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CONTENTS

Bio-efficacy of some essential oils as fumigant against Lesser grain borer, *Rhyzopertha dominica* (Fab.)

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ABSTRACT: The bio-efficacy of essential oils extracted from 16 plants was studied against Lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) under laboratory condition. The overall efficacy of oil on survival, feeding and breeding of insect was measured by observing the inhibition of F1 progeny of insects released in the treated grain. The essential oils exhibiting > 90-100, > 80-89.99, > 70-79.99 and < 70 were classified as highly, moderately, less and least effective, respectively. Significant difference in the efficacy of essential oils was recorded against the test insect. Essential oils of *Curcuma longa, Eucalyptus globulus, Mentha arvensis, Mentha. piperita, Pinus roxburghii* were found highly effective at 0.1 to 0.4 per cent concentration(v/w) while such efficacy was exhibited by *Cymbopogon winterianus*, *Eucalyptus citriodora* and *Mentha spicata* at 0.2 to 0.4 per cent. On the other hand, essential oils of *Mentha citrata* and *Pelargonium graveolens* were highly effective at 0.3 to 0.4 percent while *Cymbopogon flexuosus* exhibited such efficacy at a very high concentration of 0.6 to 1.0 per cent. Essential oils of *C. flexuosus, M. citrata* and *M. spicata* were moderately effective at 0.2 to 0.4, 0.2 and 0.1 per cent, respectively. The essential oils of *C. martini*, *E. citriodora* and *P. graveolens* were classified as less effective at 0.2 to 0.4, 0.1 and 0.2 per cent, respectively. The essential oils of *Cedardeodara*, *Cinnamomum camphora, Myristica fragrans* and *Pogostemon patchouli* were classified as least effective against *R. dominica*. The efficacy of some essential oils such as *C. flexuosus, C. martini, C. winteri anus* and *M. citrate* also decreased at 0.1 per cent due to which they were classified as least effective at lowest concentration.

Key words: Bio-efficacy, essential oil, fumigant toxicity, inhibition of progeny, Lesser grain borer, *Rhyzopertha dominica,* reproduction retardant

Lesser grain borer, *Rhyzopertha dominica* (Fabricious), (Coleoptera: Bostrichidae) is a very serious pest of stored cereals including wheat, maize, rice, oats, barley, sorghum, millet and other food stuffs in several tropical countries. The management of this insect pest under storage condition is primarily based on use of organophosphates and pyrethroids such as malathion, dichlorvos, chlorpyrifos-methyl, pirimiphos-methyl, deltamethrin, cypermethrin etc. (Huang and Subramanyam, 2005; Tiwari, 2005a; 2005b; 2005c and 2005d) and some fumigants including phosphine and methyl bromide (Bramavath *et al.,* 2017) which are being used since long. Frequent use of these synthetic pesticides have resulted in development of resistance against it in many countries due to which several cases of failures in the control of this notorious insect have been reported (Talukder, 2009; Collins and Schlipalius, 2018; Ortega *et al.*, 2021). These pesticides have also been found not suitable at farmer's level due to legal restrictions or non-compatibility with storage methods. In view of this, research across the globe is being carried out to search the viable alternatives which could be integrated with non-chemical control measures for eco-friendly management of this pest and some viable solutions are coming up from plant kingdom which is a vast storehouse of numerous metabolites. In due course of co-evolution, the plants have produced and accumulated numerous secondary metabolites and since 1950s, over 200,000 secondary metabolites have been documented in plants some of which have been found to exert antagonistic effect on insect pests (Jacobson, 1983; Jilani, 1984; Grainge and Ahmed, 1988; Shaaya *et al.,* 1990; Shaaya *et al.,* 1997; Rajendran and Sriranjini, 2008). These secondary metabolites include alkaloids, phenols and terpenes which exhibit a variety of detrimental effect on insects either by deterring them or inhibiting their feeding, survival, growth, reproduction and development. Although, all the three types of compounds are very useful in protection of grain from insect pests, highly appreciable effect has been shown by terpenes which are present as volatile component in the plant (Sharma and Tiwari, 2021b). Over a period of time, scientists have identified several essential oils of plant origin which are very rich source of pesticidal terpenes (Shaaya*et al.,* 1997; Rajendran and Sriranjini, 2008; Kumar and Tiwari, 2017a;Kumar and Tiwari, 2017b; Kumar and Tiwari, 2018a;Kumar and Tiwari, 2018b; Sharma and Tiwari, 2021a). Since these compounds do not exert harmful effect on mammals, there is a wide scope for their use in protection of grain from insect infestation.

Several attempts have been made to identify the essential oils in plants which are effective against *R. dominica* (Rao and Prakash, 2002; Tewari and Tiwari, 2008; Geetanjly *et al.*, 2016; Gangwar and Tiwari, 2017; Kumar and Tiwari, 2017a; Kumar and Tiwari, 2018a; Joshi and Tiwari, 2019). However, these explorations have covered only a handful of plants due to which more and more efforts are required in this field. In view of above mentioned facts, the present investigation was undertaken to identify new sources of essential oils effective against *R. dominica*.

MATERIALS AND METHODS

Culture of Insects

Pure culture of *R. dominica* was developed in the BOD incubator at 30.0+1.0 ˚C temperature and 70+5 per cent relative humidity. Rearing of insects was done in the plastic jars of about 1.0 kg capacity having a hole of 1.8 cm diameter in the centre of the lid which was covered with 30 mesh copper wire net to facilitate aeration in the jar. The adults of test insect were reared on the grain of wheat variety UP-2565. Before use, grains were disinfested 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 adding 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 grain

M_2 = Initial moisture content

M_2 = Required moisture content

After adding the water in the grain it was kept in closed polythene bag for a week so that moisture content of the grain could equilibrate. The grains were then filled in plastic jar and 100 adults of test insect were released in each jar after which it was kept in incubator. First generation adults (0-7 days old) were used for experimental purpose.

Preparation of Grain

All fumigation experiments on *R. dominica* were conducted on untreated graded seed of wheat variety UP 2565 which was used after heat disinfestation at 60˚C for 12 hrs. After disinfestation the moisture content of grain was determined and raised to 13.5 per cent by mixing water in the grain as described in Section 1.

Procurement of oils

Essential oils selected for the study were collected from the Medicinal and Aromatic Plants Research and Development Centre, Pantnagar and Central Institute of Medicinal and Aromatic Plants, Field Station, Pantnagar. The detail of the plant the essential oils of which were used in the study is summarized in Table 1.

Experimental details

Three sets of experiment were conducted to study the efficacy of essential oils against *R. dominica* in which different oils were evaluated at 0.1, 0.2, 0.3 and 0.4 per cent. However, in the first screening, lemon grass oil was also evaluated at 0.6, 0.8 and 1.0 per cent. Untreated grain was used as control. The experiment was conducted in a BOD incubator at 30±1°C temperature and 70±5 per cent relative humidity in the plastic vials (10 × 4 cm). Each

Table 1: Common and scientific name of plants the essential oil of which were used to study fumigant toxicity against *R. dominica*

S.N.	Scientific name of plants	Common name of plants	Family	Concentration (per cent v/w)
1.	*Cedrus deodara* (Roxb.) G. Don	Deodar	Pinaceae	0.1, 0.2, 0.3, 0.4
2.	*Cinnamomum camphora* (L.) J. Presl.	Camphor	Lauraceae	0.1, 0.2, 0.3, 0.4
3.	*Curcuma longa* Linnaeus	Turmeric	Zingiberaceae	0.1, 0.2, 0.3, 0.4
4.	*Cymbopogon flexuosus* (DC)Stapf.	Lemon grass	Poaceae	0.1, 0.2, 0.3, 0.4 0.6, 0.8, 1.0
5.	*Cymbopogon martinii* (Roxb.) Wats.	Palmarosa	Poaceae	0.1, 0.2, 0.3, 0.4
6.	*Cymbopogon winterianus* Jowitt	Citronella	Poaceae	0.1, 0.2, 0.3, 0.4
7.	*Eucalyptus citriodora* Hook.	Nilgiri	Myrtaceae	0.1, 0.2, 0.3, 0.4
8.	*Eucalyptus globulus* Labill	Eucalyptus	Myrtaceae	0.1, 0.2, 0.3, 0.4
9.	*Mentha arvensis* Linnaeus	Mint	Lamiaceae	0.1, 0.2, 0.3, 0.4
10.	*Mentha citrata* Ehrh.	Bergamot mint	Lamiaceae	0.1, 0.2, 0.3, 0.4
11.	*Mentha piperita* Linnaeus	Peppermint	Lamiaceae	0.1, 0.2, 0.3, 0.4
12.	*Mentha spicata* Linnaeus	Spearmint	Lamiaceae	0.1, 0.2, 0.3, 0.4
13.	*Myristica fragrans* Houtt.	Nutmeg	Myristicaceae	0.1, 0.2, 0.3, 0.4
14.	*Pelargonium graveolens* L'Heritier	Geranium	Geraniaceae	0.1, 0.2, 0.3, 0.4
15.	*Pinus roxburghii* Sarg.	Pine	Pinaceae	0.1, 0.2, 0.3, 0.4
16.	*Pogostemon patchouli* Pellet	Patchouli	Lamiaceae	0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0

treatment was replicated five times. Fifty gram wheat grain (moisture content 13.5 per cent) was filled in each plastic vial in which 20 adults of *R. dominica* (0-7 days old) were released. After releasing the insects, measured quantity of oil was smeared on filter paper disc which was placed inside the vials. The cap of vial was then tightly closed and was made completely airtight by sealing with paraffin film and cello tape over it. Insects were then allowed to feed till the emergence of next generation. Observations were recorded on F_1 progeny by counting adults emerged in each vial after one month. Data was analyzed in completely randomized design after suitable transformation. The essential oils inhibiting more than 90 per cent F_1 progeny were classified as highly effective while inhibition of 80 to 89.99 and 70 to 79.99 per cent were ranked as moderately and less effective, respectively. Similarly, products showing less than 70 per cent F_1 progeny inhibition were considered as least effective in the control of the insect pests.

RESULTS AND DISCUSSION

The study revealed that most of the essential oils inhibited the feeding and breeding of the test insects. However, the level of inhibition was highly correlated with the dose at which oils were used for treatment. The efficacy of oils was classified in different categories on the basis of percent inhibition of F_1 progeny.

The percentage of mean inhibition of all the three screening tests (Table 2) revealed that the essential oil of *C. deodara* was least effective against *R. dominica* as it inhibited only 18.5 to 67.4 per cent of progeny at 0.1 to 0.4 per cent in all the three studies with mean per cent inhibition of 43.9 to 46.0 per cent. In case of *C. camphora,* 97.4 per cent inhibition was observed against this insect at 0.4 per cent during first screening, however, in subsequent tests the oil inhibited only 40.6 per cent of progeny in second and third test with mean inhibition of 47.6 to 59.5 per cent which indicates that this oil was also not much effective against *R. dominica* and it may be classified as least effective. Contrary to it, this oil was reported to be highly effective against *R. dominica* at 0.05 to 0.2 per cent (Geetanjly *et al.,* 2016).

The oil of *C. longa* was highly effective against R. *dominica* as it inhibited 98.3 to 99.4 and 92.9 to 99.8 per cent of progeny during first and third screening at 0.1 to 0.4 per cent dose, although, only 70.6 to 92.8 per cent inhibition was noticed during second screening. The mean inhibition due to essential oil of *C. longa* varied from 89.7 to 94.7

Table 2: F_1 progeny of *R. dominica* emerged from grain fumigated with plant essential oils

Oil	Conc. of oil % (v/w)	I Experiment		II Experiment		III Experiment		Mean % Inhibition
		No. of adults emerged	% Inhibition	No. of adults emerged	% Inhibition	No. of adults emerged	% Inhibition	
Cedrus deodara	0.1	181.8 (5.2)	49.2	164.0 (5.1)	18.5	70.8 (4.3)	64.0	43.9
	0.2	192.6 (5.2)	46.2	152.0 (5.0)	24.5	64.0 (4.2)	67.4	46.0
	0.3	183.0 (5.2)	48.9	158.2 (5.1)	21.4	64.8 (4.2)	67.0	45.8
	0.4	177.0 (5.1)	50.5	152.6 (5.0)	24.2	83.0 (4.4)	57.8	44.2
Cinnamomum camphora	0.1	143.0 (5.0)	60.0	133.2 (4.9)	33.8	85.6 (4.5)	56.2	50.0
	0.2	79.6 (4.4)	77.7	131.0 (4.9)	34.9	137.4 (4.9)	30.1	47.6
	0.3	56.0 (3.9)	84.3	124.2 (4.8)	38.3	97.6 (4.6)	50.4	57.7
	0.4	9.2 (1.9)	97.4	119.6 (4.8)	40.6	116.8 (4.8)	40.6	59.5
Curcuma longa	0.1	6.2 (1.6)	98.3	14.4 (2.2)	92.8	13.8 (2.2)	92.9	94.7
	0.2	2.2 (1.1)	99.4	55.4 (3.8)	72.4	1.4 (0.8)	99.2	90.3
	0.3	2.2 (1.1)	99.4	59.2 (3.7)	70.6	1.6 (0.8)	99.1	89.7
	0.4	4.8 (1.4)	98.9	53.6 (3.8)	73.3	0.2 (0.1)	99.8	90.7
Cymbopogon flexuosus	0.1	–	–	144.8 (5.0)	28.1	22.6 (3.2)	88.5	58.3
	0.2	9.8 (2.3)	97.2	71.2 (4.1)	64.6	15.2 (2.8)	92.2	84.7
	0.3	–	–	62.8 (4.1)	68.6	10.6 (2.4)	94.6	81.6
	0.4	8.2 (2.2)	97.7	62.0 (4.1)	69.2	8.0 (1.8)	95.9	87.6
	0.6	6.4 (2.0)	98.2	–	–	–	–	98.2
	0.8	8.4 (2.2)	97.6	–	–	–	–	97.6
	1.0	7.8 (2.2)	97.8	–	–	–	–	97.8
Cymbopogon martinii	0.1	171.6 (5.2)	52.0	122.8 (4.8)	39.0	21.0 (3.1)	87.8	59.6
	0.2	94.0 (4.3)	73.7	94.8 (4.6)	52.9	22.0 (3.0)	88.8	71.8
	0.3	82.8 (4.2)	76.8	113.4 (4.7)	43.6	18.8 (3.0)	90.4	70.3
	0.4	114.4 (4.7)	68.0	98.8 (4.6)	50.9	12.0 (2.4)	93.9	70.9
Cymbopogon winterianus	0.1	91.0 (4.5)	74.5	119.2 (4.8)	40.8	14.0 (2.7)	92.8	69.4
	0.2	20.2 (3.1)	94.3	31.0 (3.4)	84.6	11.6 (2.5)	94.1	91.0
	0.3	12.4 (2.6)	96.5	10.6 (2.4)	94.7	0.2 (0.1)	99.8	97.0
	0.4	10.2 (2.3)	97.1	9.6 (2.3)	95.2	0.0 (0.0)	100.0	97.4
Eucalyptus citriodora	0.1	114.6 (4.7)	68.0	41.2 (3.6)	79.5	21.0 (3.1)	89.0	78.8
	0.2	4.8 (1.4)	98.6	14.4 (2.6)	92.8	0.0 (0.0)	100.0	97.1
	0.3	0.6 (0.4)	99.8	0.4 (0.2)	99.8	0.0 (0.0)	100.0	99.9
	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
Eucalyptus globulus	0.1	16.4 (2.4)	95.4	16.0 (2.7)	92.0	6.6 (1.6)	96.6	94.7
	0.2	0.8 (0.5)	99.7	0.4 (0.2)	99.8	0.0 (0.0)	100.0	99.8
	0.3	0.0 (0.0)	100.0	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
Mentha arvensis	0.1	14.4 (2.7)	95.9	26.0 (3.1)	87.0	3.4 (1.1)	98.2	93.7
	0.2	6.6 (2.0)	98.1	9.8 (2.3)	95.1	0.6 (0.3)	99.6	97.6
	0.3	1.0 (0.6)	99.7	4.8 (1.7)	97.6	0.6 (0.4)	99.6	99.0
	0.4	0.0 (0.0)	100.0	5.2 (1.8)	97.4	1.0 (0.6)	99.4	98.9
Mentha citrata	0.1	135.4 (4.9)	62.1	157.8 (5.1)	21.6	16.0 (2.8)	91.8	58.5
	0.2	26.4 (3.2)	92.6	74.8 (4.3)	62.8	12.0 (2.6)	93.9	83.1
	0.3	7.4 (2.1)	97.9	14.4 (2.7)	92.8	11.6 (2.5)	94.1	94.9
	0.4	8.0 (2.2)	97.7	12.8 (2.6)	93.6	11.6 (2.4)	94.1	95.1
Mentha piperita	0.1	12.6 (2.4)	96.5	47.4 (3.9)	76.4	0.0 (0.0)	100.0	91.0
	0.2	2.0 (0.8)	99.4	5.0 (1.8)	97.5	0.0 (0.0)	100.0	99.0
	0.3	0.2 (0.1)	99.9	5.6 (1.8)	97.2	0.0 (0.0)	100.0	99.0
	0.4	0.0 (0.0)	100.0	3.2 (1.4)	98.4	1.0 (0.5)	99.5	99.3
Mentha spicata	0.1	38.4 (3.6)	89.3	46.4 (3.8)	76.9	0.0 (0.0)	100.0	88.7
	0.2	5.8 (1.7)	98.4	0.6 (0.4)	99.7	0.0 (0.0)	100.0	99.4
	0.3	1.4 (0.7)	99.6	0.0 (0.0)	100.0	0.0 (0.0)	100.0	99.9
	0.4	0.6 (0.4)	99.8	0.0 (0.0)	100.0	0.2 (0.1)	99.9	99.9
Myristica fragrans	0.1	99.2 (4.6)	72.3	149.2 (5.0)	25.9	76.0 (4.3)	63.7	54.0

	0.2	92.2 (4.5)	74.2	138.6 (4.9)	31.1	70.0 (4.3)	61.3	55.5
	0.3	90.8 (4.5)	74.6	133.8 (4.9)	33.5	81.0 (4.4)	56.1	54.7
	0.4	88.6 (4.5)	75.2	125.0 (4.8)	37.9	105.0 (4.5)	55.6	56.2
Pelargonium graveolens	0.1	187.0 (5.2)	47.7	138.2 (4.9)	31.3	36.0 (3.6)	81.7	53.6
	0.2	85.0 (4.4)	76.2	103.4 (4.6)	48.6	24.4 (3.1)	87.6	70.8
	0.3	16.4 (2.8)	95.4	31.6 (3.4)	84.3	7.6 (1.9)	96.1	91.9
	0.4	12.0 (2.5)	96.6	12.0 (2.6)	94.0	8.4 (2.2)	95.7	95.4
Pinus roxburghii	0.1	9.6 (2.0)	97.3	15.0 (2.6)	92.5	15.4 (2.3)	92.1	94.0
	0.2	0.0 (0.0)	100.0	12.8 (2.5)	93.6	0.0 (0.0)	100.00	97.9
	0.3	0.0 (0.0)	100.0	0.4 (0.2)	99.8	0.0 (0.0)	100.0	99.9
	0.4	0.0 (0.0)	100.0	0.4 (0.2)	99.8	0.0 (0.0)	100.0	99.9
Pogostemon patchouli	0.1	251.2 (5.5)	29.8	162.8 (5.1)	19.1	131.6 (4.9)	33.1	27.3
	0.2	240.2 (5.5)	32.9	150.4 (5.0)	25.3	112.2 (4.7)	42.9	33.7
	0.3	211.4 (5.4)	40.9	146.4 (5.0)	27.3	123.0 (4.8)	37.5	35.2
	0.4	202.6 (5.3)	43.4	171.8 (5.2)	14.6	138.6 (4.9)	29.5	29.2
Control	–	358.2 (5.9)	–	201.4 (5.3)	–	196.8 (5.3)	–	–
S.Em.±		11.0 (0.2)	–	7.0 (0.2)	–	4.6 (0.2)	–	–
CD at 5%		30.7 (0.6)	–	19.6 (0.5)	–	12.9 (0.6)	–	–

*Data in parentheses indicate log (X+1) transformed values

due to which it may be classified as highly effective against *R. dominica.* In other studies, this oil was reported to inhibit 98.8 to 100 per cent progeny at 0.05 to 0.1 per cent (Gangwar and Tiwari, 2017; Joshi and Tiwari, 2019). Some variation was noticed in the efficacy in different tests which may be due to quality of oil used in different studies as they were extracted from different samples.

The oil of *C. flexuosus* was found to be moderately effective at 0.2 to 0.4 per cent at which mean inhibition varied from 84.7 to 87.6 per cent. In the first and third test the inhibition due to this oil varied from 97.2 to 97.7 and 92.2 to 95.9 per cent at 0.2 and 0.4 per cent dose, however, it inhibited only 64.6 to 69.2 per cent progeny at 0.2 and 0.4 per cent in the second test. Tripathi *et al.* (2002) reported that the adults of *R. dominica* were highly susceptible to contact action of *C. longa* leaf oil, with LD50 value of 36.71 microg/mg weight of insect and at the concentration of 40.5 mg/g (4%) food, the oil totally suppressed progeny production of this insects. However, in other studies this oil was reported to suppress 86.2 to 91.3 per cent progeny at 0.2 to 1.0 per cent (Tewari and Tiwari, 2008) and 97.7 per cent progeny at 0.2 per cent which declined to 74.6 at 0.1 per cent (Geetanjly *et al.,* 2016).The variation in these cases may be due to quality of oil which was extracted from different samples. The oil of *C. martinii* was less effective at 0.2 to 0.4 per cent at

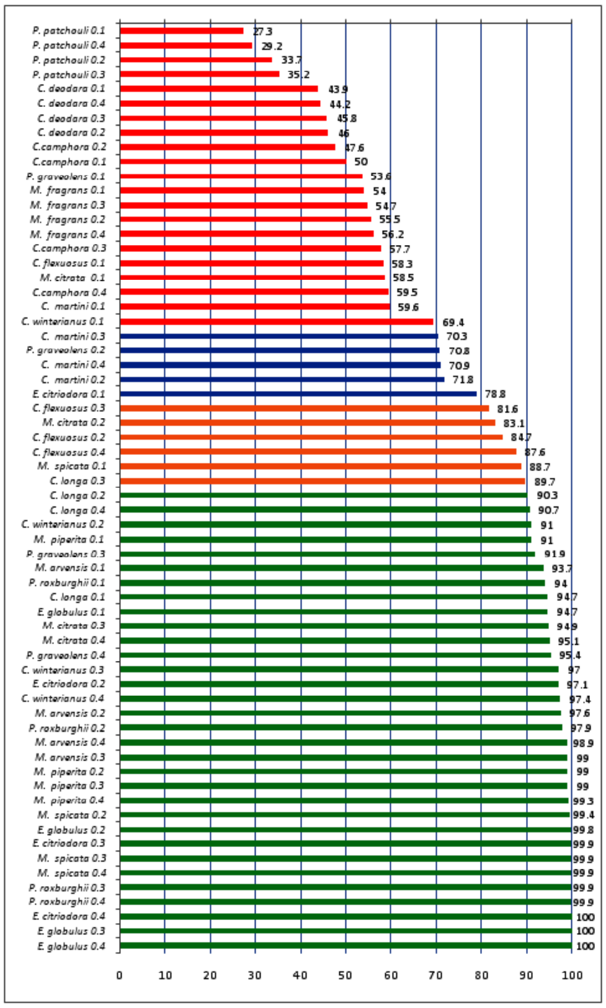

Fig. 1: Inhibition of F1 progeny of *R. dominica* by essential oils at different concentrations

which it showed 70.3 to 71.8 per cent mean inhibition of progeny. On the other hand, the oil of another species, *C. winterianus* was found to be highly effective against *R. dominica* as it caused 91.1 to 97.4 per cent mean inhibition of F_1 progeny at 0.2 to 0.4 per cent dose.

High fumigant toxicity was exhibited by *Eucalyptus* volatiles against *R. dominica*. The essential oil of *E. citriodora* achieved 97.1 to 100 per cent mean inhibition at 0.2 to 0.4 per cent due to which it was classified as highly effective against *R.dominica*. On the other hand, the essential oil of *E. globules* was more effective as compared to it as it showed 94.7 to 100 per cent mean inhibition at 0.1 to 0.4 per cent. Higher efficacy of this oil has also been reported against *R. dominica* at 0.8 and 1.0 per cent (Rao and Prakash, 2002) and 0.05 to 0.2 per cent (Geetanjly *et al.,* 2019).

Various species of *Mentha* were found to be highly effective against *R. dominica,* however, some difference in their efficacy was noticed in this study. The oil of *M. arvensis* was classified as highly effective against *R. dominica* at all the

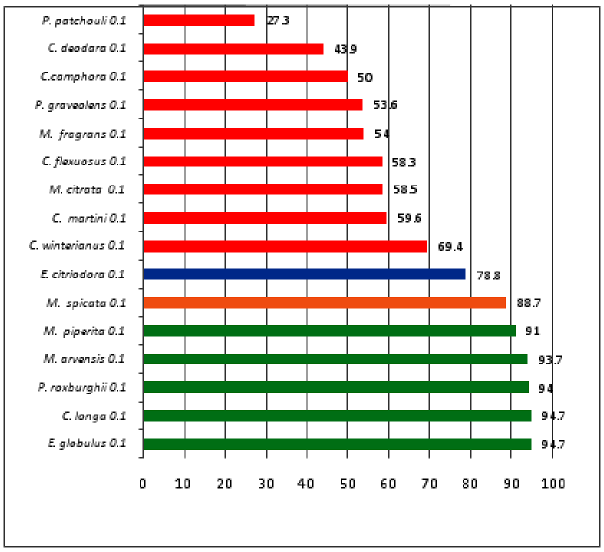

Fig. 2: Inhibition of F1 progeny of *R. dominica* by essential oils at 0.1%

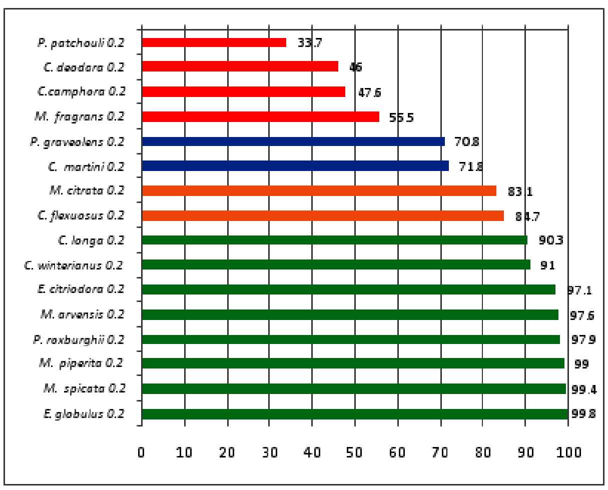

Fig. 3: Inhibition of F1 progeny of *R.dominica* by essential oils at 0.2%

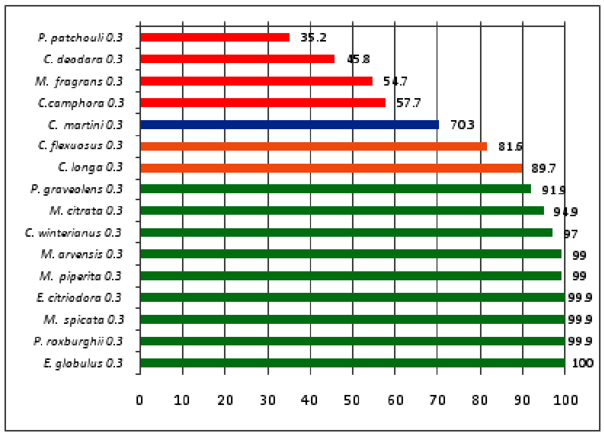

Fig. 4: Inhibition of F1 progeny of *R. dominica* by essential oils at 0.3%

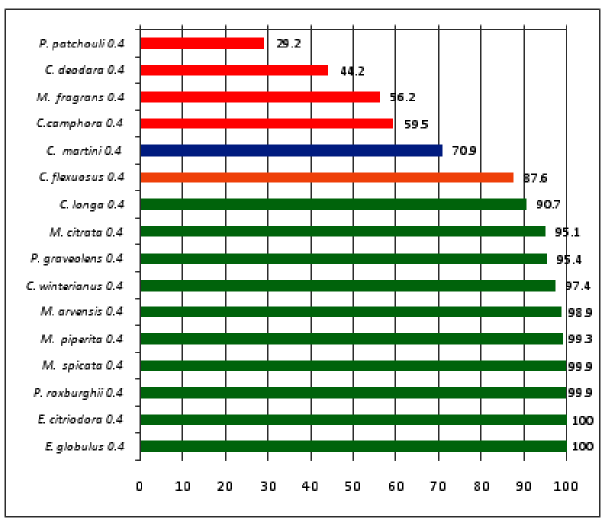

Fig. 5: Inhibition of F1 progeny of *R. dominica* by essential oils at 0.4%

concentrations in the range of 0.1 to 0.4 per cent at which it showed mean inhibition of 93.7 to 98.9 per cent. Its performance was found to be equally good in all the three tests. As compared to it, slightly lower efficacy was noticed in case of *M. citrata* which was highly effective only at 0.3 and 0.4 per cent at which it showed 94.9 and 95.1 per cent mean inhibition. The oil of this species was moderately effective at 0.2 per cent. The essential oils of other two species,*M. piperita and M. spicata* were also highly effective against *R. dominica*. The oil of *M. Piperita* suppressed 91.0 to 99.3 per cent progeny at 0.1 to 0.4 per cent due to which it was classified as highly effective. On the other hand, the essential oil of *M. spicata* inhibited 99.4 to 99.9 per cent progeny at 0.2 to 0.4 per cent due to which it was classified as highly effective. However, this oil became moderately effective at 0.1 per cent by suppressing 88.7 per cent progeny.

The oil of *M. fragrans* was not much effective against *R. dominica* in all the three tests as it showed only 54.0 to 56.2 per cent mean inhibition at 0.1 to 0.4 per cent due to which it was classified as least effective.

The essential oil of *P. graveolens* suppressed 91.9 to 95.4 per cent progeny at 0.3 to 0.4 per cent due to which it was highly effective at the above mentioned concentrations. However, it was less and least effective, at 0.2 and 0.1 per cent, respectively. The essential oil of this plant was also reported to possess repellent activity and fumigant toxicity against *R. dominica*(Ahmed *et al.,* 2020)

Treatment of grain with oil of *P. roxburghii* resulted in 94.4 to 99.9 per cent suppression of progeny production at 0.1 to 0.4 per cent dose due to which it was classified as highly effective against *R. dominica.* The efficacy of this oil was found to be consistently high in all the three tests. In another study this oil was reported to inhibit 99.9 to 100 per cent progeny of this insect at 0.05 to 0.1 per cent (Joshi and Tiwari, 2019).

The oil of *P. patchouli* was not much effective against *R. dominica* adults as it inhibited only 27.3 to 35.2 per cent of progeny at 0.1 to 0.4 per cent due to which it was classified as least effective.

The study revealed that many essential oils were highly effective against *R. dominica* at the rate of 0.1 to 0.4 per cent (v/w), however, their efficacy was influenced by concentration. The essential oils extracted from *M. piperita*, *M. arvensis, P. roxburghii, C. longa* and *E. globules* were highly effective against this insect at the lowest concentration of 0.1 per cent (Fig. 2) due to which they are much useful for the protection of grain as treatment of grain at this concentration is cost effective as compared to higher concentrations. In addition to above mentioned treatments, the efficacy of some more oils including *C. winterianus*, *E.citriodora* and *M. spicata* also increased due to increase in their concentration and they also became highly effective at 0.2 per cent (Fig.3). On the other hand, the essential oil of *P. graveolens* and *M.citrata* were highly effective at 0.3 and 0.4 per cent, respectively (Fig. 4 and 5). These oils may also be used for the protection of grain from the infestation of *R.dominica*, however, such treatments may not be cost effective.

CONCLUSION

On the basis of this study it may be concluded that the essential oils of many plants including *C. longa, C. flexuosus, C. winterianus, E. citriodora, E. globulus, M. arvensis, M. citrata, M. piperita, M. spicata, P. graveolens* and *P. roxburghii* which are highly or moderately effective against *R. dominica,* are very useful in the protection of grain from the infestation of this insect and they may be integrated with other control measures for the eco-friendly management of insects under storage condition.

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