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CONTENTS

The effect of different formulations of herbal fumigant on progeny production of stored grain insect pest, *Sitophilus oryzae*(Linnaeus)

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ABSTRACT: The experiment was conducted to evaluate the long-term efficacy of different formulations seven essential oils and their combinations on the progeny productions of notorious stored grain pest, *Sitophilus oryzae* L. (Rice weevil). The essential oils of *Mentha arvensis* (Mint), *Mentha piperita* (Peppermint), *Mentha spicata* (Spearmint), *Cymbopogon winterianus* (Citronella), *Eucalyptus citriodora* (Nilgiri), *Curcuma longa* (Turmeric) and *Pinus roxburghii* at 0.2, 0.4 per cent concentration (v/w) and in combination of 0.2+0.2, 0.14, 0.1, 0.08, 0.07, 0.06, 0.1+0.1 and 0.3+0.1 per cent each were evaluated for this purpose. It was observed that all the formulations of herbal fumigants except *M. arvensis* oil, *C. winterianus* oil, *C. longa*oil at 0.2 per cent, *M. arvensis* + *C. longa* at 0.2 per cent each, *M. piperita* + *C. longa*, *C. longa* + *P. roxburghii*, *C. longa* + *M. arvensis* at 0.1 per cent each, *C. longa* + *M. arvensis* at 0.3+0.1 per cent completely inhibited the progeny production of *S. oryzae*. Herbal fumigants used at 0.4 per cent with sole component of *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora*, *C. longa* or *P. roxburghii* oil or their two-component combination 0.2 per cent each, three component combination at 0.14 per cent each, four component combination at 0.1 per cent each, five component combination at 0.08 per cent each, or six component combination at 0.07 per cent each or seven component combination at 0.06 per cent each completely inhibited the progeny production of *S. oryzae* up to 515 days showing high efficacy of these oils as herbal fumigants.

Key words: Essential oils, herbal fumigants, fumigant toxicity, Rice weevil, *Sitophilus oryzae*, stored grain

India has got the presidency of G-20 for the year 2023. Among various major issues that has to be discussed, sustainable development and self-reliance through organic farming is one of them. In India approximately 10 per cent of food grains is lost during storage, half of which is accounted for insect pests (Narang, 2002). At present, insecticides and chemical fumigants are being employed in small and large scale storage facilities to control stored grain insect pest to avoid post-harvest losses. These insect pests control methods have certain adverse effects and drawbacks on health of consumers and environment due to their faulty applications and residual toxicity resulting in diseases like cancer, which is of great concern globally. So, switching on to organic farming may act as a decisive factor to overcome this problem. And in this context when we talk about organic farming then all natural methods come into mind. Here then, comes the roles of botanicals and essential oils as an alternative for chemical-based control of pests in stored grains. Essential oils extracted from some plants have pest control properties, with some proving to be toxic (Don- Pedro, 1996; Clemente *et al.*, 2003), repellent (Pascual and Ballesta, 2003), antifeedant, ovicidal, or oviposition inhibitors in insect pests. These oils also reported to have fumigant toxicity (Singh *et al.*, 1989; Shaaya *et al.*, 1990, 1997; Tunc *et al.*, 2000; Tripathi *et al.*, 2002; Lee *et al.*, 2002, 2004; Ngamo *et al.,* 2007). In other studies, they have been proved effective as fumigants, grain protectants in solid or liquid form without even affecting the germination qualities of the grains (Tiwari, 1993; Tewari, 2008; Gangwar and Tiwari, 2017; Kumar and Tiwari, 2017; Kumar *et al.*, 2018; Joshi and Tiwari, 2019; Tewari and Tiwari, 2021a; 2021b; 2021c; 2021d; Kumari and Tiwari, 2022a; 2022b; 2022c). But very less work has been done to study the efficacy of these essential oils in different formulations. In view of above-mentioned facts, present study was undertaken to evaluate their efficacy on progeny production of *S.oryzae* which has been considered

**A part of Ph.D. Thesis submitted by senior author to G.B. Pant University of Agriculture & Technology, Pantnagar; Present Address: Department of Zoology, Govt. P.G. College, Bageshwar- 263642, Uttarakhand* very notorious pest of stored grains. Thus, essentials oils have very promising future as grain protectant and playing crucial role to boost up the business of organic farming.

MATERIALS AND METHODS

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

Development of Culture of Insects

Pure culture of test insects was developed in the control room maintained at 27°C±1 temperature and 70±5% relative humidity. Plastic jars of about 1.0 kg capacity were used for rearing purpose. At the center of the lid a hole of 1.8 cm diameter was made and covered with 30 mesh copper wire net to facilitate aeration in the jar. The adults of *Sitophilus oryzae* were reared on the grain of wheat variety PBW-343. Before use, grains were disinfected in the oven at 60° C for 12 hrs. After disinfestation the moisture content of the grain was measured and raised to 13.5 per cent by mixing water in the grain. The quantity of water required to raise the moisture content was calculated by using following formula as described by Pixton (1967).

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

Where,

W_1=Initial weight of grains; M_1=Initial moisture content; M_2= Final moisture content

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

Preparation of Grain for Experiment

All fumigation experiments on *S. oryzae* 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^{0}C 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

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

Experimental Details

In this study seven oils found highly effective in fumigant toxicity test were used for formulating multi-ingredient compositions of herbal fumigant as per details given in Table 2. 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 *S. oryzae* 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. Then the paper disc was inserted in the vial and the vial 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. Vial in which insect population was observed was opened to record the number of adults emerged from it at specific days after fumigation. The last observations were recorded at 515, days after fumigation for *S. oryzae,* after which experiment was terminated. After 515 days storage each jar was analysed to count the number of adults emerged and per cent inhibition by using the formula described by Adams and Schulten (1976).

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

RESULTS AND DISCUSSION

The effect of different formulations of herbal fumigant on progeny production of *S. oryzae* is presented in Table 2, which indicates that all the formulations of herbal fumigants except *M. arvensis* oil, *C. winterianus* oil, *C. longa* oil at 0.2 per cent (v/w), *M. arvensis* + *C. longa* at 0.2 per cent each, *M. piperita* + *C. longa*, *C. longa* + *P. roxburghii*, *C. longa* + *M. arvensis* at 0.1 per cent each, *C. longa* + *M. arvensis* at 0.3+0.1 per cent completely inhibited the progeny production of *S. oryzae*. In grains treated with *M. arvensis,C. winterianu*s and *C. longa* at 0.2 per cent concentration adults emerged within 92 days after fumigation.Suggesting *C. longa* oil to be least effective at 0.2 per cent followed by *M. arvensis* oil and *C. winterianu*s oil. Kumari and Tiwari (2022c) also reported *C. longa* oil to be ineffective at 0.2 per cent in controlling population build-up, infestation and weight loss due to *S. oryzae*. Whereas oils of *M. piperita*, *M. spicata*, *E. citriodora* and *P. roxburghii* were highly effective at 0.2 per cent even after 515 days of fumigations, as no adults emerged. These essential oils, *M. arvensis, M. piperita, M. spicata*, *C. winterianus*, *E. citriodora, C. longa* and *P. roxburghii* proved highly promising at 0.4 per cent as not a single adult emerged even after 515 days of fumigation. Tewari and Tiwari (2021d) also reported 100 per cent inhibition of population build-up of *S. oryzae* at 0.4 per cent (v/w) on grain treated with *M. piperita* and *M. spicata* and 99.3, 98.5, 97.7 and 90.8 per cent with *P. roxburghii*, *M. arvensis*, *E. citriodora* and *C. winterianus* respectively. The two component formulations of *M. arvensis* with other six oils *viz., M. arvensis + M. piperita, M. arvensis + M. spicata, M. arvensis + C. winterianus, M. arvensis + E. citriodora, M. arvensis + P. roxburghii oils* at 0.2 + 0.2 per cent each showed complete suppression of insect population after 515 days of fumigation. Only one formulation *M. arvensis* + *C. longa* oils at 0.2 + 0.2 per cent each was not effective as adults emerged from the treated vials within 92 days after fumigation.Similarly, the two component combinations of *M. piperita* with other five essential oils *M. piperita + M. spicata, M. piperita + C. winterianus, M. piperita + E. citriodora, + M. piperita + C. longa, M. piperita + P. roxburghii* was effective even 515 days after fumigation at 0.2 + 0.2 per cent each. Also, two component combination of *M. spicata viz.,M. spicata + C. winterianus, M. spicata + E. citriodora, M. spicata + C. longa* and *M. spicata + P. roxburghii* completely checked progeny at 0.2 + 0.2 per cent each. In the same way, *C. winterianus + E. citriodora, C. winterianus + C. longa, C. winterianus + P. roxburghii, E. citriodora + C. longa, E. citriodora +P. roxburghii, C. longa + P. roxburghii* found to be highly effective at 0.2 + 0.2 per cent each concentration.This suggested that *M. piperita, M. spicata*, *C. winterianus*, *C. longa* and *P. roxburghii* oil has high efficacy and fumigant potential in comparison to *M. arvensis*. Three component combination at 0.14 per cent each of essential oils completely suppressed insect progeny even after 515 days of treatment suggesting their long-term efficacy. The four component combinations of above -mentioned essential oils at 0.1 per cent each also observed to be very promising as herbal fumigants by completely inhibiting population build-up of test insect on stored grains. Similar results were also obtained for treatments that included five component combination of oils at 0.08 per cent concentration each even after 515 days. The six component combinations of essential oils at 0.07 per cent each also resulted in complete inhibition of test insect progeny. Even the seven component combinations of *M. arvensis+M. piperita+M.*

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

Table 2: Effect of different formulation of herbal fumigants on progeny production of *S. oryzae*

Component	Dose % (v/w)	No. of adults emerged	Per cent Inhibition	Days after fumigation
M. arvensis	0.2	183.0± 183.0	65.7	92
M. piperita	0.2	0.0 ± 0.0	100	515
M. spicata	0.2	0.0 ± 0.0	100	515
C. winterianus	0.2	101.0 ± 51.0	81	92
E. citriodora	0.2	0.0 ± 0.0	100	515
C. longa	0.2	379.0± 186.1	29	92
P. roxburghii	0.2	0.0 ± 0.0	100	515
M. arvensis	0.4	0.0 ± 0.0	100	515
M. piperita	0.4	0.0 ± 0.0	100	515
M. spicata	0.4	0.0 ± 0.0	100	515
C. winterianus	0.4	0.0 ± 0.0	100	515
E. citriodora	0.4	0.0 ± 0.0	100	515
C. longa	0.4	0.0 ± 0.0	100	515
P. roxburghii	0.4	0.0 ± 0.0	100	515
M. arvensis + *M. piperita*	0.2+0.2	0.0 ± 0.0	100	515
M. arvensis + *M. spicata*	0.2+0.2	0.0 ± 0.0	100	515
M. arvensis + *C. winterianus*	0.2+0.2	0.0 ± 0.0	100	515
M. arvensis + *E. citriodora*	0.2+0.2	0.0 ± 0.0	100	515
M. arvensis + *C. longa*	0.2+0.2	124.0± 124.0	76.8	92
M. arvensis + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
M. piperita + *M. spicata*	0.2+0.2	0.0 ± 0.0	100	515
M. piperita + *C. winterianus*	0.2+0.2	0.0 ± 0.0	100	515
M. piperita + *E. citriodora*	0.2+0.2	0.0 ± 0.0	100	515
M. piperita + *C. longa*	0.2+0.2	0.0 ± 0.0	100	515
M. piperita + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
M. spicata + *C. winterianus*	0.2+0.2	0.0 ± 0.0	100	515
M. spicata + *E. citriodora*	0.2+0.2	0.0 ± 0.0	100	515
M. spicata + *C. longa*	0.2+0.2	0.0 ± 0.0	100	515
M. spicata + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
C. winterianus + *E. citriodora*	0.2+0.2	0.0 ± 0.0	100	515
C. winterianus + *C. longa*	0.2+0.2	0.0 ± 0.0	100	515
C. winterianus + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
E. citriodora + *C. longa*	0.2+0.2	0.0 ± 0.0	100	515
E. citriodora + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
C. longa + *P. roxburghii*	0.2+0.2	0.0 ± 0.0	100	515
M. arvensis + *M. piperita* + *M. spicata*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. piperita* + *C. winterianus*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. piperita* + *E. citriodora*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. piperita* + *C. longa*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. piperita* + *P. roxburghii*	0.14 E	0.0 ± 0.0	100	515
M. arvensis +*M. spicata* + *C. winterianus*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. spicata* + *E. citriodora*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. spicata* + *C. longa*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *M. spicata* + *P. roxburghii*	0.14E	0.0 ± 0.0	100	515
M. arvensis + *C. winterianus* + *E. citriodora*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *C. winterianus* + *C. longa*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *C. winterianus* + *P. roxburghii*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *E. citriodora* + *C. longa*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *E. citriodora* + *P. roxburghii*	0.14 E	0.0 ± 0.0	100	515
M. arvensis + *C. longa* + *P. roxburghii*	0.14 E	0.0 ± 0.0	100	515
M. piperita+ *M. spicata*+ *C. winterianus*	0.14 E	0.0 ± 0.0	100	515
M. piperita + *M. spicata* + *E. citriodora*	0.14 E	0.0 ± 0.0	100	515
M. piperita+ *M. spicata* + *C. longa*	0.14 E	0.0 ± 0.0	100	515

M. piperita+ M. spicata + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. piperita+ C. winterianus + E. citriodora	0.14 E	0.0 ± 0.0	100	515
M. piperita+ C. winterianus + C. longa	0.14 E	0.0 ± 0.0	100	515
M. piperita+ C. winterianus + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. piperita + E. citriodora + C. longa	0.14 E	0.0 ± 0.0	100	515
M. piperita + E. citriodora + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. piperita + C. longa + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + E. citriodora	0.14 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + C. longa	0.14 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. spicata + E. citriodora + C. longa	0.14 E	0.0 ± 0.0	100	515
M. spicata + E. citriodora + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. spicata + C. longa + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
C. winterianus + E. citriodora + C. longa	0.14 E	0.0 ± 0.0	100	515
C. winterianus + E. citriodora + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
C. winterianus + C. longa + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
E. citriodora + C. longa + P. roxburghii	0.14 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata+ C. winterianus	0.1 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata+E. citriodora	0.1 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata+ C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + M. spicata + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + E. citriodora	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + E. citriodora + C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + C. winterianus + E. citriodora	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + C. winterianus + C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + C. winterianus + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + E. citriodora + C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + C. winterianus + E. citriodora + C. longa	0.1 E	0.0 ± 0.0	100	515
M. arvensis + C. winterianus + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + C. winterianus + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis + E. citriodora + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita+M. spicata+ C. winterianus+ E. citriodora	0.1 E	0.0 ± 0.0	100	515
M. piperita+M. spicata+C. winterianus+C. longa	0.1 E	0.0 ± 0.0	100	515
M. piperita + M. spicata+ C. winterianus + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita+M. spicata+E. citriodora+C. longa	0.1 E	0.0 ± 0.0	100	515
M. piperita + M. spicata + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita + M. spicata + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita+ C. winterianus + E. citriodora + C. longa	0.1 E	0.0 ± 0.0	100	515
M. piperita + C. winterianus + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita + C. winterianus + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. piperita + E. citriodora + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + E. citriodora + C. longa	0.1 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + E. citriodora + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. spicata + E. citriodora + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
C. winterianus + E. citriodora + C. longa + P. roxburghii	0.1 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata + C. winterianus + E. citriodora	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + M. spicata + C. winterianus + C. longa	0.08 E	0.0 ± 0.0	100	515
M. arvensis+ M. piperita + M. spicata + C. winterianus + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + M. spicata + E. citriodora + C. longa	0.08 E	0.0 ± 0.0	100	515

M. arvensis+M. piperita+M. spicata+E. citriodora+P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis+ M. piperita + M. spicata + C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + E. citriodora + C. longa	0.08 E	0.0 ± 0.0	100	515
M. arvensis+ M. piperita + C. winterianus + E. citriodora + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + E. citriodora + C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis+M. spicata+C. winterianus+E. citriodora+C. longa	0.08 E	0.0 ± 0.0	100	515
M. arvensis +M. spicata+ C. winterianus + E. citriodora + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis+M. spicata+C. winterianus+C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + E. citriodora+ C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis + C. winterianus + E. citriodora+ C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. piperita + M. spicata + C. winterianus + E. citriodora + C. longa	0.08 E	0.0 ± 0.0	100	515
M. piperita + M. spicata + C. winterianus + E. citriodora + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. piperita + M. spicata + C. winterianus + C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. piperita+M. spicata+E. citriodora+C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. piperita+C. winterianus +E. citriodora+C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. spicata + C. winterianus + E. citriodora+ C. longa + P. roxburghii	0.08 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata + C. winterianus + E. citriodora + C. longa	0.07 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita+ M. spicata+ C. winterianus+ E. citriodora + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita+ M. spicata+ C. winterianus + C. longa + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita+ M. spicata + E. citriodora+ C. longa + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. arvensis + M. piperita + C. winterianus + E. citriodora+ C. longa + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. arvensis + M. spicata + C. winterianus+ E. citriodora+ C. longa + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. piperita + M. spicata+ C. winterianus+ E. citriodora+ C. longa + P. roxburghii	0.07 E	0.0 ± 0.0	100	515
M. arvensis+M. piperita+M. spicata+C. winterianus+E. citriodora +C. longa +P. roxburghii	0.06 E	0.0 ± 0.0	100	515
M. piperita + C. longa	0.1+0.1	185.3 ± 98.0	65.3	92
M. piperita + P. roxburghii	0.1+0.1	0.0 ± 0.0	100	515
C. longa + P. roxburghii	0.1+0.1	617.0 ± 13.1	-15.5	92
C. longa + M. arvensis	0.1+ 0.1	480.3 ± 69.0	10	92
C. longa + M. arvensis	0.3+ 0.1	381.3±117.3	28.6	92
P. roxburghii+ M. arvensis	0.1+0.1	0.0 ± 0.0	100	515
P. roxburghii + M. arvensis	0.3+0.1	0.0 ± 0.0	100	515
Untreated control	_	534.0 ± 82.2	0	92

(E=each)

spicata+C. winterianus+E. citriodora+C. longa +P. roxburghii at 0.06 per cent each also had tremendous inhibiting effect on test insect progeny. Tewari and Tiwari (2021c) also found different formulations of seven essential oils *M. arvensis, M. piperita, M. spicata, C. winterianus, E. citriodora, E. globulus and P. roxburghii* effective at 0.20, 0.40, 0.14 or 0.13, 0.10, 0.08, 0.07, 0.06 per cent against *S. oryzae* and *R. dominica*. On the other hand, combinations of *M. piperita + P. roxburghii* and *P. roxburghii+ M. arvensis* at 0.1 + 0.1 per cent each and *P. roxburghii + M. arvensis* at 0.3+0.1 per cent each gave similar results. But combination of essential oils that included *M. piperita + C. longa; C. longa + P. roxburghii* and *C. longa + M. arvensis* at 0.1+0.1per cent each was unable to suppress insect progeny. Whereas, high population build up was recorded from untreated control within 92 days after fumigation.

CONCLUSION

Herbal fumigants used at 0.4 per cent with sole component of *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora,C. longa* or *P. roxburghii* oil or their two component combination at 0.2 per cent each except *M. arvensis* + *C. longa*, their three component combination at 0.14 per cent each, four component combination at 0.1 per cent each, five component combination at 0.08 per cent each, or six component combination at 0.07 per cent each or seven component combination at 0.06 per cent each completely inhibited the progeny production of *S. oryzae* up to 515 days. Whereas, herbal fumigants used at 0.2 per cent with sole component of *M. piperita*, *M. spicata*, *E. citriodora,* or *P. roxburghii* oil except for *M. arvensis, C. winterianus* and *C. longa* also completely inhibited progeny production. Apart from this, *M. arvensis* and *C. longa* was not found effective as sole component at 0.2 per cent and in combination at 0.2 + 0.2, 0.1 + 0.1 and 0.3 + 0.1 per cent each suggesting their lower efficacy as herbal fumigant.All these findings pointed out that, the lower the concentrations of oils and more the component combinations, highest the synergistic effect of oils in inhibiting the progeny production of *S. oryzae*.

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