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Fumigant toxicity of essential oils and their combinations on population buildup of three stored product coleoptera in stored wheat and effect on quality of wheat

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Abstract

Experiments carried out to find the fumigant toxicity of three essential oils and their combinations from *Murraya koenigii*, *Citrus reticulata*, *Curcuma longa* on population buildup of *Sitophilus oryzae*, *Rhyzopertha dominica*, *Tribolium castaneum* in stored wheat at different days of infestation. The oil of *M. koenigii*, *C. reticulata* at 0.2% and *M. koenigii*+*C. reticulata*, *M. koenigii*+*C. longa* at 0.1% each were found highly effective against *S. oryzae* fumigated after 5, 10, 15 and 20 days. The oil of *M. koenigii* and *C. reticulata* at 0.2% *M. koenigii*+*C. reticulata*, *M. koenigii*+*C. longa*, *C. reticulata*+*C. longa* at 0.1% each and *M. koenigii*+*C. reticulata*+*C. longa* at 0.07% each were found highly effective against *R. dominica* fumigated after 5, 10, 15 and 20 days. Only *M. koenigii* at 0.2% was found highly effective against *T. castaneum* fumigated after 5, 10, 15 and 20 day. The fumigation of grain with *M. koenigii* at 0.2% completely suppress the infestation and weight loss when it was fumigated after 5, 10, 15 and 20 days while very low infestation and weight loss was observed in grain treated with *M. koenigii* +*C. reticulata* at 0.1% each and not affect the organoleptic properties and germination of wheat.

Key words: Fumigant toxicity, essential oils, Sitophilus oryzae, Rhyzopertha dominica, Tribolium castaneum

Introduction

Stored commodities are infested by more than 600 species of beetles, 70 species of moths and about 355 species of mites causing quantitative and qualitative losses at different storage level (Rajendran and Srirajinia, 2008). Stored product insects cause 10 percent postharvest losses in developing countries, but they also contaminate the food products by presence of live insects, insect products such as chemical excretions or silk, dead insects and insect body fragments. In India, only aluminum phosphide and methyl bromide are available for fumigation of stored commodities. The use of aluminum phosphide is restricted while methyl bromide has been banned and their injudicious use during many years induced resistance development in stored grain insects.

Essential oils from more than seventy five plant species belonging to different families, such as Anacardiaceae, Apiaceae, Araceae, Asteraceae, Brassicaceae, Chenopodiaceae, Cupressaceae, Graminaceae, Lamiaceae, Lauraceae, Liliaceae, Myrtaceae, Pinaceae, Rutaceae and Zingiberaceae have been studied for fumigant toxicity against several insect pests of stored grain (Rajendran and Srirajinia, 2008). In several storage structures, fumigants are the most economical and convenient tools for managing stored grain insects due to their easy penetration in stored commodities and avaibility at cheaper rates (Azelmat *et al.,* 2006). Recently research has been focusing on the utilization of essential oils and their bioactive constituents as possible alternative to traditional fumigants (Negahban *et al.,* 2007, Ogendo *et al.,* 2008). *Sitophilus oryzae* (L), *Rhyzopertha dominica* (F), and *Tribolium castaneum* (Herbst) are one of the important stored product beetles and cause serious loses to stored commodities worldwide (Kumar, 2016). *Murraya koenigii* is an annual herb growing as medicinal plants and their leaves are used as some culinary and treatment of human disease. *Curcuma longa* is used as spice while peel of *Citrus reticulata* is wastage materials. The attempt has been made to study the fumigant toxicity of essential oils and their combinations on population buildup of three stored product coleoptera in stored wheat and their effect on quality of wheat**.**

Material and Methods

Culture of the insects

Pure culture of test insects were developed in the BOD incubator maintained at 27°C±1 temperature and 70±5% relative humidity. Plastic jars of 1000 ml capacity were used for rearing of insects. 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. Adults of *R. dominica* (F) (Coleoptera: Bostrichidae) and *S. oryzae* (L) (Coleoptera: Cuculionidae) were reared on the wheat variety PBW-343 while *T. castaneum* (Herbst) (Coleoptera: Tenebrionidae) was cultured on its flour fortified with 5 per cent yeast powder. Before use, wheat was disinfested in the oven at 60^{oC} for 12 hrs. After disinfestation the moisture content of the wheat 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 the formula described by Pixton (1967).

Extraction of essential oils

Oils selected for the study were extracted from the locally available plants by steam distillation at Medicinal and Aromatic Plants Research and Development Centre, Pantnagar, and by Clevenger Apparatus in Post Harvest Entomology Laboratory Pantnagar.

Preparation of grain

All fumigation experiments on *R. dominica, S. oryzae* and *T. castaneum,* were conducted on untreated seed grade wheat of variety PBW-343. The experiment was conducted on *R. dominica, S. Oryzae* and *T. castaneum* to confirm the fumigant toxicity of essential oils and their combination and experiment was conducted same as rearing conditions.

Effect of essential oils on population build up of *R. dominica, S. oryzae*, and *T. castaneum*

The experiment was conducted in 2000 ml capacity air tight plastic jar to study the effect of essential oil and their combination on population build up of *R. dominica, S. oryzae* and *T. castaneum.* Wheat variety PBW- 343, (1500g) was filled in each plastic jar. Four sets comprising eight treatments with three replications were prepared. Twenty newly emerged adult (0-4 days old) of each specie were released in each jar after filling grains. The treatment applied after 5, 10, 15 and 20 days after artificial infestation, essential oil was poured on the absorbing mats and then mats were inserted inside the plastic jars. Screw cap of jars tightly closed and made completely airtight by sealing with parafilm wax strip. After one year of storage each jar was analyzed to count the number of adults emerged to calculate percent inhibition and the number of healthy and infested grain to calculate per cent infestation, per cent weight loss and germination atributes.

Organoleptic properties of *chapattis* made from grains treated with essential oils

Organoleptic test was performed on *chapattis* made from wheat grains treated with essential oils and their combination without washing and after washing thoroughly with water. 1000 g of grains was drawn out from each treatment and sieved thoroughly to remove unwanted impurities. After sieving 500 g wheat was used as such for preparation of flour while rest 500 g of the grain was washed thoroughly with water. Both washed and unwashed grains were sun dried for ten days, 8 hrs per day. The wheat grain was then ground in local market of Pantnagar to obtain wheat flour. The flour was then passed through a fine sieve to get a flour of the required fineness. Equal amount of flour was weighed and kneaded to dough using equal quantity of water and dough balls of same size were prepared. These balls were rolled out as thin as possible into a chapatti and were cooked on both sides on a hot iron plate without any fat or oil.

Various characteristics of chapatti i.e. colour, flavour, texture, taste, appearance and overall acceptability were tested as described by Amerine *et al.* (1965). For the evaluation of chapatti ten evaluators were invited randomly from the different departments of the university. Each member of the panel evaluated the characteristics of chapatti on a grading scale as 1-2 Very poor, 3-4 Poor, 5-6 Fair, 7-8 Good, 9-10 Very good.

Effect of essential oil on germination of wheat

Samples were drawn from experiment to record the effect of different essential oils and their combinations on germination of wheat. Germination test was done as per protocol of Chalam *et al.* (1967). Seedling vigour (vigour index) was computed as per Abdul-Baki and Anderson (1973).

Statistical analysis

Data were analyzed in Completely Randomized Design after suitable transformation with log (X+ 1).

Results

The efficacy of essential oils and their combinations was classified in different categories on the basis of first progeny production.The more weightage was given to suppression of first progeny, with this assumption, products inhibiting more than 90 percent of first progeny were classified as highly effective while inhibition of 80 to 89 and 70 to 79 percent were ranked as moderately and less effective respectively. The products showing less than 70 percent of first progeny suppression were ranked as least effective for the control of test insects.

Effect of essential oils and their combinations on population build up of *S. oryzae*

The essential oils and their combinations on population build up of *S. oryzae* is presented in Table 1. The table indicates that *M. koenigii* oil at 0.2 % and its combination with *C. reticulata* at 0.1 % each completely suppressed the feeding and breeding of the *S. oryzae* in all the treatments. The combination of *M. koenigii* + *C. longa* at 0.1 percent each was also highly effective against *S. oryzae* as caused 100, 99.81, 100 and 100 percent inhibition in grain fumigated after 5, 10, 15 and 20 days respectively. The oil of *C. reticulata* caused 100, 97.92, 100 and 93.84 % inhibition at 0.2 % in grain fumigated after 5, 10, 15 and 20 days, respectively. The combination containing *M. koenigii* + *C. reticulata* + *C. longa* at 0.07 percent each caused 95.69, 91.97, 100 and 77.44 percent inhibition in grain fumigated after 5, 10, 15 and 20 days respectively. The combination of *M. koenigii* + *C. longa*, *C. reticulata* + *C. longa* at 0.1 percent each and *M. koenigii* + *C. reticulata* + *C. longa* at 0.07 each percent each was highly effective against *S. oryzae* in the grain fumigated after 5, 10, 15 and 20 days of artificial infestation.

Effect of essential oils and their combinations on Population build up of *R. dominica*

The effect of essential oils on population build up of *R. dominica* is given in Table 2 which indicates that *M. koenigii* at 0.2 percent concentration and its combination with *C. reticulata* at 0.1 percent each were highly effective as it completely suppressed feeding and breeding of the *R. dominica* after one year of stored grain fumigated after 5, 10, 15 and 20 days. The combination containing *M. koenigii* + *C. longa* at 0.1 percent each was also highly effective against *R. dominica* as it caused 100, 99.34, 100 and 100 percent inhibition in grain fumigated after 5, 10, 15 and 20 days respectively. The oil of *M. koenigii* + *C. reticulata* + *C. longa* at 0.07 percent each concentration caused 100, 97.88, 100 and 100 percent inhibition in grain fumigated after 5, 10, 15 and 20 days respectively. The oil of *C. reticulata* at 0.2 percent caused 100, 95.70, 100 and 97.32 percent inhibition at 0.2 percent in grain fumigated after 5, 10, 15 and 20 days respectively, while its combination with *C. longa* at 0.1 percent each caused 100, 90.60, 100 and 100 percent inhibition in grain fumigated after 5, 10, 15 and 20 days, respectively.

Effect of essential oils and their combinations on Population build up of *T. castaneum*

The effect of essential oils on population build up of *T. castaneum* after one year of storage is presented in Table 3, which indicates that only *M. koenigii* at 0.2 percent completely suppressed feeding and breeding of the *T. castaneum* in grain fumigated after 5, 10, 15 and 20 days. The oil of *C. reticulata* at 0.2 % was found effective at 15 days of artificial infestation, while its combination with *C. longa* at 0.1 percent each was effective at 20 days after artificial infestation.

Tab. 1 Effect of essential oils and their combinations on population buildup of *Sitophilus oryzae* after one year of storage.

Essential Oils	% Conc.	5 days		10 days		15 days		20 days	
		Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.
M. koenigii	0.2	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0(0.0)	100.00
C. reticulata	0.2	0.0 (0.0)	100.00	29.3(1.4)	97.92	0.0 (0.0)	100.00	26.7 (1.4)	93.84
C. longa	0.2	875 (6.7)	38.22	1109(6.9)	21.71	13.3(1.2)	90.61	163.7(5.0)	62.20
M.koenigii+C. reticulata	0.2	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00
M.koenigii+C. longa	0.2	0.0 (0.0)	100.00	2.7 (0.7)	99.81	0.0 (0.0)	100.00	0.0 (0.0)	100.00
C.reticulata+C. longa	0.2	235 (5.3)	83.42	414 (5.9)	70.77	0.0 (0.0)	100.00	401.7(5.9)	70.23
M.koenigii+C. reticulata+C. longa	0.2	61 (3.1)	95.69	113.7(4.6)	91.97	0.0 (0.0)	100.00	97.7 (3.3)	77.44
Untreated		1416.3(7.2)	0.0	1416.7(7.2)	0.0	142 (4.8)	0.0	433 (6.0)	0.0
S. Em.±		(0.55)		(0.61)		(0.45)		(0.78)	
CD at 5%		(1.67)		(1.84)		(1.37)		(2.36)	

Data in parenthesis indicate log (X+1) transformed value.

Tab. 2 Effect of essential oils and their combinations on population buildup of *Rhyzopertha dominica* after one year of storage.

Essential Oils	% Conc	5 days		10 days		15 days		20 days	
		Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.
M. koenigii	0.2	0.0(0.0)	100.00	0.0(0.0)	100.00	0.0 (0.0)	100.00	0.0(0.0)	100.00
C. reticulata	0.2	0.0(0.0)	100.00	19.7(1.3)	95.70	0.0 (0.0)	100.00	15.3 (2.1)	97.32
C. longa	0.2	0.7(0.3)	99.76	130.7(4.8)	71.45	0.0 (0.0)	100.00	119.3(4.5)	79.19
M.koenigii+C. reticulata	0.2	0.0(0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00
M. koenigii+C. longa	0.2	0.0(0.0)	100.00	3.0 (0.7)	99.34	0.0 (0.0)	100.00	0.0(0.0)	100.00
C.reticulata+C. longa	0.2	0.0(0.0)	100.00	43 (2.7)	90.60	0.0 (0.0)	100.00	0.0 (0.0)	100.00
M.koenigii+C. reticulata+C. longa	0.2	0.0(0.0)	100.00	9.7 (1.1)	97.88	0.0 (0.0)	100.00	0.0 (0.0)	100.00
Untreated		276.3 (5.6)	0.0	457.7(6.1)	0.0	393.7(5.9)	0.0	573.7(6.3)	0.0
S. Em.±		(0.13)		(0.84)		(0.29)		(0.42)	
CD at 5%		(0.39)		(2.53)		(0.88)		(1.28)	

Data in parenthesis indicate log (X+1) transformed value

Tab. 3 Effect of essential oils and their combinations on population buildup of *Tribolium castaneum* after one year of storage.

Essential Oils	% Conc	5 days		10 days		15 days		20 days	
		Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.	Adult emerged	% inhib.
M. koenigii	0.2	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00	0.0 (0.0)	100.00
C. reticulata	0.2	0.0 (0.0)	100.00	44.7 (2.7)	89.75	29.7 (3.3)	88.33	262 (5.5)	31.17
C. longa	0.2	167.3 (5.0)	52.24	254.3 (5.5)	41.66	0.0 (0.0)	100.00	346.3 (5.8)	9.01
M.koenigii+C. reticulata	0.2	350.7 (5.8)	76.19	343 (5.8)	71.33	33 (2.5)	87.02	263.3 (5.5)	30.82
M. koenigii+C. longa	0.2	555.3 (6.3)	58.06	605.3 (6.4)	78.76	0.0 (0.0)	100.00	380.7 (5.9)	90.00
C.reticulata+C. longa	0.2	7.3 (1.0)	97.91	21.7 (2.3)	95.03	38.7 (2.6)	84.79	206.7 (5.3)	45.71
M.koenigii+C. reticulata+C. longa	0.2	331.7 (5.7)	75.59	187 (4.8)	57.11	60.3 (3.5)	76.27	196.3 (5.2)	48.42
Untreated		351.3 (5.8)	0.0	436 (6.0)	0.0	254.3(5.4)	0.0	380.7 (5.9)	0.0
S. Em.±		(0.38)		(0.68)		(0.74)		(0.11)	
CD at 5%		(1.16)		(2.04)		(2.19)		(0.35)	

Data in parenthesis indicate log (X+1) transformed value.

Effect of essential oils and their combinations on infestation and weight loss

The effect of essential oils on infestation and weight loss due to *S. oryzae, R. dominica* and *T. castaneum* after one year of storage is presented in Table 4, which indicates that fumigation of grain with *M. koenigii + C. reticulata* or *C. longa* at 0.1% each or *C. longa* at 0.2 % observed 2.85, 2.42 and 2.61 percent infestation, respectively, which was very low as compared to untreated control which recorded 11.76 percent infestation. Fumigation of grain with *M. koenigii + C. reticulata + C. longa* at 0.07 percent each, *C. reticulata + C. longa* at 0.1% each and *C. longa* at 0.2% concentration permitted 0.69, 0.62 and 0.49% weight loss, respectively while 6.0 percent weight loss observed after one year of storage in untreated control. The fumigation after 10 days only *M. koenigii* at 0.2 percent completely suppressed the progeny development of *S. oryzae, R. dominica* and *T. castaneum,* while *M. koenigii + C. reticulata* at 0.1% each permitted very low infestation and weight loss. The combination of *C. reticulata + C. longa* oil at 0.1 percent each, *M. koenigii + C. reticulata + C. longa* at 0.07 percent each, *C. longa*, *C. reticulata* at 0.2 percent and *M. koenigii + C. longa* at 0.1 percent each 5.56, 5.35, 4.73, 3.88 and 3.66% infestation, respectively, while in untreated control 17.07 percent infestation was found. The percent weight loss in grain treated with *M. koenigii + C. reticulata + C. longa* at 0.07 percent each, *C. reticulata + C. longa*, *M. koenigii + C. longa* at 0.1 percent each, *C. longa* and *C. reticulata* at 0. 2 percent each concentration were 2.36, 1.63, 1.19, 1.11 and 0.39 as compare to untreated control in which 7.96 percent weight loss found after one year of storage. No infestation or weight loss was recorded in grain treated with *M. koenigii* or *C. reticulata* oil at 0.2 percent and its combination at 0.1 percent each in grain fumigated after 15 days. Very less infestation and weight loss was observed in grain treated with a combination of *M. koenigii + C. reticulata + C. longa* at 0.07 percent each, and *M. koenigii + C. reticulata* at 0.1 percent each concentration. The weight loss amounting to 0.67 and 0.38 percent were recorded in grain treated with *C. longa* at 0.2 percent and *C. reticulata + C. longa* at 0.1% each, respectively, while in untreated control 5.54 percent weight loss found, The grain was fumigated after 20 days, *M. koenigii* at 0.2 percent and *M. koenigii + C. reticulata* at 0.1 percent each concentration were completely suppressed the progeny of *S. oryzae, R. dominica, and T. castaneum* after one year of storage.

Tab. 4 Effect of essential oils and their combinations on infestation and weight loss due to *Sitophilus oryzae, Rhyzopertha dominica and Tribolium castaneum* after one year of storage.

Essential Oils	% Conc	5 days		10 days		15 days		20 days	
		% Infestation	% Weight loss	% Infestation	% Weight loss	% Infestation	% Weight loss	% Infestation	% Weight loss
M. koenigii	0.2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
C. reticulata	0.2	0.0 (0.0)	0.0 (0.0)	3.88 (1.5)	0.39(0.3)	0.0 (0.0)	0.0 (0.0)	0.54 (0.4)	0.04 (0.3)
C. longa	0.2	2.61 (1.2)	0.49(0.3)	4.73 (1.7)	1.11(0.5)	2.19 (0.8)	0.67 (0.3)	6.77 (2.0)	2.86 (1.3)
M.koenigii+C. reticulata	0.2	0.0 (0.0)	0.0 (0.0)	0.51 (0.4)	0.32(0.2)	0.32 (0.2)	0.05 (0.4)	0.0 (0.0)	0.0 (0.0)
M. koenigii+C. longa	0.2	0.12 (0.1)	0.04(0.4)	3.66 (1.3)	1.19(0.6)	0.0 (0.0)	0.0 (0.0)	0.74 (0.3)	0.11 (0.1)
C.reticulata+C. longa	0.2	2.42 (1.2)	0.62(0.7)	5.56 (1.8)	1.63(0.8)	3.2 (1.4)	0.38 (0.2)	4.4 (1.6)	1.3 (0.5)
M.koenigii+C. reticulata+C. longa	0.2	2.85 (1.3)	0.69(0.5)	5.35 (1.8)	2.36(1.0)	0.96 (0.6)	0.12 (0.1)	2.38 (0.9)	0.21 (0.1)
Untreated		11.76 (2.5)	6.0 (1.6)	17.07 (2.8)	7.96(2.1)	14.05 (2.6)	5.54 (1.8)	16.33(2.8)	5.81 (1.9)
S. Em.±		(0.1)	(0.48)	(0.18)	(0.29)	(0.21)	(0.13)	(0.24)	(0.18)
CD at 5%		(0.32)	(1.4)	(0.56)	(0.87)	(0.62)	(0.41)	(0.73)	(0.56)

Data in parenthesis indicate log (X+1) transformed value

Tab. 5 Percent germination, vigour index and significance of viability of grain treated with essential oils.

Essential Oils	% Conc	Germination parameter			Organoleptic Properties						
		% Germination	Vigour Index	Significance of viability	Condition	Colour	Flavour	Texture	Taste	Appearance	Overall Acceptability
M. koenigii	0.2	100.00	15590.67	1.1	Unwashed	9.5	9.0	9.0	9.1	9.5	9.5
					Washed	10.0	9.7	10.0	10.0	10.0	10.0
C. reticulata	0.2	96.66	17271.33	1.1	Unwashed	9.4	9.0	9.7	9.6	9.5	9.5
					Washed	9.7	9.7	10.0	10.0	10.0	10.0
C. longa	0.2	95.33	16554.00	1.1	Unwashed	8.3	4.1	6.2	6.1	4.3	4.3
					Washed	9.0	7.1	8.2	6.5	6.8	7.3
M.koenigii+ C. reticulata	0.2	96.66	17813.33	1.1	Unwashed	9.1	8.7	8.2	7.2	9.7	9.7
					Washed	9.1	6.3	7.8	8.1	10.0	7.5
M. koenigii+C. longa	0.2	97.33	17838.00	1.1	Unwashed	9.0	8.6	6.3	7.8	5.3	5.3
					Washed	9.0	6.2	7.1	6.9	9.5	7.0
C. reticulata+C. longa	0.2	94.66	17866.67	1.1	Unwashed	9.0	6.3	7.8	7.1	6.2	6.2
					Washed	9.0	6.8	7.4	6.1	9.5	7.1
M.koenigii+ C. reticulata+C. longa	0.2	96.66	18041.33	1.1	Unwashed	9.3	7.9	7.1	7.2	6.1	6.1
					Washed	9.0	6.1	7.1	8.0	9.3	7.2
Untreated		86.00	10882.70		Unwashed	9.1	8.7	8.1	7.9	7.2	7.2
					Washed	9.5	8.7	7.5	8.0	9.5	8.1
S.Em.±		1.58	489.9								
CD at 5%		4.73	1468.88								

Effect of essential oils and their combinations on germination of wheat

Percent germinations is presented in table 5 which indicates that the 100% germination was recorded in grain treated with *M. koenigii* while 94.66 to 97.33% germination was recorded in grain treated with *C. reticulata, C. longa* and their combination with *M. koenigii*. Only 86.00% germination was recorded in untreated control. As compared to untreated control very high vigour index was recorded in seed treated with essential oils. The significance of viability was 1:1 in all treated grain after one year of storage.

Organoleptic properties of chapattis made from grain treated with essential oils

The organoleptic properties of chapattis made from wheat grain treated with essential oils is presented in table 5 which indicates that colour, flavor, texture, taste, appearance and overall acceptability of chapattis prepared from treated grain were supirior as compare to untreated grain. The overall acceptability rating of chapattis prepared from unwashed grain treated with *M. koenigii, C. reticulata* at 0.2% or at 0.1% each were very good as compare to untreated grain in which rating was good. Similarly the chapattis made from washed grain of different treatments showed very good overall acceptability in grain treated with *M. koenigii* and *C. reticulata* while remaining showed good overall acceptability as compare to untreated grain.

Discussion

Seventeen essential oils were evaluated against S. oryzae, R. dominica, T. castaneum and C. chinensis in wheat and checkpea, ane the ones extracted from Allium sativum, Artimisia annua, Callistemon citrinus, Chenopodium botrys, Cinnamomum zylanicum, Citrus reticulata, Cuminum cyminum, Foeniculum vulgare, Murraya koenigii, Pinus roxburghii and Piper nigrum were found highly effective at 0.2% (Kumar and Tiwari, 2017). The essential oils of Murraya koenigii, Citrus reticulata and Curcuma longa were evaluated against S. oryzae, R. dominica, T. castaneum in stored wheat to protect the grains for one year in metal bins and did not affect the organoleptic propertis of chapatti made from treated grains and germination of wheat (Kumar and Tiwari, 2017). The essential oils of Murraya koenigii, Citrus reticulata, Curcuma longa and Calistimone citrinus at 0.2% caused 100 percent mortality in R. dominica and T. castaneum after twenty four hours of treatment (Kumar et al., 2018). Essential oil of Sweet Annie, Artemisia annua evaluated by Tripathi et al.(2002) against T. castaneum and C. maculatus at 1% v/v proved to be adult repellent and revealed negative correlation between larval survival, pupal survival and adult emergence of T. castaneum. Bio-efficacy of leaf oil of Murraya koenigii was evaluated against C. chinensis, oil attracted insects at 25 mg dose and repelled at 300 mg dose in the dual choice repellency test. In both contact (0.125 mg/cm^2) and fumigant (22.5 mg/ml) toxicity test 100% mortality was observed with LC₅₀ value of 0.08 mg/cm^2 and 22.5 mg/ml, respectivily (Paranagama et al., 2002). Pathak et al. (1997) investigated toxicity and repellent activity of Murraya koenigii against C. chinensis in stored green gram, chickpea at 340 ppm and oil showed toxic effect and ovicidal properties. They concluded that the oil can be used for small level protection of legumes. Liu et. al. (2007) evaluated 40 species of Chinese medicinal herbs from 32 different botanical families for their contact, fumigant and feeding deterent activities against two stored grain coleopterans S. zeamais and T. castaneum. Thirty Chinese medicinal herbs exhibited insecticidal or feeding deterent activities against test insects. The oil of Artemisia argyi, Dictamnus dasycarpus, Evodia rutaecarpa, Lietsea cubeba, Narcissus tazetta var chinensis, Polygonum aviculare, Rhododendrum molle, Sophora flavescens, Stemona sessilifolia, Tripteryginni wilfordii, and Torreya grandis were most effective against both tested insects.

Resuls concluded that the exploration of fumigational potential of essential oils may leads to development of non-synthetic, economical, ecological safe and easily degradable alternative for sustainable stored grain insect pest management. Essential oils of *M. koenigii*, *C. reticulata* at 0.2% and *M. koenigii+C. reticulata*, *M. koenigii+C. longa* at 0.1% each were found highly effective against *S. oryzae* fumigated after 5, 10, 15 and 20 days. The oil of *M. koenigii* and *C. reticulata* at 0.2% *M.*

koenigii+C. reticulata, *M. koenigii+C. longa*, *C. reticulata+C. longa* at 0.1% each and *M. koenigii+C. reticulata+C. longa* at 0.07% each were found highly effective against *R. dominica* fumigated after 5, 10, 15 and 20 days. Only *M. koenigii* at 0.2% was found highly effective against *T. castaneum* fumigated after 5, 10, 15 and 20 day. The fumigation of grain with *M. koenigii* at 0.2% completely suppress the infestation and weight loss when it was fumigated after 5, 10, 15 and 20 days while very low infestation and weight loss was observed in grain treated with *M. koenigii +C. reticulata* at 0.1% each. Essential oils did not affect the organoleptic properties and germination of wheat.

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Fumigant toxicity of *Haplophyllum tuberculatum* (Rutaceae) and *Nepeta crispa* (Lamiaceae) on the Indian meal moth

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