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CONTENTS

Fumigant toxicity of some essential oils and their combinations against *Rhyzopertha dominica* (Fabricius) and *Sitophilus oryzae* (Linnaeus)

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ABSTRACT: Experiments were conducted to study the fumigant toxicity of essential oils of mint (*Mentha arvensis*), peppermint (*Mentha piperita*), spearmint (*Mentha spicata*), citronella (*Cymbopogon winterianus*), Nilgiri (*Eucalyptus citriodora*), eucalyptus (*Eucalyptus globulus*), and pine (*Pinus roxburghii)* and their combinations against Lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) and Rice weevil, *Sitophilus oryzae* (Linnaeus) (Coleoptera : Curculionidae). All the oils except Nilgiri and eucalyptus oils were highly effective against both the insects at 0.2 per cent (v/w) as they suppressed 90-100 per cent progeny of test insects. Increase in concentration of essential oil to 0.4 per cent enhanced their fumigant toxicity; however, Nilgiri oil remained less effective against both the insects even at this level while eucalyptus oil became moderately and highly effective against *R. dominica* and *S. oryzae*, respectively. All the two, three, four, five, six and seven essential oils combinations were highly effective against both the insects at 0.20, 0.13, 0.10, 0.08, 0.07 and 0.06 per cent each, respectively, except mint + eucalyptus which was less effective against *R. dominica* and citronella + Nilgiri, citronella + eucalyptus, Nilgiri + eucalyptus and peppermint + Nilgiri + eucalyptus oils which showed slightly less efficacy against *S. oryzae*. The mixture of peppermint + eucalyptus, peppermint + pine and eucalyptus + pine at 0.1+0.1 per cent completely checked the progeny production of both the insects.

Key words: Bio-efficacy, essential oils, fumigant-toxicity, herbal fumigants, *Rhyzopertha dominica, Sitophilus oryzae*

The essential oils of many plant species have been reported to exhibit fumigant toxicity against insect pests of stored grain (Grainge and Ahmed, 1988; Shaaya *et al.,* 1990; Shaaya *et al.,* 1997; Rajendran and Sriranjini, 2008; Tewari and Tiwari, 2008; Geetanjly *et al.*, 2016; Kumar and Tiwari, 2018a; Kumar and Tiwari, 2018b; Joshi and Tiwari, 2019; Sharma and Tiwari, 2021a; 2021b; Geetanjly and Tiwari, 2021). However, such oils have not been found much useful in protection of grain from insect infestation due to various reasons and even after intense research on this subject we do not have any commercial formulation of herbal fumigant in the market. It has been realized that their efficacy is not much appreciable at lower concentration due to which their use at higher concentration may increase the cost of protection tremendously. The cost of essential oils is also known to vary according to plant species and it is not economical to use very costly oils at effective concentration for protection of grain. Furthermore, most of these oils are not equally effective against all major insect pests of stored grain (Tripathi *et al.* 2002; Gangwar and Tiwari, 2017) due to which infestation of grain by other insects cannot be ruled out. It has been realized that use of these essential oils in combination or herbal formulation may increase their efficacy against many insect pests due to synergistic or additive effect (Kumar and Tiwari, 2017a; 2017b) and it may also help in reduction of cost by choosing combinations of inexpensive oils. Tewari and Tiwari (2021a; 2021b) reported that the essential oils of *Mentha arvensis, Mentha piperita, Eucalyptus globulus, Pinus roxburghii* were highly effective against *Rhyzopertha dominica* (F.) at 0.4 per cent, however, their efficacy was poor against *Sitophilus oryzae* (L.) at same concentration. Some other oils such as *Cymbopogon winterianus* and *Eucalyptus citriodora* used in the same study were less effective against both the insects; however, they are economical as compared to others. Under such conditions, the utility of above-mentioned essential oils may be increased if their effects are made additive or synergistic by using them in various combinations. In the present investigation, an attempt was made to study the fumigant toxicity of various combinations of essential oils against *R. dominica* and *S. oryzae*. The investigation may lead to several economical

compositions which may be used for the protection of cereals against infestation of both the insect pests.

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. Pure cultures of test insects were developed in plastic jars of about 1.0 kg capacity having a hole of 1.8 cm diameter in the center of the lid which was covered by 30 mesh copper wire net for proper aeration. The adults of *R. dominica* and *S. oryzae* were reared on the grain of wheat variety UP 2565 which was used after disinfestation in the oven at 60^0C for 12 hrs. The moisture content of disinfested grain was measured and adjusted 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 formula given by Pixton (1967). After mixing the water, the grain was stored in closed polythene bag for a week for moisture equilibration. The grain was then filled in plastic jar and 100 adults were released in each jar which was placed in BOD incubator maintained at 30 ± 1^0C temperature and 70±5 per cent relative humidity.

The experiment was conducted on seven essential oils namely, mint oil (*Mentha arvensis)*, peppermint oil (*Mentha piperita)*, spearmint oil (*Mentha spicata),* citronella oil *(Cymbopogon winterianus)*, Nilgiri oil (*Eucalyptus citriodora)*, eucalyptus oil *(Eucalyptus globulus)* and pine oil (*Pinus roxburghii)*. These oils 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 oils were used alone at 0.20 and 0.40 per cent (v/w) concentration or in two, three, four, five, six and seven oils combinations at 0.20, 0.13, 0.10, 0.08, 0.07 and 0.06 per cent each, respectively and each experiment was conducted twice to confirm the results.

The experiments were conducted in control room at 30±1°C temperature and 70±5 per cent relative humidity on wheat variety UP 2565 (13.5 per cent moisture content) stored in plastic vials (10 × 4 cm) and each treatment was replicated three times. The details of essential oils, their combinations and dose are detailed in Table 1 and 2. Untreated grain was used as control. After filling 50g grain in plastic vials, 20 adults (0-7 days old) of *R. dominica* or *S. oryzae* were released in each vial. Measured quantity of oils and their combinations were soaked on Whatman No. 42 filter paper disc (3.5 cm diameter) in the ratio indicated in the Table 1 and 2 after which paper disc were inserted in the vial before closing it to make air tight. After closing the lid, the vial was sealed with the help of paraffin wax strips and cello tape. The insects were allowed to complete one generation after which each vial was opened to record the number of adults emerged in each vial. Suppression of progeny caused by each treatment was calculated by using number of adults emerged in treated vial and control. Mean of per cent inhibition recorded in both the experiments was used to draw any conclusion. Data was analyzed in completely randomized design after log (X+1) transformation.

RESULTS AND DISCUSSION

Fumigant toxicity of various essential oils and their combinations against *R. dominica* is presented in Table 1 which indicates that mint, peppermint, spearmint, citronella and pine oil were highly effective at 0.20 and 0.40 per cent dose against this insect as they suppressed 94.2 to 100 per cent progeny. As per classification illustrated by Tewari and Tiwari (2021a), Nilgiri and eucalyptus oils were least effective at 0.20 per cent due to 36.6 and 63.1 per cent inhibition of progeny, however, the efficacy of both these oils increased at 0.4 per cent, and they became less and moderately effective, respectively. Except mint + eucalyptus, all the combinations of two essential oils were found to be highly effective against *R. dominica* at 0.20 per cent each as they exhibited 93.7 to 100 per cent mean inhibition. The former combination was found to be less effective due to 72.4 per cent mean inhibition. The fumigation of grain by combinations of three essential oils resulted in 98.6 to 100.0 mean inhibition due to which all these treatments were classified as highly

Table 1: Fumigant toxicity of some essential oils and their combinations against *R. dominica*

S. No.	Treatment	Conc. % (v/w)	I Experiment		II Experiment		Mean
			No. of adults emerged	Per cent inhibition	No. of adults emerged	Per cent inhibition	Per cent inhibition
1.	Mint	0.2	0.0 (0.0)	100.0	6.3 (2.0)	96.6	98.3
2.	Peppermint	0.2	0.0 (0.0)	100.0	1.7 (0.6)	99.1	99.6
3.	Spearmint	0.2	0.0 (0.0)	100.0	2.3 (1.0)	98.7	99.4
4.	Citronella	0.2	5.3 (1.8)	96.2	14.7 (2.7)	92.1	94.2
5.	Nilgiri	0.2	131.0 (4.9)	7.9	64.7 (4.2)	65.3	36.6
6.	Eucalyptus	0.2	88.7 (4.5)	26.1	0.0 (0.0)	100.0	63.1
7.	Pine	0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
8.	Mint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
9.	Peppermint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
10.	Spearmint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
11.	Citronella	0.4	1.0 (0.6)	99.3	5.0 (1.7)	97.3	98.3
12.	Nilgiri	0.4	50.0 (3.8)	64.8	26.3 (3.3)	88.7	76.8
13.	Eucalyptus	0.4	34.7 (3.6)	75.6	0.0 (0.0)	100.0	87.8
14.	Pine	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
15.	Mint + Peppermint	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
16.	Mint + Spearmint	0.2+0.2	1.0 (0.5)	99.3	0.0 (0.0)	100.0	99.7
17.	Mint + Citronella	0.2+0.2	0.7 (0.4)	99.5	4.0 (1.6)	97.8	98.7
18.	Mint + Nilgiri	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
19.	Mint + Eucalyptus	0.2+0.2	0.0 (0.0)	100.0	103.0 (4.6)	44.8	72.4
20.	Mint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
21.	Peppermint + Spearmint	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
22.	Peppermint + Citronella	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
23.	Peppermint + Nilgiri	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
24.	Peppermint + Eucalyptus	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
25.	Peppermint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
26.	Spearmint + Citronella	0.2+0.2	0.0 (0.0)	100.0	5.3 (1.7)	97.1	98.6
27.	Spearmint + Nilgiri	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
28.	Spearmint + Eucalyptus	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
29.	Spearmint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
30.	Citronella + Nilgiri	0.2+0.2	3.7 (1.5)	96.9	6.3 (1.9)	96.6	96.8
31.	Citronella + Eucalyptus	0.2+0.2	1.7 (0.8)	98.6	2.0 (1.1)	98.9	98.8
32.	Citronella + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
33.	Nilgiri + Eucalyptus	0.2+0.2	15.7 (2.8)	88.9	2.7 (1.3)	98.5	93.7
34.	Nilgiri + Pine	0.2+0.2	0.7 (0.5)	99.5	2.0 (0.8)	98.9	99.2
35.	Eucalyptus + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
36.	Mint + Peppermint + Spearmint	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
37.	Mint + Peppermint + Citronella	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
38.	Mint + Peppermint + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
39.	Mint + Peppermint + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
40.	Mint + Peppermint + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
41.	Mint + Spearmint + Citronella	0.13 (each)	0.0 (0.0)	100.0	2.7 (1.3)	98.5	99.3
42.	Mint + Spearmint + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
43.	Mint + Spearmint + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
44.	Mint + Spearmint + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
45.	Mint + Citronella + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
46.	Mint + Citronella + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
47.	Mint + Citronella + Pine	0.13 (each)	0.7 (0.5)	99.5	0.0 (0.0)	100.0	99.8
48.	Mint + Nilgiri + Eucalyptus	0.13 (each)	3.3 (1.0)	97.2	0.0 (0.0)	100.0	98.6
49.	Mint + Nilgiri + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
50.	Mint + Eucalyptus + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
51.	Peppermint + Spearmint + Citronella	0.13 (each)	0.0 (0.0)	100.0	3.7 (1.5)	98.0	99.0
52.	Peppermint + Spearmint + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

53.	Peppermint+ Spearmint + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
54.	Peppermint+ Spearmint + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
55.	Peppermint+ Citronella + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
56.	Peppermint+ Citronella + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
57.	Peppermint+ Citronella + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
58.	Peppermint + Nilgiri + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	5.0 (1.8)	97.3	98.7
59.	Peppermint + Nilgiri + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
60.	Peppermint + Eucalyptus + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
61.	Spearmint + Citronella + Nilgiri	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
62.	Spearmint + Citronella + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
63.	Spearmint + Citronella + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
64.	Spearmint + Nilgiri + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
65.	Spearmint + Nilgiri + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
66.	Spearmint + Eucalyptus + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
67.	Citronella + Nilgiri + Eucalyptus	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
68.	Citronella + Nilgiri + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
69.	Citronella + Eucalyptus + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
70.	Nilgiri + Eucalyptus + Pine	0.13 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
71.	Mint + Peppermint + Spearmint + Citronella	0.1 (each)	0.7 (0.4)	99.5	1.0 (0.5)	99.4	99.5
72.	Mint + Peppermint + Spearmint + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	5.3 (1.8)	97.1	98.6
73.	Mint + Peppermint + Spearmint + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
74.	Mint + Peppermint + Spearmint + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
75.	Mint + Peppermint + Citronella + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	7.0 (2.0)	96.2	98.1
76.	Mint + Peppermint + Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	4.0 (1.5)	97.8	98.9
77.	Mint + Peppermint + Citronella + Pine	0.1 (each)	8.0 (1.6)	94.4	0.0 (0.0)	100.0	97.2
78.	Mint + Peppermint + Nilgiri + Eucalyptus	0.1 (each)	0.7 (0.4)	99.8	0.0 (0.0)	100.0	99.9
79.	Mint + Peppermint + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
80.	Mint + Peppermint + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
81.	Mint + Spearmint + Citronella + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	2.3 (1.2)	98.7	99.4
82.	Mint + Spearmint + Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
83.	Mint + Spearmint + Citronella + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
84.	Mint + Spearmint + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
85.	Mint + Spearmint + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
86.	Mint + Spearmint + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
87.	Mint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	2.0 (1.1	98.3	3.0 (1.4)	98.3	98.3
88.	Mint + Citronella + Nilgiri + Pine	0.1 (each)	1.0 (0.6)	99.2	0.0 (0.0)	100.0	99.6
89.	Mint + Citronella + Eucalyptus + Pine	0.1 (each)	0.3 (0.2)	99.7	0.0 (0.0)	100.0	99.9
90.	Mint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
91.	Peppermint + Spearmint + Citronella + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
92.	Peppermint + Spearmint+ Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
93.	Peppermint + Spearmint+ Citronella + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
94.	Peppermint + Spearmint + Nilgiri + Eucalyptus	0.1 (each)	0.7 (0.5)	99.5	0.0 (0.0)	100.0	99.8
95.	Peppermint + Spearmint + Nilgiri + Pine	0.1 (each)	0.3 (0.2)	99.7	0.0 (0.0)	100.0	99.9
96.	Peppermint + Spearmint + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
97.	Peppermint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
98.	Peppermint + Citronella + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

99.	Peppermint + Citronella + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
100.	Peppermint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.3 (0.2)	99.7	0.0 (0.0)	100.0	99.9
101.	Spearmint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	5.3 (1.8)	95.5	0.0 (0.0)	100.0	97.8
102.	Spearmint + Citronella + Nilgiri + Pine	0.1 (each)	0.7 (0.5)	99.5	0.0 (0.0)	100.0	99.8
103.	Spearmint + Citronella + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
104.	Spearmint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.3 (0.2)	99.7	0.0 (0.0)	100.0	99.9
105.	Citronella + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
106.	Mint + Peppermint + Spearmint + Citronella + Nilgiri	0.08 (each)	0.3 (0.2)	99.7	2.3 (1.0)	98.7	99.2
107.	Mint + Peppermint + Spearmint + Citronella + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
108.	Mint + Peppermint + Spearmint + Citronella + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
109.	Mint + Peppermint + Spearmint + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
110.	Mint + Peppermint + Spearmint + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
111.	Mint + Peppermint + Spearmint + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
112.	Mint + Peppermint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	4.3 (1.6)	97.6	98.8
113.	Mint + Peppermint + Citronella + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
114.	Mint + Peppermint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
115.	Mint + Peppermint + Nilgiri + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
116.	Mint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
117.	Mint + Spearmint + Citronella + Nilgiri + Pine	0.08 (each)	0.3 (0.2)	99.7	0.0 (0.0)	100.0	99.9
118.	Mint + Spearmint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
119.	Mint + Spearmint + Nilgiri+ Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
120.	Mint + Citronella + Nilgiri+ Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
121.	Peppermint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
122.	Peppermint + Spearmint + Citronella + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
123.	Peppermint + Spearmint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
124.	Peppermint + Spearmint + Nilgiri + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
125.	Peppermint + Citronella + Nilgiri + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
126.	Spearmint + Citronella + Nilgiri+ Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
127.	Mint+ Peppermint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

128.	Mint + Peppermint+ Spearmint+ Citronella+ Nilgiri + Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
129.	Mint + Peppermint+ Spearmint+ Citronella + Eucalyptus + Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
130.	Mint + Peppermint+ Spearmint + Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
131.	Mint + Peppermint + Citronella + Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
132.	Mint + Spearmint + Citronella+ Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
133.	Peppermint + Spearmint+ Citronella+ Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
134.	Mint+Peppermint+Spearmint+ Citronella+Nilgiri+Eucalyptus+Pine	0.06 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
135.	Peppermint + Eucalyptus	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
136.	Peppermint + Pine	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
137.	Eucalyptus + Pine	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
138.	Untreated control	–	142.3 (5.0)	–	186.7 (5.2)	–	
	S.Em.±		2.8 (0.2)	–	1.5 (0.1)	–	
	CD at 5%		7.7 (0.4)	–	4.1 (0.4)	–	

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

effective. More or less similar effect was noticed in case of four oils combinations on which mean inhibition varied from 92.2 to 100.0 per cent. Treatment of grain by five oils combination exhibited 98.8 to 100.0 per cent mean inhibition while all six and seven oil combinations completely checked the progeny production by *R. dominica*. Most interestingly, fumigation of grain by peppermint + eucalyptus, peppermint + pine and eucalyptus + pine at 0.1+0.1 per cent resulted in complete inhibition of progeny of test insect. The results indicated that most of the combinations are highly effective against *R. dominica*.

The efficacy of various essential oils and their combinations against *S. oryzae* is presented in Table 2. All the essential oils were highly effective against this insect at 0.20 and 0.40 except Nilgiri oil which inhibited 59.3 and 77.2 per cent progeny, respectively. The eucalyptus oil was moderately effective at 0.20 per cent; however, it became highly effective at 0.40 per cent. Among two oil combinations, citronella + Nilgiri and citronella + eucalyptus were moderately effective while combination of Nilgiri + eucalyptus was least effective. All other combinations of two essential oils were highly effective against *S. oryzae* as they inhibited 91.3 to 100.0 per cent progeny of test insect. Except three oils combination of peppermint + Nilgiri + eucalyptus which inhibited 87.0 per cent progeny, all other treatments were highly effective against this insect due to 93.0 to 100.0 per suppression of progeny. All the four, five, six and seven oils combination were found to be highly effective against *S. oryzae* as they caused 98.5 to 100.0, 99.7 to 100, 99.9 to 100.0 and 100.0 per cent mean inhibition, respectively. Complete inhibition of progeny was also obtained when the grain was fumigated by peppermint + eucalyptus, peppermint + pine and eucalyptus + pine at 0.1+0.1 per cent. The study revealed that various combinations of essential oils are highly effective against *S. oryzae*.

A comparison of response of *R. dominica* and *S. oryzae* toward various essential oils and their combinations indicated that except few, all other combinations were highly effective against both the major insects pests of stored cereals. The essential oil of Nilgiri was least effective against both the insects at 0.20 per cent, however, its efficacy increased at 0.40 per cent at which it became less effective against both the insects by suppressing 76.8 to 77.2 per cent progeny. The eucalyptus oil was found to be least and moderately effective against *R. dominica* and *S. oryzae*, respectively, at 0.20 per cent, however, it became moderately and highly effective at 0.40 per cent. The combination of mint + eucalyptus was less effective against *R. dominica*

Table 2: Fumigant toxicity of some essential oils and their combinations against *S. oryzae*

S. No.	Treatment	Conc. % (v/w)	I Experiment		II Experiment		Mean
			No. of adults emerged	Per cent inhibition	No. of adults emerged	Per cent inhibition	Per cent inhibition
1.	Mint	0.2	0.0 (0.0)	100.0	0.3 (0.2)	99.8	99.9
2.	Peppermint	0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
3.	Spearmint	0.2	0.0 (0.0)	100.0	0.3 (0.3)	99.8	99.9
4.	Citronella	0.2	11.3 (2.2)	96.2	12.0 (2.5)	90.0	93.1
5.	Nilgiri	0.2	129.0 (4.9)	55.9	44.7 (3.8)	62.7	59.3
6.	Eucalyptus	0.2	98.0 (4.6)	66.5	0.0 (0.0)	100.0	83.3
7.	Pine	0.2	0.0 (0.0)	100.0	5.3 (1.8)	95.6	97.8
8.	Mint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
9.	Peppermint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
10.	Spearmint	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
11.	Citronella	0.4	0.0 (0.0)	100.0	2.7 (1.3)	97.7	98.9
12.	Nilgiri	0.4	76.7 (4.3)	73.8	23.3 (3.2)	80.6	77.2
13.	Eucalyptus	0.4	34.0 (3.5)	88.4	0.0 (0.0)	100.0	94.2
14.	Pine	0.4	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
15.	Mint + Peppermint	0.2+0.2	0.0 (0.0)	100.0	0.3 (0.2)	99.8	99.9
16.	Mint + Spearmint	0.2+0.2	0.7 (0.4)	99.8	0.0 (0.0)	100.0	99.9
17.	Mint + Citronella	0.2+0.2	1.7 (0.8)	99.4	2.0 (1.1)	98.3	98.9
18.	Mint + Nilgiri	0.2+0.2	12.7 (2.6)	95.7	13.0 (2.6)	89.1	92.4
19.	Mint + Eucalyptus	0.2+0.2	3.7 (0.8)	98.7	0.0 (0.0)	100.0	99.4
20.	Mint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
21.	Peppermint + Spearmint	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
22.	Peppermint + Citronella	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
23.	Peppermint + Nilgiri	0.2+0.2	0.0 (0.0)	100.0	2.0 (1.1)	98.3	99.2
24.	Peppermint + Eucalyptus	0.2+0.2	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
25.	Peppermint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
26.	Spearmint + Citronella	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
27.	Spearmint + Nilgiri	0.2+0.2	0.0 (0.0)	100.0	0.3 (0.2)	99.8	99.9
28.	Spearmint + Eucalyptus	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
29.	Spearmint + Pine	0.2+0.2	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
30.	Citronella + Nilgiri	0.2+0.2	55.0 (4.0)	81.2	17.0 (2.9)	85.8	83.5
31.	Citronella + Eucalyptus	0.2+0.2	65.7 (4.2)	77.6	3.0 (1.4)	97.5	87.6
32.	Citronella + Pine	0.2+0.2	1.0 (0.6)	99.6	4.0 (1.3)	96.6	98.1
33.	Nilgiri + Eucalyptus	0.2+0.2	154.3 (5.0)	47.2	20.7 (3.1)	82.7	65.0
34.	Nilgiri + Pine	0.2+0.2	16.7 (1.5)	94.2	14.0 (2.7)	88.3	91.3
35.	Eucalyptus + Pine	0.2+0.2	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
36.	Mint + Peppermint + Spearmint	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
37.	Mint + Peppermint + Citronella	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
38.	Mint + Peppermint + Nilgiri	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
39.	Mint + Peppermint + Eucalyptus	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
40.	Mint + Peppermint + Pine	0.14 (each)	0.0 (0.0)	100.0	0.7 (0.4)	99.4	99.7
41.	Mint + Spearmint + Citronella	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
42.	Mint + Spearmint + Nilgiri	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
43.	Mint + Spearmint + Eucalyptus	0.14 (each)	15.0 (2.1)	94.8	0.0 (0.0)	100.0	97.4
44.	Mint + Spearmint + Pine	0.14 (each)	1.0 (0.5)	99.6	0.0 (0.0)	100.0	99.8
45.	Mint + Citronella + Nilgiri	0.14 (each)	1.7 (0.9)	99.4	2.3 (1.2)	98.0	98.7
46.	Mint + Citronella + Eucalyptus	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
47.	Mint + Citronella + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
48.	Mint + Nilgiri + Eucalyptus	0.14 (each)	26.3 (3.3)	91.0	6.0 (1.9)	95.0	93.0
49.	Mint + Nilgiri + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
50.	Mint + Eucalyptus + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
51.	Peppermint + Spearmint + Citronella	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
52.	Peppermint + Spearmint + Nilgiri	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

53.	Peppermint+ Spearmint + Eucalyptus	0.14 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
54.	Peppermint+ Spearmint + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
55.	Peppermint+ Citronella + Nilgiri	0.14 (each)	6.0 (1.0)	97.9	0.0 (0.0)	100.0	99.0
56.	Peppermint+ Citronella + Eucalyptus	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
57.	Peppermint+ Citronella + Pine	0.14 (each)	4.7 (1.7)	99.7	3.3 (1.4)	97.2	98.5
58.	Peppermint + Nilgiri + Eucalyptus	0.14 (each)	44.3 (3.8)	84.8	13.0 (2.6)	89.1	87.0
59.	Peppermint + Nilgiri + Pine	0.14 (each)	14.3 (1.9)	95.1	1.3 (0.7)	98.8	97.0
60.	Peppermint + Eucalyptus + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
61.	Spearmint + Citronella + Nilgiri	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
62.	Spearmint + Citronella + Eucalyptus	0.14 (each)	1.0 (0.5)	99.6	0.0 (0.0)	100.0	99.8
63.	Spearmint + Citronella + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
64.	Spearmint + Nilgiri + Eucalyptus	0.14 (each)	6.0 (1.9)	97.9	1.3 (0.8)	98.8	98.4
65.	Spearmint + Nilgiri + Pine	0.14 (each)	1.0 (0.5)	99.6	0.0 (0.0)	100.0	99.8
66.	Spearmint + Eucalyptus + Pine	0.14 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
67.	Citronella + Nilgiri + Eucalyptus	0.14 (each)	4.3 (1.7)	98.5	6.0 (1.9)	95.0	96.8
68.	Citronella + Nilgiri + Pine	0.14 (each)	0.0 (0.0)	100.0	1.0 (0.6)	99.1	99.6
69.	Citronella + Eucalyptus + Pine	0.14 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
70.	Nilgiri + Eucalyptus + Pine	0.14 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
71.	Mint + Peppermint + Spearmint + Citronella	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
72.	Mint + Peppermint + Spearmint + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
73.	Mint + Peppermint + Spearmint + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
74.	Mint + Peppermint + Spearmint + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
75.	Mint + Peppermint + Citronella + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
76.	Mint + Peppermint + Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
77.	Mint + Peppermint + Citronella + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
78.	Mint + Peppermint + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
79.	Mint + Peppermint + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
80.	Mint + Peppermint + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
81.	Mint + Spearmint + Citronella + Nilgiri	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
82.	Mint + Spearmint + Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
83.	Mint + Spearmint + Citronella + Pine	0.1 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
84.	Mint + Spearmint + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
85.	Mint + Spearmint + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
86.	Mint + Spearmint + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
87.	Mint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	5.3 (1.5)	98.1	1.3 (0.8)	98.9	98.5
88.	Mint + Citronella + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
89.	Mint + Citronella + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
90.	Mint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
91.	Peppermint + Spearmint + Citronella + Nilgiri	0.1 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
92.	Peppermint + Spearmint+ Citronella + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
93.	Peppermint + Spearmint+ Citronella + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
94.	Peppermint + Spearmint + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
95.	Peppermint + Spearmint + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
96.	Peppermint + Spearmint + Eucalyptus + Pine	0.1 (each)	0.7 (0.4)	99.7	0.0 (0.0)	100.0	99.9
97.	Peppermint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

98.	Peppermint + Citronella + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
99.	Peppermint + Citronella + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
100.	Peppermint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
101.	Spearmint + Citronella + Nilgiri + Eucalyptus	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
102.	Spearmint + Citronella + Nilgiri + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
103.	Spearmint + Citronella + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
104.	Spearmint + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
105.	Citronella + Nilgiri + Eucalyptus + Pine	0.1 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
106.	Mint + Peppermint + Spearmint + Citronella + Nilgiri	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
107.	Mint + Peppermint + Spearmint + Citronella + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
108.	Mint + Peppermint + Spearmint + Citronella + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
109.	Mint + Peppermint + Spearmint + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
110.	Mint + Peppermint + Spearmint + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
111.	Mint + Peppermint + Spearmint + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
112.	Mint + Peppermint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
113.	Mint + Peppermint + Citronella + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
114.	Mint + Peppermint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
115.	Mint + Peppermint + Nilgiri + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
116.	Mint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
117.	Mint + Spearmint + Citronella + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
118.	Mint + Spearmint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
119.	Mint + Spearmint + Nilgiri+ Eucalyptus + Pine+ Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
120.	Mint + Citronella + Nilgiri+ Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
121.	Peppermint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
122.	Peppermint + Spearmint + Citronella + Nilgiri + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
123.	Peppermint + Spearmint + Citronella + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
124.	Peppermint + Spearmint + Nilgiri + Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
125.	Peppermint + Citronella + Nilgiri + Eucalyptus + Pine	0.08 (each)	1.7 (0.8)	99.4	0.0 (0.0)	100.0	99.7
126.	Spearmint + Citronella + Nilgiri+ Eucalyptus + Pine	0.08 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
127.	Mint+ Peppermint + Spearmint + Citronella + Nilgiri + Eucalyptus	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0

128.	Mint + Peppermint+ Spearmint+ Citronella+ Nilgiri + Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
129.	Mint + Peppermint+ Spearmint+ Citronella + Eucalyptus + Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
130.	Mint + Peppermint+ Spearmint + Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.7 (0.4)	99.7	0.0 (0.0)	100.0	99.9
131.	Mint + Peppermint + Citronella + Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.3 (0.2)	99.8	0.0 (0.0)	100.0	99.9
132.	Mint + Spearmint + Citronella+ Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
133.	Peppermint + Spearmint+ Citronella+ Nilgiri+ Eucalyptus+ Pine	0.07 (each)	0.7 (0.4)	99.7	0.0 (0.0)	100.0	99.9
134.	Mint+Peppermint+Spearmint+Citronella +Nilgiri+Eucalyptus+Pine	0.06 (each)	0.0 (0.0)	100.0	0.0 (0.0)	100.0	100.0
135.	Peppermint + Eucalyptus	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
136.	Peppermint + Pine	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
137.	Eucalyptus + Pine	0.1+0.1	–	–	0.0 (0.0)	100.0	100.0
138.	Untreated control	–	292.7 (5.7)	–	120.0 (4.8)	–	
S.Em.±			4.2 (0.2)	–	0.7 (0.1)	–	
CD at 5%			11.7 (0.7)	–	1.9 (0.3)	–	

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

while it was found to be highly effective against *S. oryzae*. The combinations of citronella + Nilgiri and Nilgiri + eucalyptus was highly effective against *R. dominica* but it showed moderate and least efficacy, respectively, against *S. oryzae*. Three oils combination of peppermint + Nilgiri + eucalyptus was found to be highly effective against *R. dominica* while it was moderately effective against *S. oryzae.* Rest of the combinations were highly effective against both the insects. Fumigation of grain by combination of peppermint + eucalyptus, peppermint + pine and eucalyptus + pine at 0.10+0.10 per cent resulted in complete suppression of progeny of *R. dominica* and *S. oryzae.* Such finding indicated that other combinations may also be highly effective against both the insects at lower concentrations and further attempts should be made to study the fumigant toxicity of various combinations at reduced rate as it may reduce the cost of treatment.

CONCLUSION

The study revealed that essential oils of mint, peppermint, spearmint, citronella, Nilgiri, eucalyptus and pine and their two, three, four, five, six and seven oil combinations are highly effective against *R. dominica* and *S. oryzae* due to which they may be used for protection of grain against these insect pests. It also became very clear that many of these combinations may retain their high fumigant toxicity even at lower concentrations and further experiments should be conducted to reduce their dose without compromising their efficacy. As the cost of the essential oils is known to vary widely, attempt should be made to choose the components which are economical. Furthermore, attempt should also be made to study their efficacy under natural condition in big storage receptacles.

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