.5	88.3	213	0.0 ± 0.0	100	150
M. spicata	0.2	2.3 ± 2.3	88.3	213	0.0 ± 0.0	100	150
M. spicata	0.3	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. spicata	0.4	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. piperita	0.1	23.0±15.0	-16.8	263	0.0 ± 0.0	100	150
M. piperita	0.2	23.0±23.0	-16.8	263	0.0 ± 0.0	100	150
M. piperita	0.3	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. piperita	0.4	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
C. winterianus	0.1	17.2±5.5	12.7	263	1.7±1.7	94.6	150
C. winterianus	0.2	17.3±10.0	12.2	263	0.0 ± 0.0	100	150
C. winterianus	0.3	0.3 ± 0.3	98.5	263	0.0 ± 0.0	100	150
<i>C</i> winterianus	0.4	9.7 ± 5.9	50.8	263	0.0 ± 0.0	100	150
P roxburghii	0.1	27.0 ± 14.0	-37.1	263	6.0 ± 0.60	80.8	150
P roxburghii	0.2	2.3 ± 1.5	88.3	213	0.0 ± 0.0	100	150
P roxburghii	0.3	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
P roxburghii	0.4	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
C longa	0.1	29 0+7 0	-47.2	263	6 3+3 5	80.8	150
C longa	0.2	97+52	50.8	263	9.0+1.2	71.2	150
C longa	0.3	9.0+1.5	54.3	213	13+13	95.8	150
C longa	0.5	15 7+3 5	20.3	263	1.5=1.5	94.6	150
M cardiaca	0.1	0.3+0.3	98.5	120	0.0+0.0	100	150
M. cardiaca	0.2	0.0+0.0	100	263	0.0+0.0	100	150
M. cardiaca	0.3	5.0+4.5	74.6	203	0.0 ± 0.0	100	150
M. cardiaca	0.5	0.0 ± 1.0	100	263	0.0 ± 0.0	100	150
M. citrata	0.1	6 0+5 5	69.5	213	0.0+0.0	100	150
M. citrata	0.2	0.0+0.0	100	263	0.0+0.0	100	150
M. citrata	0.3	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
M. citrata	0.5	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150
C flexuosus	0.1	12.0+3.1	39.1	263	0.0 ± 0.0	100	150
C flexuosus	0.2	1 70+0 9	91.4	213	23+23	92.7	150
C flexuosus	0.3	12.0+6.40	39.1	263	8 7+5 5	72.7	150
C flexuosus	0.5	0.0 ± 0.0	100	263	0.7 ± 0.0	100	150
P graveolens	0.1	11 7+1 9	40.6	203	0.0 ± 0.0	100	150
P graveolens	0.1	13+13	93.4	213	0.0 ± 0.0	100	150
P graveolens	0.3	3.0+1.7	84.8	213	0.0 ± 0.0	100	150
P graveolens	0.5	3.0 ± 1.7 3.0 ± 2.5	84.8	213	0.0 ± 0.0	100	150
C martini	0.1	19.0 ± 2.5	3.6	263	0.0 ± 0.0	100	150
C. martini	0.1	10.0 ± 0.2	49.2	263	0.0 ± 0.0	100	150
C. martini	0.2	18.3 ± 7.2	7.1	263	0.0 ± 0.0	100	150
C. martini	0.5	11 7+4 9	40.6	263	1.00 ± 0.0	96.8	150
T cinerariifolium	0.1	11 3+8 10	42.6	263	0.0+0.0	100	150
T cinerariifolium	0.2	0.0+0.0	100	263	0.0+0.0	100	150
T. cinerariifolium	0.2	0.0+0.0	100	263	0.0+0.0	100	150
T. cinerariifolium	0.5	0.0±0.0	100	203	0.0+0.0	100	150
0 hasilicum	0.1	0.0+0.0	100	263	0.0+0.0	100	150
O basilicum	0.2	0.0 ± 0.0	100	263	0.0 ± 0.0	100	150

 Table 2: Number of adults of C. cephalonica emerged in grain treated with different essential oils in preliminary and confirmatory test

O. basilicum	0.3	$0.0{\pm}0.0$	100	263	2.30±2.3	92.7	150
O. basilicum	0.4	$0.0{\pm}0.0$	100	263	87.5±5.5	-179.6	150
L. alba	0.1	4.70±3.3	76.1	160	$0.0{\pm}0.0$	100	150
L. alba	0.2	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
L. alba	0.3	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
L. alba	0.4	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
S. officinalis	0.1	$0.0{\pm}0.0$	100	263	0.30±0.30	99	150
S. officinalis	0.2	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
S. officinalis	0.3	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
S. officinalis	0.4	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
F. asafoetida	0.1	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
F. asafoetida	0.2	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
F. asafoetida	0.3	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
F. asafoetida	0.4	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
L. angustifolia	0.1	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
L. angustifolia	0.2	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
L. angustifolia	0.3	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
L. angustifolia	0.4	$0.0{\pm}0.0$	100	263	0.0 ± 0.0	100	150
E. citriodora	0.1	16.3±9.50	17.3	263	4.7±3.3	85	150
E. citriodora	0.2	11.3±2.90	42.6	263	5.3±5.3	83.1	150
E. citriodora	0.3	11.0±3.60	44.2	263	4.3±2.2	86.3	150
E. citriodora	0.4	12.0±2.90	39.1	263	0.0 ± 0.0	100	150
E. globulus	0.1	16.7±5.50	15.2	263	2.7±2.7	91.4	150
E. globulus	0.2	1.00 ± 1.00	94.9	160	$0.0{\pm}0.0$	100	150
E. globulus	0.3	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
E. globulus	0.4	$0.0{\pm}0.0$	100	263	$0.0{\pm}0.0$	100	150
Untreated	_	19.7±3.0		263	31.3±3.5		150

Table 3: Number of adults of S. cerealella emerged in grain treated	I with different essential oil in preliminary and							
confirmatory test								

Essential oils	Dose		Preliminar	y test	Confirmatory test		
	(%) v/w	Number of adults emerged	% Inhibition	Days after fumigation	Number of adults emerged	% Inhibition	Days after fumigation
M. arvensis	0.1	0.0±0.0	100	234	0.0±0.0	100	100
M. arvensis	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. arvensis	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. arvensis	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. spicata	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. spicata	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. spicata	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. spicata	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. piperita	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. piperita	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. piperita	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. piperita	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. winterianus	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. winterianus	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. winterianus	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. winterianus	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
P. roxburghii	0.1	18.3±18.3	59.3	234	3.7±2.0	65.4	100
P. roxburghii	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
P. roxburghii	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
P. roxburghii	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. longa	0.1	0.0 ± 0.0	100	234	2.3±1.2	78.5	100

C. longa	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. longa	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
C. longa	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. cardiaca	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
M. cardiaca	0.2	0.0 ± 0.0	100	234	3.0±1.5	72	100
M. cardiaca	0.3	0.0+0.0	100	234	0.0±0.0	100	100
M cardiaca	0.4	0 0+0 0	100	234	0 0+0 0	100	100
M citrata	0.1	0.0+0.0	100	234	0.0+0.0	100	100
M. citrata	0.1	0.0±0.0	100	234	8 7+1 9	18 7	100
M. citrata	0.2	0.0±0.0	100	234	0.0+0.0	100	100
M. citrata	0.5	0.0±0.0	100	234	0.0 ± 0.0	100	100
C flarmosus	0.4	0.0 ± 0.0	100	234	10.7+3.9	0	100
C. floruosus	0.1	0.0 ± 0.0	100	234	10.7 ± 3.9 12 7±4 0	187	100
C. flexuosus	0.2	0.0 ± 0.0	100	234	12.7 ± 4.9 2.0 ±1.7	-18.7	100
C. flexuosus	0.3	0.0 ± 0.0	100	234	3.0 ± 1.7	100	100
C. Jiexuosus	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	25.2	100
P. graveolens	0.1	0.0 ± 0.0	100	234	8.0 ± 1.0	25.2	100
P. graveolens	0.2	0.0 ± 0.0	100	234	14.3 ± 8.1	-33.6	100
P. graveolens	0.3	0.0 ± 0.0	100	234	9.0±7.1	15.9	100
P. graveolens	0.4	0.0±0.0	100	234	12./±10./	-18.7	100
C. martini	0.1	0.0±0.0	100	234	25.7±4.5	-140.2	100
C. martini	0.2	0.0 ± 0.0	100	234	21.0±4.7	-96.3	100
C. martini	0.3	0.0 ± 0.0	100	234	37.7±2.9	-252.3	100
C. martini	0.4	0.0 ± 0.0	100	234	26.3 ± 3.9	-145.8	100
T. cinerariifolium	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
T. cinerariifolium	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
T. cinerariifolium	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
T. cinerariifolium	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
O. basilicum	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
O. basilicum	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
O. basilicum	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
O. basilicum	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. alba	0.1	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. alba	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. alba	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. alba	0.4	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
S. officinalis	0.1	0.0 ± 0.0	100	234	5.3 ± 2.9	50.5	100
S. officinalis	0.2	0.0 ± 0.0	100	234	5.3±5.3	50.5	100
S. officinalis	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
S. officinalis	0.4	0.0+0.0	100	234	0.0±0.0	100	100
F. asafoetida	0.1	8.3±4.9	81.6	68	26.3±8.3	-145.8	100
F asafoetida	0.2	0 0+0 0	100	234	0.0 ± 0.0	100	100
F asafoetida	0.3	0.0+0.0	100	234	3.3 ± 1.7	69.2	100
F asafoetida	0.4	0.0+0.0	100	234	2.0+2.0	81.3	100
L angustifolia	0.1	0.0±0.0	100	234	2.0-2.0 2.0+2.0	81.3	100
L. angustifolia	0.1	0.0±0.0	100	234	0.0+0.0	100	100
L. angustifolia	0.2	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. ungustifolia	0.3	0.0 ± 0.0	100	234	0.0 ± 0.0	100	100
L. ungusiijonu E. citriodora	0.4	24.7 ± 14.8	100	234	0.0 ± 0.0	28	100
E. citriodora	0.1	24.7 ± 14.0 21.7±10.7	45.1	234	20.2+5.6	20	100
E. curiodora E. cituiodora	0.2	5 2 1 0 A	27.0 00 0	234	20.3 ± 3.0	-07./ 1215	100
E. CURIOAORA	0.3	5.3 ± 4.84	88.Z	234	23.7 ± 2.9	-121.5	100
E. CIIrioaora	0.4	$50./\pm/.9$	-12./	234	22.0 ± 1.2	-105.6	100
E. globulus	0.1	5./±5./	8/.5	234	5.5 ± 2.0	09.2	100
E. globulus	0.2	0.0±0.0	100	234	0.0±0.0	100	100
E. globulus	0.3	0.0±0.0	100	234	25.0±22.6	-133.6	100
E. globulus	0.4	0.0±0.0	100	234	3.7±1.2	65.4	100
Untreated	_	45.0±8.9		234	10.7±1.5		100

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Essential oils	Dose		Prelimina	y test	Confirmatory test		
	- (%) v/w	Number	%	Days	Number	%	Days
		of adults	Inhibition	after	of adults	Inhibition	after
		emerged		fumigation	emerged		fumigation
M. arvensis	0.1	0.00 ± 0.00	100	102	0.00±0.00	100	175
M. arvensis	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. arvensis	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. arvensis	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. spicata	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. spicata	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. spicata	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. spicata	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. piperita	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. piperita	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. piperita	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. piperita	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. winterianus	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. winterianus	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. winterianus	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. winterianus	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. roxburghii	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. roxburghii	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. roxburghii	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. roxburghii	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. longa	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. longa	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. longa	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. longa	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. cardiaca	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. cardiaca	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. cardiaca	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. cardiaca	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. citrata	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. citrata	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. citrata	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
M. citrata	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. flexuosus	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. flexuosus	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. flexuosus	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. flexuosus	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. graveolens	0.1	0.00 ± 0.00	100	102	0.00±0.00	100	175
P. graveolens	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. graveolens	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
P. graveolens	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. martini	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. martini	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. martini	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
C. martini	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	1/5
1. cinerariifolium	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
1. cinerariifolium	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	1/5
1. cinerariifolium	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
1. cinerariifolium	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	1/5
O. basilioum	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	1/5
\cup <i>pasuicum</i>	U 2	0.00 ± 0.00	100	107	0.00+0.00	100	1/2

 Table 4: Number of adults of C. chinensis emerged in grain treated with different essential oils in preliminary and confirmatory test

O. basilicum	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
O. basilicum	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. alba	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. alba	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. alba	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. alba	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
S. officinalis	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
S. officinalis	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
S. officinalis	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
S. officinalis	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
F. asafoetida	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
F. asafoetida	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
F. asafoetida	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
F. asafoetida	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. angustifolia	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. angustifolia	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. angustifolia	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
L. angustifolia	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. citriodora	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. citriodora	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. citriodora	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. citriodora	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. globulus	0.1	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. globulus	0.2	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. globulus	0.3	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
E. globulus	0.4	0.00 ± 0.00	100	102	0.00 ± 0.00	100	175
Untreated	_	732±81.19		102	364±17.58		175

cinerariifolium oil was effective against R. dominica. The essential oil of C. winterianus is also known to exhibit knockdown effect against this insect (Krishnarajah et al., 1985). The essential oils of C. longa, M. cardiaca, M. citrata, C. flexuosus, P. graveolens, C. martini, S. officinalis and L. angustifolia oil were found effective at 0.1-0.4 percent in preliminary study while in confirmatory tests only P. roxburghii, C. longa and L. angustifolia oil were highly effective at 0.2-0.4 percent against this insect. The oil of P. roxburghii has also reported to be highly effective at 0.1 to 0.4 percent (Tewari and Tiwari, 2021b) and at 0.05 to 0.1 percent (Joshi and Tiwari, 2019) against R. dominica. Yalamanchilli and Punukollu (2000) observed that the oil obtained from the leaves of C. longa could effectively protect the seeds at a low concentration of 2 percent (w/w)under the experimental conditions. Turmeric oil was also found effective in deterring the attack of stored grain pest, C. chinensis on four pulses and wheat grains. The oil also proved toxic in contact and fumigant assay when applied on rice, wheat, wheat flour to control R. dominica, S. oryzae and T.

castaneum (Tripathi et al., 2002). The adults of R. dominica were highly susceptible in contact action with LD₅₀ value of 36.71 µg/ml whereas S. oryzae adults were susceptible in fumigant assay with LC_{50} value of 11.36 mg/l of air. At 5.2 mg/cm² dose oviposition and egg hatchability was reduced by 72 and 80 percent in T. castaneum and showed >81 percent antifeedant activity to R. dominica, S. oryzae and T. castaneum at 40.5 mg/g food dose. The C. *longa* oil was reported to be highly effective against R. dominica as it inhibited 98.3 to 99.4 and 92.9 to 99.8 percent progeny at 0.1 to 0.4 percent dose during first and third screening (Tewari and Tiwari, 2021b). This oil was also found effective, inhibiting 98.8 to 100 percent progeny of R. dominica at 0.05 to 0.1 percent (Gangwar and Tiwari, 2017; Joshi and Tiwari, 2019). The essential oils of *M. cardiaca*, M. citrata and S. officinalis completely inhibited progeny production at 0.3-0.4 percent in present study while E. globulus and F. asafoetida were effective at 0.2 percent. The essential oil of C. flexuosus was highly effective against S. cerealella at 0.4 percent in both the studies.

The bio-efficacy of different essential oils against C. chinensis is presented in Table 4 which indicate that all the oils were highly effective against this insect at 0.1-0.4 percent as no adults emerged from treated grains in both the tests, resulting in complete inhibition of test insects. On the other hand, 732 and 364 adults emerged from untreated grains after 102 and 175 days in preliminary and confirmatory test, respectively. Vapour toxicity and strong repellent activity of Mentha arvensis oil on Callosobruchus spp., has been reported in previous studies (Ahmed and Eapen, 1986 and Tripathi et al., 2000). Tewari and Tiwari (2021a) reported high efficacy of this oil against S. oryzae at 0.2 and 0.4 percent causing 93.6 and 95.9 percent inhibition. They classified *M. spicata* oil highly effective at 0.2, 0.3 and 0.4 percent due to 97.2, 97.7 and 98.0 percent inhibition of F1 progeny. The oil of P. roxburghii was also found highly effective in their study at 0.3 and 0.4 percent suppressing almost 99.1 and 100 percent progeny, respectively. Efficacy of citrus clean (composed of citronella oil, pine oil and natural oils from lemongrass and marigold) was tested against C. chinensis in cowpea by Dwivedi and Kumari (2000) who reported reduction in the oviposition, 66.65 percent egg mortality and 100 percent repellency. Deterrent activity of turmeric oil was also observed by Yalamanchilli and Punukollu (2000) on four pulses and wheat grains. Fumigant toxicity of Cymbopogon citratus (lemongrass) was observed by Gbolade and Adebayo (1993) on cowpea at dose 5-50µg/9.9g of seed. Paranagama et al., (2002) recorded 100 percent mortality in contact toxicity bioassay at 0.15g/l resulting in reduced oviposition and F1 adult emergence in stored cowpea. Raja and William (2008) noticed highest mortality and ovicidal activity of C. flexuosus on C. maculatus. Tewari and Tiwari (2021a) found this oil highly effective against S. oryzae at 0.4 percent by suppressing 90.7 percent progeny.Saraswathi and Rao (1987) and Lale (1991) also found efficacy of C. nardus oil against Callosobruchus spp. Srivastava et al.(1988) reported that E. globulus oil was effective in controlling C. chinensis on gram. Higher efficacy of this oil has also been reported against R. dominica at 0.8 and 1.0 percent (Rao and Prakash, 2002), 0.05

to 0.2 percent (Geetanjly *et al.*, 2016) and 0.1 to 0.4 percent (Tewari and Tiwari, 2021b).

CONCLUSION

Present study revealed many essential oils of plant origin which are highly effective against three very important insect pests under storage condition. It was also proved beyond doubt that just like any conventional fumigant, the essential oils are also capable to cause complete mortality of storage insects under airtight condition. The efficacy was found to be dose dependent, however, in many cases, they caused 100 per cent mortality at the lowest dose of 0.1 per cent. The oil of M. arvensis, F. asafoetida and L. angustifolia were highly effective against C. cephalonica at 0.1-0.4 percent while M. citrata, T. cinerariifolium, L. alba and S. officinalis showed such pronounced effect at 0.2-0.4 percent. The essential oils of M. spicata, M. piperita, P. roxburghii and E. globulus inhibited the progeny production of C. cephalonica at 0.3-0.4 percent while C. flexuosus was effective at 0.4 percent. The essential oils of M. arvensis, M. spicata, M. piperita, C. winterianus, T. cinerariifolium, O. basilicum and L. alba completely suppressed the F1 progeny of S. cerealella at 0.1-0.4 percent while oils of P. roxburghii, C. longa and L. angustifolia were highly effective at 0.2-0.4 percent and M. citrata and S. officinalis at 0.3-0.4 percent. The essential oil of F. asafoetida and E. globulus showed their effectiveness at 0.2 percent while C. flexuosus was highly effective against S. cerealella at 0.4 percent. All the above mentioned nineteen plants essential oils were highly effective against C. chinensis at 0.1-0.4 percent as no adult emerged from treated grains. The study identified many essential oils which may be used for protection of grain under storage condition. However, to make them more reliable and useful, it is necessary to study their long-term efficacy and effect on organoleptic properties of treated grain.

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