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CONTENTS

Effect of sixteen essential oils on the progeny production of *Sitophilus oryzae* (Linnaeus)

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ABSTRACT: Three sets of experiment were conducted at 0.1, 0.2, 0.3 and 0.4 per cent (v/w) to study the effect of sixteen essential oils on the progeny production of *Sitophilus oryzae*. The essential oils showing >90.00, 80.00 to 89.99, 70.00-79.99 and <70.00 per cent mean inhibition were classified as highly, moderately, less and least effective, respectively. None of the oil was found to be highly effective at 0.1 per cent. The essential oils of *Mentha arvensis* and *Mentha spicata* suppressed more than 90 per cent progeny of test insect at 0.2 per cent due to which they were classified as highly effective at this level. Similar result was also observed in case of *Cymbopogon winterianus, Eucalyptus citriodora, Eucalyptus globulus, Mentha piperita, Mentha spicata* and *Pinus roxburghii* at 0.3 and 0.4 per cent due to which they were also classified as highly effective at these concentrations. The essential oil of *Cymbopogon flexuosus* was highly effective at 0.4 per cent. The oil of *Cymbopogon martinii* was moderately effective at 0.2 to 0.4 per cent while the oils of *Cedrus deodara*, *Cinnamomum camphora* , *Curcuma longa*, *Myristica fragrans, Pelargonium graveolens, Pogostemon patchouli* were least effective against *S. oryzae* in the present study.

Key words: Essential oils, fumigant toxicity, progeny inhibition, reproduction retardant, rice weevil, *Sitophilus oryzae*

The essential oils of several plant species have been reported to be a very rich source of many aromatic compounds such as carvone, caryophyllene, cinnamate, citronellal, coumarin, cubebene, cymene, elemene, eucalyptol, farnesene, geranial, germacrene, globulol, limonene, linalool, methyl cinnamate, methyl eugenol, myrcene, neral, ocimene, pinene, precocene I, precocene II, sabinene, sesquisabinene, spathulenol, terpineol, thymol, verbenyl and vetivenene etc. (Noriega, 2020). These compounds are commonly known as monoterpenes or sesquiterpenes which are present in higher quantity in the plants of several families including Anacardiaceae, Apiaceae (Umbeliferae), Araceae, Asteraceae (Compositae), Brassicaceae (Cruciferae) Chenopodiaceae, Cupressaceae, Graminaceae, Lamiaceae (Labiatae), Lauraceae, Liliaceae, Myrtaceae, Pinaceae, Rutaceae and Zingiberaceae. The essential oils of many plants belonging to these families have been reported to influence the survival, feeding, growth, development and reproduction of several insect pests of stored grain (Jacobson, 1983; Grainge and Ahmed, 1988; Singh *et al*., 1989; Shaaya *et al*., 1990; 1997; Lee *et al*., 2001a & 2001b; Rajendran and Sriranjini, 2008; Geetanjly *et al.,* 2016; Kumar and Tiwari, 2017a; 2017b; 2018a; 2018b; Joshi and Tiwari, 2019; Kumar *et al.,* 2020; Sharma and Tiwari, 2021a; 2021b).

The essential oils are easily transformed to gaseous state at room temperature and diffuse adequately in mass of grains. Being highly toxic to several species of insects, they are capable to work like any other conventional fumigant in airtight storage structures. However, intensive research is required for identification of plants suppressing 90-100 per cent feeding and breeding of different stored grain insects and standardization of its attributes leading to maximization of active ingredients because the components and quality of essential oil vary with geographical distribution, harvesting time, growing conditions, and extraction method. Being one of the highly diversified regions in fauna and flora, India may play leading role in identification of plant species having higher level of fumigant toxicity. In the present investigation an attempt was made to study the effect of sixteen essential oils on the population buildup of rice weevil, *Sitophilus oryzae* (Linnaeus) (Coleoptera: Curculionidae) which is a major pest of stored cereals in several tropical countries.

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.

Culture of Insects

Pure culture of test insect was developed in the BOD incubator at 30.0±1.0 ˚C temperature and 70.0±5.0 per cent relative humidity. The rearing of the insect was done in a plastic jar of about 1.0 kg capacity. The lid of the jar was having a circular hole of 1.8 cm diameter which was covered with 30 mesh copper wire net to facilitate aeration in the jar and check the escape of insects. The adults of *S. oryzae* were reared on the grain of wheat variety UP-2565. Before use, grain was 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 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 grain
M_2 = Initial moisture content
M_2 = Required moisture content

After mixing 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 grain was then filled in plastic jar and 100 adults 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 *S. oryzae* were conducted on untreated graded seed of wheat variety UP 2565 which was used after heat disinfestations at 60^{0}C for 12 hrs followed by adjustment of moisture content to 13.5 per cent as per details given 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 essential oil plants used in the study is detailed in Table 1.

Experimental details

The experiment was conducted thrice to confirm the efficacy of essential oil of plants detailed in Table 1 and in all the three tests different oils were evaluated at 0.1, 0.2, 0.3 and 0.4 per cent. However, in the first screening lemon grass oil and patchouli oil were also evaluated at 0.6, 0.8 and 1.0 per cent against *S. oryzae*. Untreated grain was used as control. The experiment was conducted in a BOD incubator at 30.0±1.0°C temperature and 70.0±5.0 per cent relative humidity in the plastic vials (10 × 4 cm). Each treatment was replicated five times. Fifty gram wheat grain (moisture content 13.5 per cent) was filled in plastic vials after which 20 adults of *S. oryzae* (0-7 days old) were released in each vial. After releasing the insects, the required quantity of oil was smeared on filter paper disc (3.5 cm diameter) which was placed inside the vials. Screw caps of vials were then tightly closed and were made completely airtight by sealing with paraffin film and cello tapes over it. Insects were then allowed to feed and breed for one month after which the adults emerged in each vial were counted at two days interval for 10 days. Number of adults emerged in each vial was calculated by subtracting the number of adults released from total number of adults emerged in each vial. Data was analyzed in completely randomized design after suitable transformation. Per cent inhibition was calculated by using following formula:

Per cent Inhibition = (NC – NT) 100/NC

Where NC = Number of adults emerged in control
NT = Number of adults emerged in treatment

The efficacy of oils was classified in four categories on the basis of mean per cent inhibition. The essential oils showing >90.00, 80.00 to 89.99, 70.00-79.99 and <70.00 per cent mean inhibition were classified as highly, moderately, less and least effective, respectively.

RESULTS AND DISCUSSION

The number of progenies produced by the adults of *S. oryzae* and percentage of inhibition recorded in different treatments along with mean per cent inhibition is presented in Table 1 which indicates that the oil of *C. deodara* was least effective against *S. oryzae* as only 42.6 to 52.2 per cent inhibition was recorded at all four concentrations.The oil of *C. camphora* also exhibited more or less similar performance by suppressing 33.8 to 59.9 per cent progeny at 0.1 to 0.4 per cent.The essential oil of *C. longa* was also least effective against *S. oryzae* as it inhibited only 34.7 to 50.7 per cent progeny in all three tests. The oil of *C. flexuosus* was moderately effective against *S. oryzae* at 0.2 to 0.3 per cent while it became highly effective at 0.4 per cent by suppressing 90.7 per cent progeny. The oil of *C. martinii* showed 81.2 to 85.1 per cent inhibition at 0.2 to 0.4 per cent due to which it was classified as moderately effective against *S. oryzae*. This oil became less effective at 0.1 per cent due to reduction in suppression to 78.4 per cent. On the other hand, the essential oil of *C. winterianus* was found to be highly effective at 0.3 and 0.4 per cent due to 91.0 and 94.2 per cent reduction in progeny production, respectively. However, its efficacy declined with further reduction in concentrations to 0.2 and 0.1 per cent at which it became less and least effective, respectively. The essential oil of *E. citriodora* was also found to be highly effective against *S. oryzae* at 0.3 and 0.4 per cent at which it caused 93.4 and 97.7 per cent inhibition, respectively. Its efficacy declined at lower concentrations and it became less and least effective at 0.2 and 0.1 per cent, respectively. Similar trend was observed in case of *E. globulus* which was highly effective at 0.3 to 0.4 per cent but less and least effective at 0.2 and 0.1 per cent, respectively. The oil of *M. arvensis* showed high efficacy against *S. oryzae* at 0.2 and 0.4 per cent causing 93.6 and 95.9 per cent inhibition. On the other hand, the essential oil of *M. citrata* was moderately effective at 0.3 and 0.4 per cent dose as it inhibited 81.2 and 85.1 per cent progeny. This oil

Table 1: Common and scientific name of plants the essential oil of which was used to study fumigant toxicity against *S. oryzae*

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

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

Oil	Conc. of oil % (v/w)	I screening		II screening		III screening		Mean % inhibition
		No. of adults emerged	% inhibition	No. of adults emerged	% inhibition	No. of adults emerged	% inhibition	
Cedrus deodara	0.1	234.2 (5.4)	51.3	80.2 (4.3)	64.6	117.2 (4.8)	36.1	50.7
	0.2	277.8 (5.6)	42.3	119.4 (4.7)	47.2	113.4 (4.7)	38.2	42.6
	0.3	264.2 (5.6)	45.1	82.0 (4.3)	63.7	95.8 (4.6)	47.8	52.2
	0.4	272.0 (5.6)	43.5	84.0 (4.4)	62.8	110.6 (4.7)	39.7	48.7
Cinnamomum camphora	0.1	312.0 (5.7)	35.2	161.4 (5.1)	28.7	114.4 (4.8)	37.6	33.8
	0.2	216.2 (5.3)	55.1	120.4 (4.8)	46.8	97.8 (4.6)	46.7	49.5
	0.3	110.4 (4.6)	77.0	116.6 (4.8)	48.4	83.8 (4.4)	54.3	59.9
	0.4	190.6 (5.0)	60.4	95.8 (4.5)	57.6	109.4 (4.7)	40.4	52.8
Curcuma longa	0.1	418.4 (6.0)	13.1	85.0 (4.5)	62.4	131.0 (4.9)	28.6	34.7
	0.2	310.2 (5.7)	35.6	92.2 (4.5)	59.2	131.8 (4.9)	28.2	41.0
	0.3	355.2 (5.9)	26.2	79.6 (4.4)	64.8	140.8 (4.9)	23.7	38.2
	0.4	481.8 (5.8)	33.0	76.0 (4.3)	66.4	87.0 (4.4)	52.6	50.7
Cymbopogon flexuosus	0.1	–	–	79.8 (4.4)	64.7	81.0 (4.3)	55.8	60.3
	0.2	33.6 (3.5)	93.0	30.2 (3.4)	86.6	41.6 (3.6)	77.3	85.6
	0.3	–	–	18.0 (2.8)	92.0	23.4 (3.2)	87.2	89.6
	0.4	26.4 (3.2)	94.5	28.0 (3.3)	87.6	18.4 (3.0)	89.9	90.7
	0.6	26.2 (3.1)	94.6	–	–	–	–	94.6
	0.8	22.6 (2.7)	95.3	–	–	–	–	95.3
	1	12.8 (2.4)	97.3	–	–	–	–	97.3
Cymbopogon martinii	0.1	70.8 (4.2)	85.3	56.8 (4.0)	74.9	45.6 (3.8)	75.1	78.4
	0.2	78.6 (4.3)	83.6	29.4 (3.3)	87.0	30.2 (3.4)	83.5	84.7
	0.3	55.4 (3.9)	88.5	53.8 (3.6)	76.2	17.2 (2.7)	90.6	85.1
	0.4	35.2 (2.7)	92.6	78.8 (4.4)	65.1	25.8 (3.2)	85.9	81.2
Cymbopogon winterianus	0.1	218.2 (5.4)	54.7	80.2 (4.4)	64.5	134.6 (4.9)	26.6	48.6
	0.2	81.2 (4.4)	83.1	61.2 (4.1)	72.9	59.6 (4.1)	67.5	74.5
	0.3	45.2 (3.8)	90.6	26.2 (3.3)	88.4	11.0 (2.3)	94.0	91.0
	0.4	28.0 (3.4)	94.1	15.2 (2.8)	93.2	8.6 (1.8)	95.3	94.2
Eucalyptus citriodora	0.1	208.8 (5.3)	56.6	112.0 (4.7)	50.5	118.8 (4.8)	35.2	47.4
	0.2	142.4 (4.9)	70.4	43.8 (3.0)	80.6	70.0 (4.2)	61.8	70.9
	0.3	67.0 (2.8)	86.0	0.0 (0.0)	100	10.6 (1.9)	94.2	93.4
	0.4	32.6 (1.8)	93.0	0.0 (0.0)	100	0.0 (0.0)	100	97.7
Eucalyptus globulus	0.1	73.4 (4.3)	84.7	99.2 (4.6)	56.1	93.2 (4.5)	49.2	63.3
	0.2	97.4 (4.4)	79.7	0.8 (0.3)	99.6	87.2 (4.5)	52.2	77.2
	0.3	28.8 (3.1)	94.0	0.0 (0.0)	100.0	13.6 (2.1)	92.5	95.5
	0.4	14.2 (1.7)	97.0	0.0 (0.0)	100.0	7.4 (1.2)	95.9	97.6
Mentha arvensis	0.1	180.8 (5.1)	62.4	54.2 (3.9)	76.9	72.2 (4.2)	60.6	66.3
	0.2	37.0 (3.6)	92.3	17.2 (2.9)	92.4	6.8 (2.0)	96.2	93.6
	0.3	54.2 (4.0)	88.7	53.2 (4.0)	76.5	0.0 (0.0)	100.0	88.4
	0.4	28.4 (3.1)	94.1	4.6 (2.6)	93.5	0.0 (0.0)	100.0	95.9
Mentha citrata	0.1	246.6 (5.5)	48.8	105.4 (4.7)	53.4	106.4 (4.7)	42.0	48.1
	0.2	191.4 (5.2)	60.2	53.4 (4.0)	76.4	59.6 (4.1)	67.5	68.0
	0.3	96.8 (4.4)	79.9	53.8 (4.0)	76.2	23.0 (3.1)	87.4	81.2
	0.4	59.0 (4.0)	87.7	61.0 (3.9)	73.0	10.0 (2.2)	94.5	85.1
Mentha piperita	0.1	126.0 (4.7)	73.8	124.2 (4.8)	45.1	0.0 (0.0)	100.0	73.0
	0.2	25.0 (2.8)	94.7	60.4 (3.9)	73.3	0.0 (0.0)	100.0	89.3
	0.3	2.4 (1.0)	99.5	19.6 (2.9)	91.3	0.0 (0.0)	100.0	96.9
	0.4	0.0 (0.0)	100.0	1.6 (0.7)	99.2	0.0 (0.0)	100.0	99.7
Mentha spicata	0.1	21.4 (3.0)	95.5	70.2 (4.2)	68.9	12.4 (2.0)	93.2	85.9
	0.2	19.8 (3.0)	95.8	9.4 (2.3)	95.8	0.0 (0.0)	100.0	97.2
	0.3	21.2 (3.1)	95.6	5.6 (1.8)	97.5	0.0 (0.0)	100.0	97.7
	0.4	16.6 (2.9)	96.5	5.8 (1.9)	97.4	0.0 (0.0)	100.0	98.0
Myristica fragrans	0.1	362.8 (5.9)	24.7	187.4 (5.2)	17.2	110.0 (4.7)	4.0	15.3

	0.2	365.0 (5.9)	24.2	136.2 (4.9)	39.8	110.2 (4.7)	39.9	34.6
	0.3	314.6 (5.7)	34.7	143.0 (5.0)	36.8	93.2 (4.5)	49.2	40.2
	0.4	301.8 (5.7)	37.3	167.2 (5.1)	26.1	86.0 (4.4)	53.1	38.8
Pelargonium graveolens	0.1	172.8 (5.1)	64.1	116.4 (4.8)	48.5	48.4 (3.9)	73.6	62.1
	0.2	146.4 (4.8)	69.6	88.6 (4.4)	60.8	38.4 (3.6)	79.0	69.8
	0.3	165.0 (5.1)	65.7	83.6 (4.4)	63.0	21.0 (3.0)	88.5	72.4
	0.4	140.0 (4.9)	70.9	99.8 (4.6)	55.9	12.4 (2.5)	93.2	73.3
Pinus roxburghii	0.1	194.0 (5.3)	59.6	106.6 (4.7)	52.9	8.2 (2.1)	95.5	69.3
	0.2	2.8 (1.2)	99.4	76.6 (4.3)	66.1	2.2 (1.0)	98.8	88.1
	0.3	10.8 (1.8)	97.7	0.6 (0.4)	99.7	0.0 (0.0)	100.0	99.1
	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100	0.0 (0.0)	100.0	100.0
Pogostemon patchouli	0.1	–	–	79.6 (4.2)	64.8	156.4 (5.1)	14.8	39.8
	0.2	331.2 (5.7)	31.2	58.4 (4.1)	74.2	143.0 (5.0)	22.1	42.5
	0.3	–	–	108.2 (4.6)	52.2	150.4 (5.0)	18.8	35.5
	0.4	420.8 (6.0)	12.6	97.0 (4.6)	57.1	131.2 (4.9)	28.5	32.7
	0.6	394.2 (6.0)	18.1	–	–	–	–	18.1
	0.8	391.2 (6.0)	18.8	–	–	–	–	18.8
	1	338.0 (5.8)	29.8	–	–	–	–	29.8
Control	–	481.8 (6.2)	–	226.4 (5.4)	–	183.6 (5.2)	–	–
S.Em.±		23.0 (0.3)	–	10.5 (0.2)	–	7.7 (0.2)	–	–
CD at 5%		64.2 (0.9)	–	29.1 (0.6)	–	21.3 (0.6)	–	–

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

was found to be least effective at lower concentrations. As compared to other species *M. spicata* showed higher fumigant toxicity at all four concentrations. The essential oil of this plant was classified as highly effective at 0.2, 0.3 and 0.4 per cent due to 97.2, 97.7 and 98.0 per cent inhibition of F1 progeny, respectively. It showed moderate toxicity at lowest concentration. The oil of *M. fragrans* was not much effective against *S. oryzae* as it suppressed only 15.3 to 40.2 per cent progeny at different concentrations due to which it was found to be least effective. In case of *P. graveolens* 72.4 to 73.3 per cent inhibition was recorded at 0.3 and 0.4 per cent, respectively, due to which it was classified as less effective. Its efficacy declined at lower concentrations at which it became least effective against *S. oryzae*. The oil of *P. roxburghii* was highly effective at 0.3 and 0.4 per cent, at which it suppressed 99.1 and 100 per cent progeny, respectively. This oil became moderately and least effective at 0.2 and 0.1 per cent. The oil of *P. patchouli* was found to be least effective against *S. oryzae* at all concentrations.

Present study revealed that most of the essential oils showed low efficacy against *S. oryzae* at the lowest concentration of 0.1 per cent as none of it was highly effective at this level (Fig.2). However, the oil of *M. spicata* was moderately effective by inhibiting 85.9 per cent progeny at this concentration. On the other hand, the essential oils of *M. piperita* and *C. martini* were less effective by suppressing 73.0 and 78.4 per cent progeny, respectively. Rests of the oils were least effective as they suppressed less than 70 per cent progeny. The efficacy of some oils increased with increase in concentration to 0.2 per cent at which the oils of *M. arvensis* and *M. spicata* were found to be highly effective against *S. oryzae* (Fig.3). The efficacy of *P. roxburghii* and *C. flexuosus* also increased at this concentration due to which they became moderately effective along with *M. piperita* and *C. martini*. The oils of *E. globulus, C. winterianus* and *E. citriodora* were found to be less effective by inhibiting 77.2, 74.5 and 70.9 per cent progeny, respectively. Others oils were found to be least effective against *S. oryzae* at 0.2 per cent. Further increase in concentration to 0.3 per cent enhanced the efficacy of some other oils including *P. roxburghii*, *M. piperita*, *E. globulus*, *E. citriodora* and *C. winterianus* which became highly effective at this level (Fig.4). The oils of *C. flexuosus*, *M. arvensis*, *C. martini* and *M. citrata* were found to be moderately effective while *P. graveolens* was less effective against *S. oryzae* at 0.3 per cent. Seven

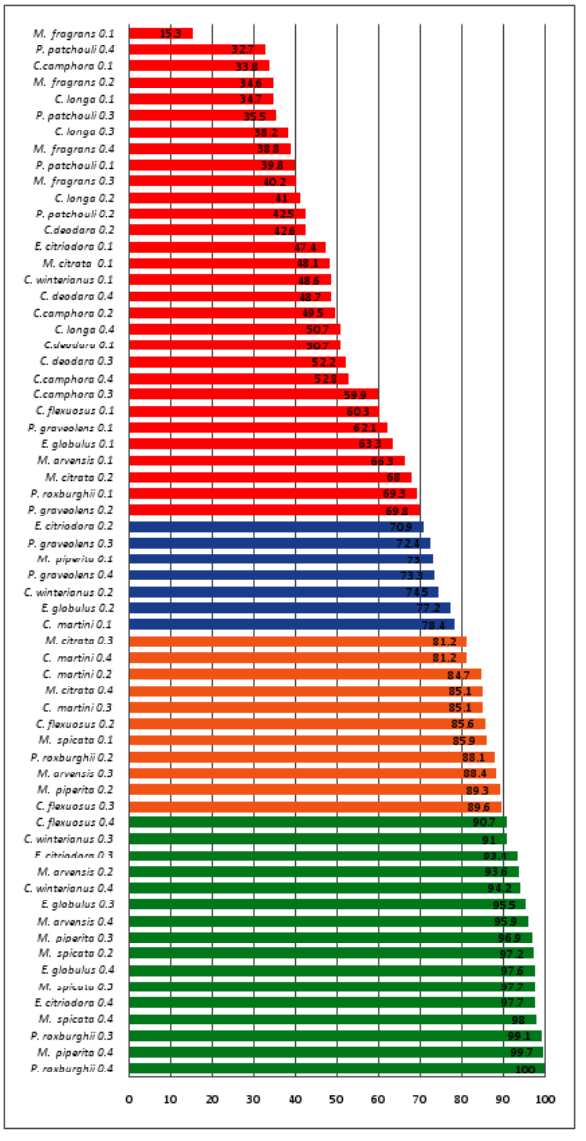

Fig. 1: Inhibition of F1 progeny of *S. oryzae* by essential oils at different concentrations

essential oils including *P. roxburghii, M. piperita, M. spicata, E. citriodora, E. globulus, C. winterianus* and *C. flexuosus* were classified as highly effective at the highest concentration of 0.4 per cent while *M. citrata* and *C. martini* were moderately effective and *P. graveolens* was less effective (Fig.5). The essential oils of *C. deodara*, C. *camphora*, *C. longa*, *M. fragrance* and *P. patchouli* were least effective against *S. oryzae* at 0.1 to 0.4 per cent due to which they are not much useful in management of this insect pest.

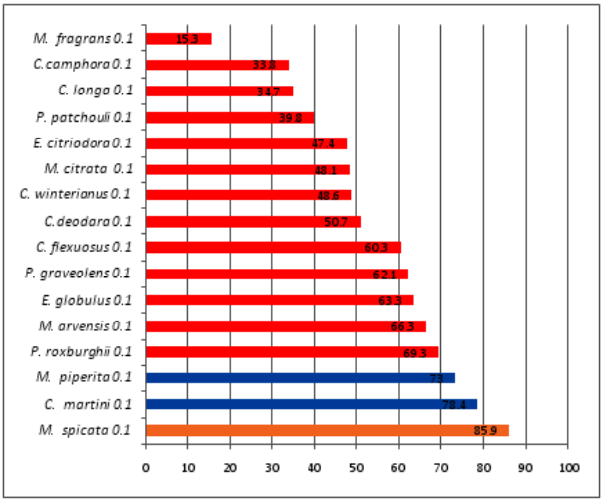

Fig. 2: Inhibition of F1 progeny of *S. oryzae* by essential oils at 0.1 %

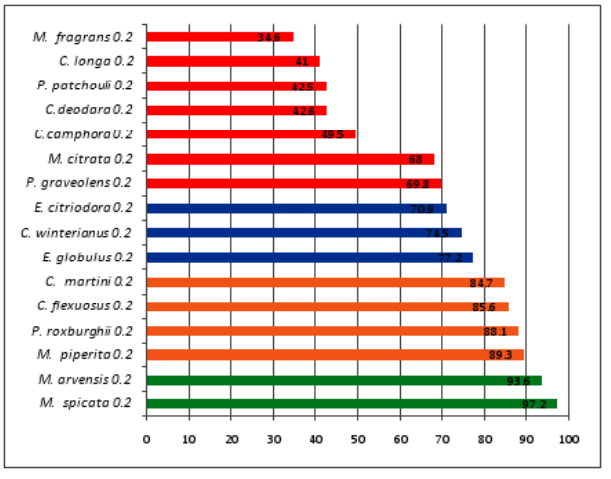

Fig. 3: Inhibition of F1 progeny of *S. oryzae* by essential oils at 0.2 %

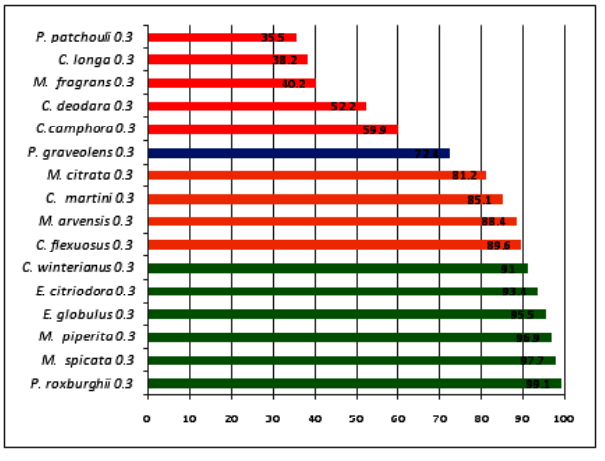

Fig. 4: Inhibition of F1 progeny of *S. oryzae* essential oils at 0.3 %

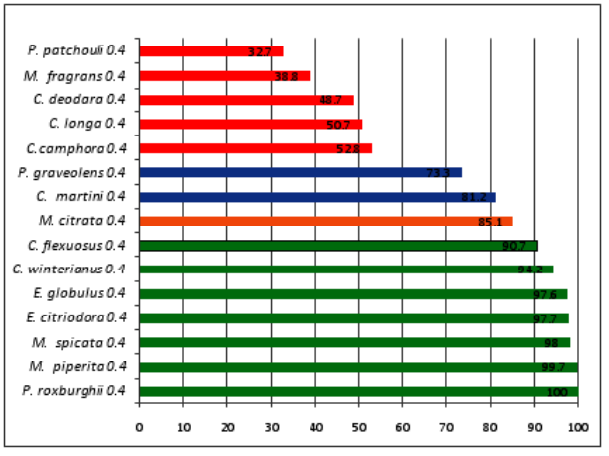

Fig.5: Inhibition of F1 progeny of *S. oryzae* by essential oils at 0.4%

In the present study, the essential oil of *C. deodara* was not found to be much effective, however, previous studies conducted on this plant indicated some reproduction retardant and fumigant properties against *S. oryzae* at 0.1 per cent (Singh *et al.*,1989). The essential oil of *C. longa* inhibited only 50.7 per cent progeny of *S. oryzae* at 0.4 per cent in the present study while adults of this insect were found to be highly susceptible to this oil with LC_{50} value of 11.36 mg/liter air and completely suppressed the progeny of this insect 40.5 mg/g (4.05 per cent) (Tripathi *et al.,* 2002). On the other hand, Gangwar and Tiwari (2017) reported that the essential oil extracted from the leaf of *C. longa* and its different fractions I, II, IV and V inhibited 95.5 to 100.0 per cent progeny of *S. oryzae* at 0.1 per cent due to which they were classified as highly effective against this insect. This oil was also reported to be highly effective against *S. oryzae* at 0.2 per cent (Kumar *et al.,* 2019). In the present study, the essential oil of *C. winterianus* inhibited 91.0 and 94.2 per cent progeny at 0.3 and 0.4 per cent, respectively. However, the grain treated by essential oil of *C. winterianus* at 0.1 per cent was reported to show low damage during 90 days storage period (Singh *et al.*, 1989).

CONCLUSION

On the basis of this study, it may be concluded that the essential oils of *P. roxburghii, M. piperita, M. spicata, E. citriodora, E. globulus, C. winterianus* and *C. flexuosus, M. arvensis, M. citrata* and *C. martini* possess significant toxicity and reproduction retardant property against *S. oryzae* and they may be explored for management of this insect pests.

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