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CONTENTS

Long term efficacy of different herbal fumigants against *Rhyzopertha dominica* (Fabricius) and *Tribolium castaneum* (Herbst)

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ABSTRACT: Laboratory experiments were conducted to study the long-term efficacy of 141 formulations of herbal fumigants against *Rhyzopertha dominica* and *Tribolium castaneum.* The herbal fumigants were formulated by compounding the essential oils of *Mentha arvensis, Mentha piperita, Mentha spicata, Cymbopogon winterianus, Eucalyptus citriodora, Curcuma longa* and *Pinus roxburghii* at different concentrations. All seven essential oils were studied at 0.20 and 0.40 per cent (v/w) while their two, three, four, five, six and seven component combinations were evaluated at 0.20, 0.14, 0.10, 0.08, 0.07 and 0.06, per cent (v/w) each. Some other formulations such as *M. piperita* + *C. longa*, *M. piperita* + *P. roxburghii*, *C. longa* + *P. roxburghii*, *C. longa* + *M. arvensis* and *P. roxburghii* + *M. arvensis* were also evaluated at 0.10+0.10 per cent each while *C. longa* + *M. arvensis* and *P. roxburghii* + *M. arvensis* were tested at 0.30+ 0.10 per cent against both the insects. The test insects were reared on the grain treated with different formulations. The number of progenies produced by 10 adult insects were counted after 469 and 446 days, in case of *R. dominica* and *T. castaneum*, respectively. Inhibition of progeny by test formulation was calculated by using the number of adults emerged in treated and untreated grain. No adult of *R. dominica* emerged in any of the treatment after 469 days while 386 adults emerged from untreated grain. In case of *T. castaneum*, 153.3 adults emerged from untreated grain after 446 days while treated grain did not permit any adult. The results indicated that all the formulations of herbal fumigants completely checked the progeny production of both the insects for more than a year.

Key words: Essential oils, fumigant toxicity, herbal fumigants, *Rhyzopertha dominica*, stored wheat, storage insects, *Tribolium castaneum*

India is estimated to lose 14 million tonnes of food grains in storage annually worth Rs 7000 crore, of which about Rs 1300 crore is lost due to insects alone (IGSMRI, 2019). Due to limited pest control options and lack of scientific storage facilities at farmers level, we are not successful in reducing such post-harvest losses due to insect pests. In India and many other countries, phosphine is the only chemical which is recommended for use under technical supervision. Since most of the farmers don't have any training for its use and airtight storage facilities, injudicious application of this highly poisonous chemical results in to various types of health hazards in addition to development of resistance in insect pests. In such a situation, efforts are being made to find a safer alternative and over the past six decades, many plants have been investigated for their insect control properties (Jacobson, 1975; Golob and Webley, 1980; Jacobson,1983; Grainge and Ahmed, 1988). Many essential oils of plant origin have also shown appreciable antifeedant, ovicidal, oviposition inhibitory, repellent and fumigant toxicity against storage insects (Don- Pedro, 1996; Clemente *et al.*, 2003; Pascual and Ballesta, 2003; Singh *et al.*,1989; Shaaya *et al.*, 1990, 1997; Tiwari, 1993; Singh and Upadhyay, 1993; Regnault-Roger, 1997; Tunc *et al.*, 2000; Tripathi *et al.*, 2002; Lee *et al.*, 2002, 2004; Ngamo *et al.,* 2007 ; Tewari, 2008; Rajendran and Sriranjini, 2008; Geetanjly *et al.,* 2016; Gangwar and Tiwari, 2017; Kumar and Tiwari, 2017a; 2017b; Kumar *et al.*, 2018; Joshi and Tiwari, 2019; Geetanjly and Tiwari, 2021;Tewari and Tiwari, 2021a; 2021b; 2021c; 2021d; Kumari and Tiwari, 2022a; 2022b; 2022c; Kumari and Tiwari, 2023). The review of literature indicates that majority of plants do not show appreciable activity against all the insect pest of stored grain due to which

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they have very limited practical applicability.

Furthermore, their efficacy is limited for short duration due to which they cannot be used for the protection of grain in long term storage. Tewari and Tewari (2021c) studied the fumigant toxicity of seven essential oils and their 2,3,4,5,6 and 7 oil combinations against *R. dominica* and *S. oryzae*, however, they could not report the long-term efficacy of these formulations because of termination of experiment after completion of only one generation. Since most of the oils were found to be highly effective against both the insects, the present investigation was undertaken to study their long-term efficacy against *R. dominica* and *T. castaneum* for longer duration of more than one year. The study may reveal the potential of several herbal fumigants in long term protection of grain against storage insect pests.

MATERIALS AND METHODS

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

Rearing of Rhyzopertha dominica and Tribolium castaneum

Pure culture of test insects was developed in the control room of laboratory 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. The adults of *R. dominica* were reared on the grain of wheat variety PBW-343 while *T. castaneum* was cultured on its flour fortified with 5 per cent yeast powder. 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 was kept in incubator. First generation adults (0-7 days old) were used for experimental purpose.

Preparation of Grain for Experiment

All fumigation experiments on *R. dominica* and *T. castaneum* 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 as described in previous section. 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.

Procurement of Oil for Experiment

To ensure the purity and quality, the oils selected for the study were collected from the Medicinal and Aromatic Plants Research and Development Centre, Haldi and Central Institute of Medicinal and

Table 1: Scientific and common names of the plants, the essential oils of which was used for study

Sl. No.	Scientific name	Common name
1	*Mentha arvensis*	Mint
2	*Mentha piperita*	Peppermint
3	*Mentha spicata*	Spearmint
4	*Cymbopogon winterianus*	Citronella
5	*Eucalyptus citriodora*	Nilgiri
6	*Curcuma longa*	Turmeric
7	*Pinus roxburghii*	Pine

Aromatic Plants, Field Station, Nagla (Uttarakhand) and Central Institute of Medicinal and Aromatic Plants, Lucknow (Uttar Pradesh). The common and scientific name of plants, the oils used in the experiment are given in Table 1.

Experimental Details

The herbal fumigants were formulated by mixing different essential oils as per composition and concentrations given in Table 2 and 3. The experiment was conducted in control room at 27±1°C temperature and 70±5 per cent relative humidity on wheat variety PBW-343 (13.5 per cent moisture content). Fifty-gram grain was filled in 100ml capacity plastic vial. Each treatment was replicated three times. After filling the grain in plastic vial 10 adults (0-7 days old) of *R. dominica*

Table 2: Effect of different formulations of herbal fumigants on progeny production of *R. dominica*

S. No.	Component	Conc.% (v/w)	No. of adults emerged	Percent Inhibition	Days after fumigation
1	*M. arvensis*	0.2	0.0±0.0	100	469
2	*M. piperita*	0.2	0.0±0.0	100	469
3	*M. spicata*	0.2	0.0±0.0	100	469
4	*C. winterianus*	0.2	0.0±0.0	100	469
5	*E. citriodora*	0.2	0.0±0.0	100	469
6	*C. longa*	0.2	0.0±0.0	100	469
7	*P. roxburghii*	0.2	0.0±0.0	100	469
8	*M. arvensis*	0.4	0.0±0.0	100	469
9	*M. piperita*	0.4	0.0±0.0	100	469
10	*M. spicata*	0.4	0.0±0.0	100	469
11	*C. winterianus*	0.4	0.0±0.0	100	469
12	*E. citriodora*	0.4	0.0±0.0	100	469
13	*C. longa*	0.4	0.0±0.0	100	469
14	*P. roxburghii*	0.4	0.0±0.0	100	469
15	*M. arvensis* + *M. piperita*	0.2+0.2	0.0±0.0	100	469
16	*M. arvensis* + *M. spicata*	0.2+0.2	0.0±0.0	100	469
17	*M. arvensis* + *C. winterianus*	0.2+0.2	0.0±0.0	100	469
18	*M. arvensis* + *E. citriodora*	0.2+0.2	0.0±0.0	100	469
19	*M. arvensis* + *C. longa*	0.2+0.2	0.0±0.0	100	469
20	*M. arvensis* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
21	*M. piperita* + *M. spicata*	0.2+0.2	0.0±0.0	100	469
22	*M. piperita* + *C. winterianus*	0.2+0.2	0.0±0.0	100	469
23	*M. piperita* + *E. citriodora*	0.2+0.2	0.0±0.0	100	469
24	*M. piperita* + *C. longa*	0.2+0.2	0.0±0.0	100	469
25	*M. piperita* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
26	*M. spicata* + *C. winterianus*	0.2+0.2	0.0±0.0	100	469
27	*M. spicata* + *E. citriodora*	0.2+0.2	0.0±0.0	100	469
28	*M. spicata* + *C. longa*	0.2+0.2	0.0±0.0	100	469
29	*M. spicata* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
30	*C. winterianus* + *E. citriodora*	0.2+0.2	0.0±0.0	100	469
31	*C. winterianus* + *C. longa*	0.2+0.2	0.0±0.0	100	469
32	*C. winterianus* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
33	*E. citriodora* + *C. longa*	0.2+0.2	0.0±0.0	100	469
34	*E. citriodora* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
35	*C. longa* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	469
36	*M. arvensis* + *M. piperita* + *M. spicata*	0.14 E	0.0±0.0	100	469
37	*M. arvensis* + *M. piperita* + *C. winterianus*	0.14 E	0.0±0.0	100	469
38	*M. arvensis* + *M. piperita* + *E. citriodora*	0.14 E	0.0±0.0	100	469
39	*M. arvensis* + *M. piperita* + *C. longa*	0.14 E	0.0±0.0	100	469
40	*M. arvensis* + *M. piperita* + *P. roxburghii*	0.14 E	0.0±0.0	100	469
41	*M. arvensis* +*M. spicata* + *C. winterianus*	0.14 E	0.0±0.0	100	469

42	*M. arvensis + M. spicata + E. citriodora*	0.14 E	0.0±0.0	100	469
43	*M. arvensis + M. spicata + C. longa*	0.14 E	0.0±0.0	100	469
44	*M. arvensis + M. spicata + P. roxburghii*	0.14E	0.0±0.0	100	469
45	*M. arvensis + C. winterianus + E. citriodora*	0.14 E	0.0±0.0	100	469
46	*M. arvensis + C. winterianus + C. longa*	0.14 E	0.0±0.0	100	469
47	*M. arvensis + C. winterianus + P. roxburghii*	0.14 E	0.0±0.0	100	469
48	*M. arvensis + E. citriodora + C. longa*	0.14 E	0.0±0.0	100	469
49	*M. arvensis + E. citriodora + P. roxburghii*	0.14 E	0.0±0.0	100	469
50	*M. arvensis + C. longa + P. roxburghii*	0.14 E	0.0±0.0	100	469
51	*M. piperita+ M. spicata+ C. winterianus*	0.14 E	0.0±0.0	100	469
52	*M. piperita + M. spicata + E. citriodora*	0.14 E	0.0±0.0	100	469
53	*M. piperita+ M. spicata + C. longa*	0.14 E	0.0±0.0	100	469
54	*M. piperita+ M. spicata + P. roxburghii*	0.14 E	0.0±0.0	100	469
55	*M. piperita+ C. winterianus + E. citriodora*	0.14 E	0.0 ± 0.0	100	469
56	*M. piperita+ C. winterianus + C. longa*	0.14 E	0.0 ± 0.0	100	469
57	*M. piperita+ C. winterianus + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
58	*M. piperita + E. citriodora + C. longa*	0.14 E	0.0 ± 0.0	100	469
59	*M. piperita + E. citriodora + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
60	*M. piperita + C. longa + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
61	*M. spicata + C. winterianus + E. citriodora*	0.14 E	0.0 ± 0.0	100	469
62	*M. spicata + C. winterianus + C. longa*	0.14 E	0.0 ± 0.0	100	469
63	*M. spicata + C. winterianus + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
64	*M. spicata + E. citriodora + C. longa*	0.14 E	0.0 ± 0.0	100	469
65	*M. spicata + E. citriodora + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
66	*M. spicata + C. longa + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
67	*C. winterianus + E. citriodora + C. longa*	0.14 E	0.0 ± 0.0	100	469
68	*C. winterianus + E. citriodora + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
69	*C. winterianus + C. longa + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
70	*E. citriodora + C. longa + P. roxburghii*	0.14 E	0.0 ± 0.0	100	469
71	*M. arvensis+ M. piperita+ M. spicata+ C. winterianus*	0.1 E	0.0 ± 0.0	100	469
72	*M. arvensis+ M. piperita+ M. spicata+ E. citriodora*	0.1 E	0.0 ± 0.0	100	469
73	*M. arvensis+ M. piperita+ M. spicata+ C. longa*	0.1 E	0.0 ± 0.0	100	469
74	*M. arvensis + M. piperita + M. spicata + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
75	*M. arvensis + M. piperita + C. winterianus + E. citriodora*	0.1 E	0.0 ± 0.0	100	469
76	*M. arvensis + M. piperita + C. winterianus + C. longa*	0.1 E	0.0 ± 0.0	100	469
77	*M. arvensis + M. piperita + C. winterianus + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
78	*M. arvensis + M. piperita + E. citriodora + C. longa*	0.1 E	0.0 ± 0.0	100	469
79	*M. arvensis + M. piperita + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
80	*M. arvensis + M. piperita + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
81	*M. arvensis + M. spicata + C. winterianus + E. citriodora*	0.1 E	0.0 ± 0.0	100	469
82	*M. arvensis + M. spicata + C. winterianus + C. longa*	0.1 E	0.0 ± 0.0	100	469
83	*M. arvensis + M. spicata + C. winterianus + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
84	*M. arvensis + M. spicata + E. citriodora + C. longa*	0.1 E	0.0 ± 0.0	100	469
85	*M. arvensis + M. spicata + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
86	*M. arvensis + M. spicata + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
87	*M. arvensis + C. winterianus + E. citriodora + C. longa*	0.1 E	0.0 ± 0.0	100	469
88	*M. arvensis + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
89	*M. arvensis + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
90	*M. arvensis + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
91	*M. piperita+ M. spicata+ C. winterianus+ E. citriodora*	0.1 E	0.0 ± 0.0	100	469
92	*M. piperita+ M. spicata + C. winterianus+ C. longa*	0.1 E	0.0 ± 0.0	100	469
93	*M. piperita + M. spicata+ C. winterianus + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
94	*M. piperita+ M. spicata+ E. citriodora +C. longa*	0.1 E	0.0 ± 0.0	100	469
95	*M. piperita + M. spicata + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
96	*M. piperita + M. spicata + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
97	*M. piperita+ C. winterianus + E. citriodora + C. longa*	0.1 E	0.0 ± 0.0	100	469

98	*M. piperita + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
99	*M. piperita + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
100	*M. piperita + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
101	*M. spicata + C. winterianus + E. citriodora + C. longa*	0.1 E	0.0 ± 0.0	100	469
102	*M. spicata + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
103	*M. spicata + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
104	*M. spicata + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
105	*C. winterianus + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0 ± 0.0	100	469
106	*M. arvensis+ M. piperita+ M. spicata + C. winterianus + E. citriodora*	0.08 E	0.0 ± 0.0	100	469
107	*M. arvensis + M. piperita + M. spicata + C. winterianus + C. longa*	0.08 E	0.0 ± 0.0	100	469
108	*M. arvensis+ M. piperita + M. spicata + C. winterianus + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
109	*M. arvensis + M. piperita + M. spicata + E. citriodora + C. longa*	0.08 E	0.0 ± 0.0	100	469
110	*M. arvensis+ M. piperita+ M. spicata+ E. citriodora+ P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
111	*M. arvensis+ M. piperita + M. spicata + C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
112	*M. arvensis + M. piperita + C. winterianus + E. citriodora + C. longa*	0.08 E	0.0 ± 0.0	100	469
113	*M. arvensis+ M. piperita + C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
114	*M. arvensis + M. piperita + C. winterianus + C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
115	*M. arvensis + M. piperita + E. citriodora + C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
116	*M. arvensis+ M. spicata+ C. winterianus+ E. citriodora+ C. longa*	0.08 E	0.0 ± 0.0	100	469
117	*M. arvensis +M. spicata+ C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
118	*M. arvensis+ M. spicata+ C. winterianus+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
119	*M. arvensis + M. spicata + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
120	*M. arvensis + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
121	*M. piperita + M. spicata + C. winterianus + E. citriodora + C. longa*	0.08 E	0.0 ± 0.0	100	469
122	*M. piperita + M. spicata + C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
123	*M. piperita + M. spicata + C. winterianus + C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
124	*M. piperita+ M. spicata+ E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
125	*M. piperita+ C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
126	*M. spicata + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0 ± 0.0	100	469
127	*M. arvensis+ M. piperita+ M. spicata + C. winterianus + E. citriodora + C. longa*	0.07 E	0.0 ± 0.0	100	469
128	*M. arvensis + M. piperita+ M. spicata+ C. winterianus+ E. citriodora + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
129	*M. arvensis + M. piperita+ M. spicata+ C. winterianus + C. longa + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
130	*M. arvensis + M. piperita+ M. spicata + E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
131	*M. arvensis + M. piperita + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
132	*M. arvensis + M. spicata + C. winterianus+ E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
133	*M. piperita + M. spicata+ C. winterianus+ E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0 ± 0.0	100	469
134	*M. arvensis+ M. piperita+ M. spicata+ C. winterianus+ E. citriodora+ C. longa +P. roxburghii*	0.06 E	0.0 ± 0.0	100	469
135	*M. piperita + C. longa*	0.1+0.1	0.0 ± 0.0	100	469
136	*M. piperita + P. roxburghii*	0.1+0.1	0.0 ± 0.0	100	469
137	*C. longa + P. roxburghii*	0.1+0.1	0.0 ± 0.0	100	469
138	*C. longa + M. arvensis*	0.1+ 0.1	0.0 ± 0.0	100	469
139	*C. longa + M. arvensis*	0.3+ 0.1	0.0 ± 0.0	100	469
140	*P. roxburghii+ M. arvensis*	0.1+0.1	0.0 ± 0.0	100	469
141	*P. roxburghii + M. arvensis*	0.3+0.1	0.0 ± 0.0	100	469
142	*Untreated control*	_	386.0±70.7	0	469

E= each

or *T. castaneum* were released in each vial. Measured quantity of component oil was soaked on Whatman No. 42 filter paper disc (3.5 cm diameter) in the ratio indicated in the Table 2 and 3. The paper disc soaked

Table 3: Effect of different formulation of herbal fumigants on progeny production of *T. castaneum*

S.No.	Component	Conc. % (v/w)	No. of adults emerged	Percent Inhibition	Days after fumigation
1	*M. arvensis*	0.2	0.0±0.0	100	446
2	*M. piperita*	0.2	0.0±0.0	100	446
3	*M. spicata*	0.2	0.0±0.0	100	446
4	*C. winterianus*	0.2	0.0±0.0	100	446
5	*E. citriodora*	0.2	0.0±0.0	100	446
6	*C. longa*	0.2	0.0±0.0	100	446
7	*P. roxburghii*	0.2	0.0±0.0	100	446
8	*M. arvensis*	0.4	0.0±0.0	100	446
9	*M. piperita*	0.4	0.0±0.0	100	446
10	*M. spicata*	0.4	0.0±0.0	100	446
11	*C. winterianus*	0.4	0.0±0.0	100	446
12	*E. citriodora*	0.4	0.0±0.0	100	446
13	*C. longa*	0.4	0.0±0.0	100	446
14	*P. roxburghii*	0.4	0.0±0.0	100	446
15	*M. arvensis* + *M. piperita*	0.2+0.2	0.0±0.0	100	446
16	*M. arvensis* + *M. spicata*	0.2+0.2	0.0±0.0	100	446
17	*M. arvensis* + *C. winterianus*	0.2+0.2	0.0±0.0	100	446
18	*M. arvensis* + *E. citriodora*	0.2+0.2	0.0±0.0	100	446
19	*M. arvensis* + *C. longa*	0.2+0.2	0.0±0.0	100	446
20	*M. arvensis* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
21	*M. piperita* + *M. spicata*	0.2+0.2	0.0±0.0	100	446
22	*M. piperita* + *C. winterianus*	0.2+0.2	0.0±0.0	100	446
23	*M. piperita* + *E. citriodora*	0.2+0.2	0.0±0.0	100	446
24	*M. piperita* + *C. longa*	0.2+0.2	0.0±0.0	100	446
25	*M. piperita* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
26	*M. spicata* + *C. winterianus*	0.2+0.2	0.0±0.0	100	446
27	*M. spicata* + *E. citriodora*	0.2+0.2	0.0±0.0	100	446
28	*M. spicata* + *C. longa*	0.2+0.2	0.0±0.0	100	446
29	*M. spicata* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
30	*C. winterianus* + *E. citriodora*	0.2+0.2	0.0±0.0	100	446
31	*C. winterianus* + *C. longa*	0.2+0.2	0.0±0.0	100	446
32	*C. winterianus* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
33	*E. citriodora* + *C. longa*	0.2+0.2	0.0±0.0	100	446
34	*E. citriodora* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
35	*C. longa* + *P. roxburghii*	0.2+0.2	0.0±0.0	100	446
36	*M. arvensis* + *M. piperita* + *M. spicata*	0.14 E	0.0±0.0	100	446
37	*M. arvensis* + *M. piperita* + *C. winterianus*	0.14 E	0.0±0.0	100	446
38	*M. arvensis* + *M. piperita* + *E. citriodora*	0.14 E	0.0±0.0	100	446
39	*M. arvensis* + *M. piperita* + *C. longa*	0.14 E	0.0±0.0	100	446
40	*M. arvensis* + *M. piperita* + *P. roxburghii*	0.14 E	0.0±0.0	100	446
41	*M. arvensis* +*M. spicata* + *C. winterianus*	0.14 E	0.0±0.0	100	446
42	*M. arvensis* + *M. spicata* + *E. citriodora*	0.14 E	0.0±0.0	100	446
43	*M. arvensis* + *M. spicata* + *C. longa*	0.14 E	0.0±0.0	100	446
44	*M. arvensis* + *M. spicata* + *P. roxburghii*	0.14 E	0.0±0.0	100	446
45	*M. arvensis* + *C. winterianus* + *E. citriodora*	0.14 E	0.0±0.0	100	446
46	*M. arvensis* + *C. winterianus* + *C. longa*	0.14 E	0.0±0.0	100	446
47	*M. arvensis* + *C. winterianus* + *P. roxburghii*	0.14 E	0.0±0.0	100	446
48	*M. arvensis* + *E. citriodora* + *C. longa*	0.14 E	0.0±0.0	100	446
49	*M. arvensis* + *E. citriodora* + *P. roxburghii*	0.14 E	0.0±0.0	100	446
50	*M. arvensis* + *C. longa* + *P. roxburghii*	0.14 E	0.0±0.0	100	446
51	*M. piperita*+ *M. spicata*+ *C. winterianus*	0.14 E	0.0±0.0	100	446
52	*M. piperita* + *M. spicata* + *E. citriodora*	0.14 E	0.0±0.0	100	446

53	*M. piperita+ M. spicata + C. longa*	0.14 E	0.0±0.0	100	446
54	*M. piperita+ M. spicata + P. roxburghii*	0.14 E	0.0±0.0	100	446
55	*M. piperita+ C. winterianus + E. citriodora*	0.14 E	0.0±0.0	100	446
56	*M. piperita+ C. winterianus + C. longa*	0.14 E	0.0±0.0	100	446
57	*M. piperita+ C. winterianus + P. roxburghii*	0.14 E	0.0±0.0	100	446
58	*M. piperita + E. citriodora + C. longa*	0.14 E	0.0±0.0	100	446
59	*M. piperita + E. citriodora + P. roxburghii*	0.14 E	0.0±0.0	100	446
60	*M. piperita + C. longa + P. roxburghii*	0.14 E	0.0±0.0	100	446
61	*M. spicata + C. winterianus + E. citriodora*	0.14 E	0.0±0.0	100	446
62	*M. spicata + C. winterianus + C. longa*	0.14 E	0.0±0.0	100	446
63	*M. spicata + C. winterianus + P. roxburghii*	0.14 E	0.0±0.0	100	446
64	*M. spicata + E. citriodora + C. longa*	0.14 E	0.0±0.0	100	446
65	*M. spicata + E. citriodora + P. roxburghii*	0.14 E	0.0±0.0	100	446
66	*M. spicata + C. longa + P. roxburghii*	0.14 E	0.0±0.0	100	446
67	*C. winterianus + E. citriodora + C. longa*	0.14 E	0.0±0.0	100	446
68	*C. winterianus + E. citriodora + P. roxburghii*	0.14 E	0.0±0.0	100	446
69	*C. winterianus + C. longa + P. roxburghii*	0.14 E	0.0±0.0	100	446
70	*E. citriodora + C. longa + P. roxburghii*	0.14 E	0.0±0.0	100	446
71	*M. arvensis+ M. piperita+ M. spicata+ C. winterianus*	0.1 E	0.0±0.0	100	446
72	*M. arvensis+ M. piperita+ M. spicata+ E. citriodora*	0.1 E	0.0±0.0	100	446
73	*M. arvensis+ M. piperita+ M. spicata+ C. longa*	0.1 E	0.0±0.0	100	446
74	*M. arvensis + M. piperita + M. spicata + P. roxburghii*	0.1 E	0.0±0.0	100	446
75	*M. arvensis + M. piperita + C. winterianus + E. citriodora*	0.1 E	0.0±0.0	100	446
76	*M. arvensis + M. piperita + C. winterianus + C. longa*	0.1 E	0.0±0.0	100	446
77	*M. arvensis + M. piperita + C. winterianus + P. roxburghii*	0.1 E	0.0±0.0	100	446
78	*M. arvensis + M. piperita + E. citriodora + C. longa*	0.1 E	0.0±0.0	100	446
79	*M. arvensis + M. piperita + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
80	*M. arvensis + M. piperita + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
81	*M. arvensis + M. spicata + C. winterianus + E. citriodora*	0.1 E	0.0±0.0	100	446
82	*M. arvensis + M. spicata + C. winterianus + C. longa*	0.1 E	0.0±0.0	100	446
83	*M. arvensis + M. spicata + C. winterianus + P. roxburghii*	0.1 E	0.0±0.0	100	446
84	*M. arvensis + M. spicata + E. citriodora + C. longa*	0.1 E	0.0±0.0	100	446
85	*M. arvensis + M. spicata + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
86	*M. arvensis + M. spicata + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
87	*M. arvensis + C. winterianus + E. citriodora + C. longa*	0.1 E	0.0±0.0	100	446
88	*M. arvensis + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
89	*M. arvensis + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
90	*M. arvensis + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
91	*M. piperita+ M. spicata+ C. winterianus+ E. citriodora*	0.1 E	0.0±0.0	100	446
92	*M. piperita+ M. spicata + C. winterianus+ C. longa*	0.1 E	0.0±0.0	100	446
93	*M. piperita + M. spicata+ C. winterianus + P. roxburghii*	0.1 E	0.0±0.0	100	446
94	*M. piperita+ M. spicata+ E. citriodora +C. longa*	0.1 E	0.0±0.0	100	446
95	*M. piperita + M. spicata + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
96	*M. piperita + M. spicata + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
97	*M. piperita+ C. winterianus + E. citriodora + C. longa*	0.1 E	0.0±0.0	100	446
98	*M. piperita + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
99	*M. piperita + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
100	*M. piperita + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
101	*M. spicata + C. winterianus + E. citriodora + C. longa*	0.1 E	0.0±0.0	100	446
102	*M. spicata + C. winterianus + E. citriodora + P. roxburghii*	0.1 E	0.0±0.0	100	446
103	*M. spicata + C. winterianus + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
104	*M. spicata + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
105	*C. winterianus + E. citriodora + C. longa + P. roxburghii*	0.1 E	0.0±0.0	100	446
106	*M. arvensis+ M. piperita+ M. spicata + C. winterianus + E. citriodora*	0.08 E	0.0±0.0	100	446
107	*M. arvensis + M. piperita + M. spicata + C. winterianus + C. longa*	0.08 E	0.0±0.0	100	446
108	*M. arvensis+ M. piperita + M. spicata + C. winterianus + P. roxburghii*	0.08 E	0.0±0.0	100	446
109	*M. arvensis + M. piperita + M. spicata + E. citriodora + C. longa*	0.08 E	0.0±0.0	100	446

110	*M. arvensis+ M. piperita+ M. spicata+ E. citriodora+ P. roxburghii*	0.08 E	0.0±0.0	100	446
111	*M. arvensis+ M. piperita + M. spicata + C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
112	*M. arvensis + M. piperita + C. winterianus + E. citriodora + C. longa*	0.08 E	0.0±0.0	100	446
113	*M. arvensis+ M. piperita + C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0±0.0	100	446
114	*M. arvensis + M. piperita + C. winterianus + C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
115	*M. arvensis + M. piperita + E. citriodora + C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
116	*M. arvensis+ M. spicata+ C. winterianus+ E. citriodora+ C. longa*	0.08 E	0.0±0.0	100	446
117	*M. arvensis +M. spicata+ C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0±0.0	100	446
118	*M. arvensis+ M. spicata+ C. winterianus+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
119	*M. arvensis + M. spicata + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
120	*M. arvensis + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
121	*M. piperita + M. spicata + C. winterianus + E. citriodora + C. longa*	0.08 E	0.0±0.0	100	446
122	*M. piperita + M. spicata + C. winterianus + E. citriodora + P. roxburghii*	0.08 E	0.0±0.0	100	446
123	*M. piperita + M. spicata + C. winterianus + C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
124	*M. piperita+ M. spicata+ E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
125	*M. piperita+ C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
126	*M. spicata + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.08 E	0.0±0.0	100	446
127	*M. arvensis+ M. piperita+ M. spicata + C. winterianus + E. citriodora + C. longa*	0.07 E	0.0±0.0	100	446
128	*M. arvensis + M. piperita+ M. spicata+ C. winterianus+ E. citriodora + P. roxburghii*	0.07 E	0.0±0.0	100	446
129	*M. arvensis + M. piperita+ M. spicata+ C. winterianus + C. longa + P. roxburghii*	0.07 E	0.0±0.0	100	446
130	*M. arvensis + M. piperita+ M. spicata + E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0±0.0	100	446
131	*M. arvensis + M. piperita + C. winterianus + E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0±0.0	100	446
132	*M. arvensis + M. spicata + C. winterianus+ E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0±0.0	100	446
133	*M. piperita + M. spicata+ C. winterianus+ E. citriodora+ C. longa + P. roxburghii*	0.07 E	0.0±0.0	100	446
134	*M. arvensis+ M. piperita+ M. spicata+ C. winterianus+ E. citriodora+ C. longa +P. roxburghii*	0.06 E	0.0±0.0	100	446
135	*M. piperita + C. longa*	0.1+0.1	0.0±0.0	100	446
136	*M. piperita + P. roxburghii*	0.1+0.1	0.0±0.0	100	446
137	*C. longa + P. roxburghii*	0.1+0.1	0.0±0.0	100	446
138	*C. longa + M. arvensis*	0.1+ 0.1	0.0±0.0	100	446
139	*C. longa + M. arvensis*	0.3+ 0.1	0.0±0.0	100	446
140	*P. roxburghii+ M. arvensis*	0.1+0.1	0.0±0.0	100	446
141	*P. roxburghii + M. arvensis*	0.3+0.1	0.0±0.0	100	446
142	*Untreated control*	_-	153.3±71.9	0	446

E=each

with herbal fumigant was inserted in the grain filled in vial which was closed 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 generations on the treated grains. The observations were recorded at 469 and 446 days after fumigation for *R. dominica* and *T. castaneum*, respectively, after which experiment was terminated as the untreated vial was completely rotten due to insect feeding. After 469- and 446-days storage each jar was analysed to count the number of adults emerged and percent inhibition by using the formula described by Adams and Schulten (1976).

$$\text{Percent inhibition} = \frac{\text{Control - treated}}{Control} \times 100$$

RESULTS AND DISCUSSION

The effect of different herbal fumigants on the progeny production of *R. dominica* is presented in

Table 2 which indicates that *Mentha arvensis*, *Mentha piperita*, *Mentha spicata, Cymbopogon winterianus*, *Eucalyptus citriodora*, *Curcuma longa* or *Pinus roxburghii* at 0.2 or 0.4 percent or their two component combination at 0.2 percent each, three component combination at 0.14 percent each, four component combination at 0.1 percent each, five component combination at 0.08 percent each or six component combination at 0.07 percent each or seven component combination at 0.06 percent each were highly effective against this insect as they completely checked the progeny production of it. Tewari and Tiwari (2021c) also reported that different formulations of seven essential oils *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora*, *E. globulus* and *P. roxburghii* were effective at 0.20, 0.40, 0.14, 0.13, 0.10, 0.08, 0.07, 0.06 percent against *S.* oryzae and *R. dominica*. The combination of *M. piperita* + *C. longa* or *M. piperita* + *P. roxburghii* or *C. longa* + *P. roxburghii* or *C. longa* + *M. arvensis* or *P. roxburghii* + *M. arvensis* at 0.1 percent each were also highly effective against this insect as they completely inhibited the progeny of it. Herbal fumigant having *C. longa* + *M. arvensis* at 0.3+0.1 percent or *P. roxburghii* + *M. arvensis* at 0.3+0.1 percent was also found highly effective against *R. dominica* for 469 days. Kumari and Tiwari (2023) also reported their high efficacy of tested formulations against *Sitophilus oryzae* for 515 days except for *M. arvensis, C. winterianus* and *Curcuma longa* at 0.2 percent each.

The effect of different formulation of herbal fumigant on the progeny production of *T. castaneum* is presented in Table 3 which indicates that all the formulations having *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora*, *C. longa* or *P. roxburghii* oil at 0.2 or 0.4 percent or their two components' combinations at 0.2 percent each, three component combination at 0.14 percent each or four component combination at 0.1 percent each or five component combinations at 0.08 percent each or six component combinations at 0.07 percent each or seven component combination at 0.06 percent each, completely checked the population development of this insect up to 446 days. Herbal fumigant having *M. piperita* + *C. longa* or *M. piperita* + *P. roxburghii* or *C. longa* + *P. roxburghii* or *C. longa* + *M. arvensis* or *P. roxburghii* + *M. arvensis* at 0.1 percent or *C. longa* + *M. arvensis* or *P. roxburghii* + *M. arvensis* at 0.3+0.1 percent were also highly effective against these insects for 446 days. Kumar *et al.* (2018) observed that herbal fumigants having *M. koenigii* + *C. reticulata, M. koenigii* + *C. longa, C. reticulata* + *C. longa* and *M. koenigii* + *C. reticulata* + *C. longa* protected the grain from infestation of *R. dominica, S. oryzae* and *T. castaneum* for one year without affecting the organoleptic properties of treated grain or its germination when used at 0.2%. A long-term study also indicated that essential oils of *M. arvensis, M. piperita, M. spicata, P. roxburghii, C. winterianus and E. globulus* were highly effective against *R. dominica* and *S. oryzae* at 0.40 per cent for 6 months (Tewari and Tiwari, 2021d).

CONCLUSION

The study revealed that all the seven essential oils of *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora*, *C. longa* or *P. roxburghii* at 0.20 and 0.40 per cent and their 2, 3, 4, 5, 6, 7 oil combinations at 0.14, 0.13, 0.10, 0.08, 0.07, 0.06 percent each were highly effective against *R. dominica* and *T. castaneum* up to 469 and 446 days, respectively. The formulations of essential oils having *M. piperita* + *C. longa* or *M. piperita* + *P. roxburghii* or *C. longa* + *P. roxburghii* or *C. longa* + *M. arvensis* or *P. roxburghii* + *M. arvensis* at 0.10 percent or *C. longa* + *M. arvensis* or *P. roxburghii* + *M. arvensis* at 0.30+0.10 percent were also highly effective against both the insects for the same duration. The study revealed several formulations of herbal fumigants which are highly effective against *R. dominica* and T. castaneum. These formulations have already been reported to be highly effective for 515 days against *S. oryzae*. Since *S. oryzae*, *R. dominica* and *T. castaneum* are the major insect pests of stored cereals in most part of India and other tropical and sub-tropical countries, these may prove to be an eco-friendly and cheap non-chemical alternative for the management of all above-mentioned pests under storage conditions. The wide availability of component plants in most of the countries may help to develop a local

alternative in most of the countries.

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