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CONTENTS

Long - term efficacy of some herbal fumigants against *Sitophilus oryzae* (Linnaeus), *Rhyzopertha dominica* (Fabricius) and *Tribolium castaneum* (Herbst)

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ABSTRACT: The experiments were conducted to study the long-term efficacy of essential oils of *Curcuma longa* and *Pinus roxburghii* at 0.2 and 0.4 per cent along with their combinations at 0.2+0.2 and 0.1 +0.1per cent each against three major insect pests of stored grains, *Sitophilus oryzae*, *Rhyzopertha dominica* and *Tribolium castaneum*. The wheat grain artificially infested by these insects were fumigated by above mentioned formulations on 5th, 10th, 15th and 20th days of infestation.The observations on population buildup of test insects were recorded after 6- and 8-months storage while percent infestation and per cent weight loss of grain was recorded after 10 months storage. The study revealed that the herbal fumigants having essential oil of *C. longa* or *P. roxburghii* oil at 0.4 per cent or *C. longa* + *P. roxburghii* at 0.2 per cent each or *P. roxburghii* at 0.2 per cent were highly effective against *S.oryzae* because no adults emerged from these treatments even when grains were fumigated on 20th days of artificial infestation by this insect.On the other hand, all the herbal fumigants were highly effective against *R. dominica* for more than 8 months when they were used for fumigation on 5, 10, 15 and 20 days of artificial infestation. In case of *T. castaneum*, *C. longa* oil was not very effective at 0.2-0.4 per cent against this insect. However, the combinations of *C. longa*+ *P. roxburghii* completely checked the progeny production for more than 8 months at 0.1+0.1 and 0.2+0.2per cent. The study revealed that the herbal fumigant having essential oil of *C. longa* and *P. roxburghii* in equal proportion is highly effective against all three major insect pests of stored cereals at lowest dose of 0.2 percent.Due to very high efficacy for 10 months and low cost of treatment, it may be used for protection of cereal grain or seed stored in airtight containers.

Key words: *Curcuma longa*, essential oils, fumigant toxicity, herbal fumigants, *Pinus roxburghii, Rhyzopertha dominica*, *Sitophilus oryzae*, *Tribolium castaneum*

The essential oils present in many plant species are known to exhibit fumigant toxicity against insect pests of stored grain (Shaaya *et al.,* 1990; Singh and Upadhyay, 1993; Regnault-Roger, 1997; Rajendran and Sriranjini,2008; Geetanjly *et al.,* 2016; Gangwar and Tiwari, 2017; Kumar and Tiwari, 2018; Joshi andTiwari,2019; Sharma and Tiwari, 2021; Geetanjly and Tiwari, 2021; Tewari and Tiwari, 2021a; 2021b;2021c; 2021d). However, such activity of oils has been found to be species specific and an oil highly effective against a species may be ineffective or less effective against another species (Kumari and Tiwari, 2022). Moreover, the level and duration of toxicity is also known to vary from species to species and in majority of cases they are of no practical use if they control only a small population of insect for very shorter duration. The cost of essential oils is also very high due to which they cannot be used for protection of grain if they show appreciable mortality at very high dose. Due to presence of different types of compounds, theses oils may also affect the test and smell of treated commodity and they may be used for protection of grain only when such undesirable property is removed after processing or cooking.Nevertheless, such herbal fumigants affecting the organoleptic properties may be utilized in protection of organic seed, if they do not affect the germination. Since most of the essential oils are ecofriendly and biodegradable (Jacobson, 1983), they may be used for protection of grain if we are able to develop some formulations which are highly toxic to all species of insect pests at very low dosages and their efficacy persists for longer duration as the tropical climate of many countries is highly favorable for continuous occurrence of storage insect pests throughout the year (Srivastava and Subramanian, 2016).It has also been advocated that it is always less hazardous to

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use plant materials with antifeedant, repellent or insecticidal action than to use synthetic pesticides (Pereira and Wohlgemuth, 1982; Prakash *et al.,* 1982; Allotey and Azalekor, 2000) as indiscriminate and prolonged use of conventional fumigants and insecticides have led to the development of resistance in insects and health hazards in human beings and other non-target organism. Such materials of plant origin are also suitable for management of insect pests in storage of organic foods (Barbercheck, 2022).

Recently some experiments have been conducted in this direction and some very useful formulations of herbal fumigants have been reported to be highly effective against many stored grain insect pests for longer duration. 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%. In another study, Tewari and Tiwari (2021c) reported that several formulations of herbal fumigants formulated by using two, three, four, five, six and seven essential oils combinations of *M. arvensis*, *M. piperita*, *M. spicata*, *C. winterianus*, *E. citriodora*, *E. globulus* and *P. roxburghii* at 0.20, 0.13, 0.10, 0.08, 0.07 and 0.06 per cent each, respectively, were highly effective against *R. dominica* and *S. oryzae*. 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). Very recently, Kumari and Tiwari (2022) studied the fumigant toxicity of essential oils of *M. cardiaca*, *T. cinerariifolium*, *O. basilicum*, *L. alba, F. asafoetida, S. officinalis* and *L. angustifolia* against *R. dominica*, *S.oryzae* and *T. castaneum* at 0.1, 0.2, 0.3, and 0.4 percent (v/w) concentration. It was reported that the essential oils of *M. cardiaca* and *O. basilicum* completely checked the progeny production of *S.oryzae* for 180 days at all four concentrations while such pronounced effect was exhibited by *T. cinerariifolium* at 0.2-0.4 per cent; *L. angustifolia* at 0.3-0.4 per cent and *L. alba* at 0.4 per cent only. In case of *R.dominica,* the oils of *M. cardiaca, T. cinerariifolium,O. basilicum* and *F. asafoetida* completely checked the F1 progeny for 220-228 days at all four concentrations while complete inhibition was achieved by *L. angustifolia* at 0.2-0.4 percent and *L. alba* and *S. officinalis* at 0.3-0.4 percent. The essential oil of *O. basilicum* completely checked the reproduction of *T. castaneum* at 0.1-0.4 percent for 90 days while such high efficacy was shown by *M. cardiaca* at 0.2-0.4 per cent and *T. cinerariifolium* and *L. angustifolia* at 0.4 per cent. In view of above-mentioned facts, the present investigation was undertaken to study the additive or synergistic effects and long-term efficacy of some formulation of herbal fumigants against *S. oryzae*, *R. dominica* and *T. castaneum.*

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.

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 *Rhyzopertha dominica* and *Sitophilus oryzae* were reared on the grain of wheat variety PBW-343 while *Tribolium 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 it was kept in incubator. To prepare the culture medium of *T. castaneum*, wheat grain was ground to a fine powder and yeast powder was mixed in it at the rate of 5 per cent. The medium was filled in plastic jars and adults were released in it. First generation adults (0-7 days old) were used for experimental purpose.

Procurement of Oils

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 and Central Institute of Medicinal and Aromatic Plants, Lucknow. The scientific name of plants, the oils of which were used in the experiment is given in Table 1.

Preparation of Grain

All fumigation experiments on *R. dominica, S. oryzae* 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. 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.

Table 1: Composition and rate of application of herbal fumigants used to study their effect on survival/ mortality of *R. dominica, S. oryzae* and *T. castaneum*

S.N.	Composition	Conc. % (v/w)
1	*Curcuma longa*	0.4
2	*Pinus roxburghii*	0.4
3	*Curcuma longa* + *Pinus roxburghii*	0.2 + 0.2
4	*Curcuma longa*	0.2
5	*Pinus roxburghii*	0.2
6	*Curcuma longa* + *Pinus roxburghii*	0.1 + 0.1
7	Untreated	-

Details of Experiment Conducted

The experiment was conducted in 2000 ml capacity air tight plastic jar to study the effect of *Curcuma longa* (Turmeric) and *Pinus roxburghii* (Pine) oils and their combinations (Table 1) on population buildup of *R. dominica*, *S. oryzae* and *T. castaneum.* Wheat grain of variety PBW-343 measuring 1700

Table 2: Effect of some herbal fumigants on population buildup of *S. oryzae* after 6 months storage

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	0.0(1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa + *P. roxburghii*	0.2+0.2	0.0 1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	729.0 (25.3)	-28.3	418.3(20.3)	73.2	909.0 (30.0)	16.5	861.0 (29.3)	72.1
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa + *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	84.0 (6.0)	97. 3
Untreated	-	568.0 (24.0)	-	1560.3 (39.5)	-	1088.0 (33.0)	-	3084.0 (54.0)	-
S.Em.±		(3.0)		(1.0)		(2.0)		(4.0)	
CD at 5%		(8.0)		(2.5)		(6.0)		(12.3)	

Data in parenthesis indicates square root (X+1) transformed value

gm was filled in each plastic jar. Four sets comprising seven treatments and three replications were prepared to study the effect against different insects. Ten adults each of three test insects were released in each jar after filling the jar with grains. The grain was then treated with the oils after 5th, 10th, 15th and 20th days interval. For this purpose, the oil was poured on the absorbing mats and then the mats were inserted inside the plastic jars. Screw cap of jar was then tightly closed and made completely airtight by sealing with paraffin wax strip and cello tape. After 6- and 8-month storage each jar was analyzed to count the number of adults emerged and per cent inhibition. After 10 months storage per cent infestation and per cent weight loss was calculated in each jar.

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

$$\text{Per cent infestation} = \frac{Nd}{Nu + Nd} \times 100$$

Per cent weight loss was calculated by using the formula described by Adams and Schulten (1976).

$$\text{Per cent weight loss} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu\,(Nd + Nu)} \times 100$$

Where,

Wu = weight of undamaged grain
Wd = weight of damaged grain
Nu = number of undamaged grains
Nd = number of damaged grains

Table 3: Effect of some herbal fumigants on population buildup of *S. oryzae* after 8 months storage

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.2+0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	859.3 (28.4)	-6188	693.0 (24.1)	-876	1757.0 (41.1)	-354.3	2028.0 (45.0)	-298.2
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
Untreated	-	14 (3.5)	-	71.0 (8.1)	-	387.0 (17.0)	-	509.3 (22.0)	-
S.Em.±		(2.)	-	(3.0)	-	(3.5)	-	(2.0)	-
CD at 5%		(6.1)	-	(9.0)	-	(11.0)	-	(5.0)	-

Data in parenthesis indicates square root (X+1) transformed value

Table 4: Effect of some herbal fumigants on population buildup of *R. dominica* after 6 months storage

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.2+0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	149.0 (10.3)	85	0.0 (1.0)	100	89.3 (6.1)	94.3	0.0 (1.0)	100
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
Untreated	-	973.0 (31.2)	-	1804.3 (42.0)	-	1555.0 (39.4)	-	752.3 (25.5)	-
S.Em.±		(2.0)	-	(2.0)	-	(2.1)	-	(3.0)	-
CD at 5%		(5.4)	-	(6.0)	-	(6.3)	-	(8.3)	-

Data in parenthesis indicates square root (X+1) transformed value

Table 5: Effect of some herbal fumigants on population buildup of *R. dominica* after 8 months storage

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P.roxburghii*	0.2+0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	760.0 (23.0)	48.4	0.0 (1.0)	100	0.3 (1.1)	99.9	1.0 (1.2)	99.9
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
Untreated	-	1473.0 (38.4)	-	1715.3 (41.3)	-	1060.0 (30.0)	-	980.3 (31.1)	-
S.Em.±		(4.1)	-	(1.0)	-	(3.5)	-	(1.0)	-
CD at 5%		(12.5)	-	(3.0)	-	(10.5)	-	(3.0)	-

Data in parenthesis indicates square root (X+1) transformed value

Table 6: Effect of some herbal fumigants on population buildup of *T. castaneum* after 6 months storage

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	802.0(23.4)	-296.5	129.0 (10.0)	-105.9	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.2+0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	593.3 (24.0)	-193.2	502.0 22.1)	-700.5	347.0 (15.4)	-75.7	465.0 (21.5)	-107.7
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
Untreated	-	202.3 (14.2)	-	63.0 (7.9)	-	197.3 (14.0)	-	224.0 (15.0)	-
S.Em.±		(5.0)		(2.0)		(3.0)		(1.0)	
CD at 5%		(14.0)		(6.0)		(9.0)		(2.0)	

Data in parenthesis indicates square root (X+1) transformed value

Table 7: Effect of some herbal fumigants on population buildup of *T. castaneum* after 8 months storage.

Essential oils	Dose % (v/w)	Days of treatment after artificial infestation							
		5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition	Adults emerged	% Inhibition
C. longa	0.4	151.0 (10.3)	-44.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
P. roxburghii	0.4	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.2+0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa	0.2	180.0 (12.0)	-72.5	232.3 (14.2)	-8612.5	249.3 (13.3)	-648	325.3 (18.0)	-1034.9
P. roxburghii	0.2	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
C. longa+ *P. roxburghii*	0.1+0.1	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100	0.0 (1.0)	100
Untreated	-	104.3 (10.0)	-	3.0 (2.0)	-	33.3 (6.0)	-	29.0 (5.3)	-
S.Em.±		(2.5)		(2.0)		(2.3)		(1.2)	
CD at 5%		(8.0)		(5.0)		(7.1)		(4.0)	

Data in parenthesis indicates square root (X+1) transformed value

Table 8: Effect of herbal fumigants on infestation and weight loss due to *S. oryzae, R. dominica and T. castaneum* after 10 month storage

Essential oils	Dose %	5th day treatment		10th day treatment		15th day treatment		20th day treatment	
		% Infestation	% Weight loss	% Infestation	% Weight loss	% Infestation	% Weight loss	% Infestation	% Weight loss
C. longa	0.4	46.4 (6.9)	2.1	10.4 (3.1)	0.9	1.0 (1.4)	-0.1	0.9 (1.4)	0.0
P. roxburghii	0.4	0.6 (1.3)	0.0	4.3 (2.0)	3.7	0.6 (1.3)	-0.1	1.0 (1.4)	0.0
C. longa+ *P. roxburghii*	0.2+0.2	0.7 (1.3)	-0.1	0.7 (1.3)	-0.1	0.8 (1.3)	-0.1	0.8 (1.3)	0.0
C. longa	0.2	67.6 (8.2)	2.6	47.8 (6.9)	9.3	59.4 (7.8)	8.0	64.0 (8.0)	13.1
P. roxburghii	0.2	0.8 (1.3)	-0.1	0.6 (1.3)	0.0	0.5 (1.2)	0.0	1.1 (1.4)	-0.1
C. longa+ *P. roxburghii*	0.1+0.1	0.8 (1.3)	-0.1	0.7 (1.3)	0.0	1.1 (1.5)	0.0	5.3 (2.2)	-1.2
Untreated	-	84.2 (9.2)	22.4	98.4 (10.0)	*	97.7 (10.0)	*	95.1 (9.8)	*
S.Em.±		(0.3)	-	(0.6)	-	(0.1)	-	(0.4)	-
CD at 5%		(0.8)	-	(1.7)	-	(0.4)	-	(1.2)	-

Data in parenthesis indicates square root (X+1) transformed value
•Weight loss not calculated due to lack of completely healthy grain as most were damaged by fungal growth

Table 9: Inhibition of *S. oryzae* by different herbal fumigants used on different days of artificial infestation

Essential oils	Dose % (v/w)	Inhibition (%) after 10 months storage			
		5th day treatment	10th day treatment	15th day treatment	20th day treatment
C. longa	0.4	100.0	100.0	100.0	100.0
P. roxburghii	0.4	100.0	100.0	100.0	100.0
C. longa + P. roxburghii	0.2+0.2	100.0	100.0	100.0	100.0
C. longa	0.2	-1823.8	-833.0	-50.6	-197.4
P. roxburghii	0.2	100.0	100.0	100.0	100.0
C. longa+ P.roxburghii	0.1+0.1	100.0	100.0	100.0	100.0

Table 10: Inhibition of *R. dominica* by different herbal fumigants used on different days of artificial infestation

Essential oils	Dose % (v/w)	Inhibition (%) after 10 months storage			
		5th day treatment	10th day treatment	15th day treatment	20th day treatment
C. longa	0.4	100.0	100.0	100.0	100.0
P. roxburghii	0.4	100.0	100.0	100.0	100.0
C. longa + P. roxburghii	0.2+0.2	100.0	100.0	100.0	100.0
C. longa	0.2	58.1	100.0	99.9	100.0
P. roxburghii	0.2	100.0	100.0	100.0	100.0
C. longa+ P. roxburghii	0.1+0.1	100.0	100.0	100.0	100.0

Table 11: Inhibition of *T. castaneum* by different herbal fumigants used on different days of artificial infestation

Essential oils	Dose % (v/w)	Inhibition (%) after 10 months storage			
		5th day treatment	10th day treatment	15th day treatment	20th day treatment
C. longa	0.4	99.9	-41700.0	100.0	100.0
P. roxburghii	0.4	100.0	100.0	100.0	100.0
C. longa + P. roxburghii	0.2+0.2	100.0	100.0	100.0	100.0
C. longa	0.2	-244.4	-2000.0	-172.2	-766.7
P. roxburghii	0.2	100.0	100.0	100.0	100.0
C. longa + P. roxburghii	0.1+0.1	100.0	100.0	100.0	100.0

Statistical analysis

Standard error of mean was computed in all those experiments where observations were recorded at different interval after development of insect population. In other experiments laid out in Completely Randomized Design data was analyzed

after suitable transformation.

RESULTS AND DISCUSSION

The effect of some herbal fumigants on population buildup of *S. oryzae* after 6 months storage is given in Table 2. In this experiment the grain stored in 2000ml capacity plastic jar was fumigated on 5th, 10th, 15th and 20th day of artificial infestation. The herbal fumigants having *C. longa* or *P. roxburghii* oil at 0.4 per cent or *C. longa* + *P. roxburghii* at 0.2 per cent each or *P. roxburghii* at 0.2 per cent were highly effective as no adults emerged from these treatments even when grain was fumigated on 20th days of artificial infestation by this insect. Fumigation of grain by *C. longa* + *P. roxburghii* at 0.1 per cent each on 20thdays of artificial infestation resulted in 97.3 per cent inhibition while fumigation made on 5th, 10th and 15th days of infestation did not permit this insect to feed and breed in this treatment.The essential oil of *C.longa* was not found effective against this insect at 0.2 per cent.

The effect of above-mentioned herbal fumigants against *S. oryzae* after 8 months storage is present in Table 3 which indicates that fumigation of the grains by *C. longa* or *P. roxburghii* oil at 0.4 per cent, *C.longa* + *P. roxburghii* at 0.2 per cent each, *P. roxburghii* oil at 0.2 per cent or *C. longa* + Pine at 0.1 per cent were highly effective when they were used for fumigation on 5, 10, 15and 20th days of artificial infestation. The study indicates that all the above-mentioned herbal fumigants are highly effective against *S. oryzae* for more than 8 months. The essential oil of *P. roxburghii* also suppressed 100 per cent progeny of this insect at 0.4 per cent (Tewari and Tiwari (2021c).

The effect of herbal fumigants on population buildup of *R. dominica* after6- and 8-months storage is given in Table 4 and 5 which indicate that all the herbal fumigants were highly effective against this insect for more than 8 months when they were used for fumigation on 5, 10, 15 and 20th days of artificial infestation. Tewari and Tiwari (2021c) also reported that the essential oil of *P. roxburghii* was highly effective against this insect at 0.2 and 0.4 per cent concentration at which it suppressed 97.8 and 100.0 per cent insect population, respectively.

The effect of herbal fumigants on the population buildup of *T. castaneum* after 6- and 8-months storage is presented in Table 6 and 7 which indicate that *C. longa* oil was not very effective at 0.2-0.4 per cent against this insect. On the other hand, *P. roxburghii* oil completely checked the population buildup of this insect when it was used for fumigation on 5, 10, 15 and 20thdays after fumigation at 0.2 per cent. The combination of *C.longa*+ *P. roxburghii* at 0.2 per cent each or *C. longa* + *P. roxburghii* at 0.1 per cent each was also found to be highly effective for more than 8 months as no adult emerged from the grain fumigated by it on 5, 10, 15 or 20th days of artificial infestation.

The effect of different herbal fumigants on infestation and weight loss due to *S. oryzae, R. dominica* and *T. castaneum* after 10 month storage is presented in Table 8 which indicates that the fumigation of grain with *P. roxburghii* oil at 0.4 per cent, *C.longa*+ *P. roxburghii* at 0.2 per cent each, *P. roxburghii* oil at 0.2per cent and *C.longa* and *P. roxburghii* at 0.1 per cent each checked the infestation of all three insects as only 0.6-0.8 per cent infested grain were observed in these treatments when grain was fumigated on 5th day of artificial infestation. On the other hand, 84.2 per cent infestation was recorded in untreated control. The loss in weight of grain was also very low in all these treatments. Fumigation of the grain on 10thdays of artificial infestation caused 0.6-0.7 per cent infestation when *C.longa* + *P. roxburghii* (0.2 per cent each), *P. roxburghii* (0.2 per cent), *C. longa* + *P. roxburghii* (0.1 per cent each) was used for fumigation. The weight loss was also very low in these treatments. Fumigation of grain with *C.longa* or *P. roxburghii* at 0.4 per cent, *C.longa* + *P. roxburghii* at 0.2 per cent each, *P. roxburghii* at 0.2 per cent, or *C.longa* + *P. roxburghii* at 0.1 per cent each caused 0.5-1.0 per cent infestation of the grain when fumigation was done on 15thdays of artificial infestation. No loss of weight due to insect infestation was recorded in these treatments. All the above-mentioned treatments except *C.longa* + *P.*

roxburghii at 0.1 per cent also caused very low infestation when used on 20 day of artificial infestation and no weight loss was recorded during this period. Among all these treatments only *C. longa* oil did not give satisfactory fumigant toxicity.

Table 9 and 10 indicates that all herbal fumigants except *C.longa* oil at 0.2 per cent completely inhibited the population buildup of *S. oryzae* and *R. dominica* for 10 months. In case of *T. castaneum* (Table 11) *P. roxburghii* oil at 0.4 per cent, *C.longa* + *P. roxburghii* at 0.2 per cent each, *P. roxburghii* at 0.2 per cent or *C. longa* + *P. roxburghii* at 0.1 per cent each gave similar results.

CONCLUSION

Present study indicated that herbal fumigants are highly effective against *R. dominica*, *S. oryzae* and *T. castaneum* for more than 10 months as during study period they showed 100 per cent control of all three test insects. Since most of the treatments were insect free during last observation, it is expected that they will keep the grain insect free for more longer duration if airtightness is maintained during storage. The herbal fumigants having *C.longa* or *P. roxburghii* oil at 0.4 per cent or *C. longa* + *P. roxburghii* at 0.2 per cent each or *P. roxburghii* at 0.2 per cent were highly effective as no adults emerged from these treatments even when grain was fumigated on 20th days of artificial infestation by *S. oryzae*. In case of *C.longa* + *P. roxburghii* at 0.1 per cent each, 97.3 per cent inhibition was obtained when the grain was fumigated on 20thdays of artificial infestation while the grain fumigated on 5th, 10th and 15thdays did not permit this insect to breed in this treatment.The fumigation of grain with *P. roxburghii* oil at 0.4 per cent, *C.longa*+ *P. roxburghii* at 0.2 per cent each, *P. roxburghii* oil at 0.2per cent and *C.longa* and *P. roxburghii* at 0.1 per cent each checked the infestation of all three insects *S. oryzae, R. dominica and T. castaneum*. The loss in weight of grain was also very low in all these treatments. Current finding revealed that except *C.longa* oil at 0.2 per cent,all assessed essential oils and their combinations were highly effective in controlling the population buildup, infestation and weight loss due to these three insect pests. Such high efficacy of herbal fumigant is parallel to conventional fumigants due to which they have great potential in post-harvest management of insect pests. Since the components of herbal fumigants are highly volatile, it can be used only under hermetic conditions just like any conventional fumigants. Therefore, such fumigants are very useful for protection of grain stored in metal bins at farmers or consumer level for which we are not having any viable alternative. Since, most of the ingredients are easily available in many countries, farmers may be encouraged to prepare such herbal fumigants at domestic level.In some cases, the volatile compounds present in essential oils may adversely affect the organoleptic properties. Under such conditions, the herbal fumigants may be used for protection of seed at different level. As herbal fumigants of plant origin are biodegradable and ecofriendly, they may provide green solutions to insect pest problem under storage condition.

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