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CONTENTS

Long-term efficacy of nineteen essential oils against C*orcyra 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 *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 above-mentioned 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°C±1 temperature and 70±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).

$$\text{Quantity of water to be added} = \frac{W_1(M_2 - M_1)}{100 - M_2}$$

Where,

W_1 = Initial weight of grains
M_1 = Initial moisture content
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 60^0C 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 angustifolia*Mill.	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 basilicum*Linn.	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 cinerariifolium*Sch.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^{0}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.*

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

Essential oils	Dose	Preliminary 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	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
C. 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	9.7±5.2	50.8	263	9.0±1.2	71.2	150
C. longa	0.3	9.0±1.5	54.3	213	1.3±1.3	95.8	150
C. longa	0.4	15.7±3.5	20.3	263	1.7±1.7	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	213	0.0±0.0	100	150
M. cardiaca	0.4	0.0±0.0	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	0.4	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	2.3±2.3	92.7	150
C. flexuosus	0.3	12.0±6.40	39.1	263	8.7±5.5	72.2	150
C. flexuosus	0.4	0.0±0.0	100	263	0.0±0.0	100	150
P. graveolens	0.1	11.7±1.9	40.6	213	0.0±0.0	100	150
P. graveolens	0.2	1.3±1.3	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	0.4	3.0±2.5	84.8	213	0.0±0.0	100	150
C. martini	0.1	19.0±8.2	3.6	263	0.0±0.0	100	150
C. martini	0.2	10.0±6.1	49.2	263	0.0±0.0	100	150
C. martini	0.3	18.3±7.2	7.1	263	0.0±0.0	100	150
C. martini	0.4	11.7±4.9	40.6	263	1.00±1.00	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	0.3	0.0±0.0	100	263	0.0±0.0	100	150
T. cinerariifolium	0.4	0.0±0.0	100	263	0.0±0.0	100	150
O. basilicum	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

O. basilicum	0.3	0.0±0.0	100	263	2.30±2.3	92.7	150
O. basilicum	0.4	0.0±0.0	100	263	87.5±5.5	-179.6	150
L. alba	0.1	4.70±3.3	76.1	160	0.0±0.0	100	150
L. alba	0.2	0.0±0.0	100	263	0.0±0.0	100	150
L. alba	0.3	0.0±0.0	100	263	0.0±0.0	100	150
L. alba	0.4	0.0±0.0	100	263	0.0±0.0	100	150
S. officinalis	0.1	0.0±0.0	100	263	0.30±0.30	99	150
S. officinalis	0.2	0.0±0.0	100	263	0.0±0.0	100	150
S. officinalis	0.3	0.0±0.0	100	263	0.0±0.0	100	150
S. officinalis	0.4	0.0±0.0	100	263	0.0±0.0	100	150
F. asafoetida	0.1	0.0±0.0	100	263	0.0±0.0	100	150
F. asafoetida	0.2	0.0±0.0	100	263	0.0±0.0	100	150
F. asafoetida	0.3	0.0±0.0	100	263	0.0±0.0	100	150
F. asafoetida	0.4	0.0±0.0	100	263	0.0±0.0	100	150
L. angustifolia	0.1	0.0±0.0	100	263	0.0±0.0	100	150
L. angustifolia	0.2	0.0±0.0	100	263	0.0±0.0	100	150
L. angustifolia	0.3	0.0±0.0	100	263	0.0±0.0	100	150
L. angustifolia	0.4	0.0±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±0.0	100	150
E. globulus	0.3	0.0±0.0	100	263	0.0±0.0	100	150
E. globulus	0.4	0.0±0.0	100	263	0.0±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 with different essential oil in preliminary and confirmatory test

Essential oils	Dose	Preliminary 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	0.2	0.0±0.0	100	234	8.7±1.9	18.7	100
M. citrata	0.3	0.0±0.0	100	234	0.0±0.0	100	100
M. citrata	0.4	0.0±0.0	100	234	0.0±0.0	100	100
C. flexuosus	0.1	0.0±0.0	100	234	10.7±3.9	0	100
C. flexuosus	0.2	0.0±0.0	100	234	12.7±4.9	-18.7	100
C. flexuosus	0.3	0.0±0.0	100	234	3.0±1.7	72	100
C. flexuosus	0.4	0.0±0.0	100	234	0.0±0.0	100	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	12.7±10.7	-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	81.3	100
L. angustifolia	0.2	0.0±0.0	100	234	0.0±0.0	100	100
L. angustifolia	0.3	0.0±0.0	100	234	0.0±0.0	100	100
L. angustifolia	0.4	0.0±0.0	100	234	0.0±0.0	100	100
E. citriodora	0.1	24.7±14.8	45.1	234	7.7±2.7	28	100
E. citriodora	0.2	31.7±19.7	29.6	234	20.3±5.6	-89.7	100
E. citriodora	0.3	5.3±4.84	88.2	234	23.7±2.9	-121.5	100
E. citriodora	0.4	50.7±7.9	-12.7	234	22.0±1.2	-105.6	100
E. globulus	0.1	5.7±5.7	87.3	234	3.3±2.0	69.2	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

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

Essential oils	Dose (%) v/w	Preliminary test			Confirmatory test		
		Number of adults emerged	% Inhibition	Days after fumigation	Number of adults emerged	% Inhibition	Days after 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	175
T. cinerariifolium	0.1	0.00±0.00	100	102	0.00±0.00	100	175
T. cinerariifolium	0.2	0.00±0.00	100	102	0.00±0.00	100	175
T. cinerariifolium	0.3	0.00±0.00	100	102	0.00±0.00	100	175
T. cinerariifolium	0.4	0.00±0.00	100	102	0.00±0.00	100	175
O. basilicum	0.1	0.00±0.00	100	102	0.00±0.00	100	175
O. basilicum	0.2	0.00±0.00	100	102	0.00±0.00	100	175

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 LD_{50} 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/cm^2 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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