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PROTECTIVE EFFECTS OF MINTWEED, KITCHEN MINT AND KAFFIR LIME LEAF EXTRACTS AGAINST RICE WEEVILS, *STITOPHILUS ORYZAE L.*, IN STORED, MILLED RICE

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Abstract- The protective effects of the extracts of three edible aromatic plants, mintweed *Hyptis suaveolens*, kitchen mint *Mentha cordifolia* and kaffir lime *Citrus hystrix*, against rice weevil *Sitophilus oryzae* infestation in stored, milled rice were investigated. The efficacy of the ethanolic and the water leaf crude extracts on the repellency, insecticidal activity, grain weight loss protection, and growth inhibition of rice weevil progeny was assessed. The ethanolic extracts affected rice weevils higher than the water extracts. The extract toxicity on rice weevil adults and larvae compared as kitchen mint > kaffir lime > mintweed. The highest repellent efficacy, 24 h, of the ethanolic extract was from kaffir lime with EC_{50} of 13.23 mg/ml or 3.4 fold of the control and of the water extract was from kitchen mint with EC_{50} of 19.04 mg/ml or 3.6 fold of the control. Rice weevils were totally ridded within 20 days by kitchen mint ethanolic extracts. All extracts highly protected over the grain texture and the loss of grain weight, and inhibited the growth of rice weevil progeny. The treated grain weight loss was approximately 2% in 35 days and 16% in 49 days. The progeny emergence was inhibited ranging from 55% (water extract) to 89% (ethanolic extract). Obviously, the leaves of these three aromatic plants are highly toxic to rice weevil adults and larvae. This finding is very promising to further develop bio-insecticidal agents from mintweed, kitchen mint and kaffir lime for protecting stored, milled, rice in larger scales, household and industrial storages.
Keywords: rice weevil, stored milled rice, mintweed, kitchen mint, kaffir lime, repellency, insecticidal activity, rice grain protection, progeny growth and development inhibition.

Introduction

Rice *Oryza sativa* L. is one of the most important staple foods in the world. Stored rice seeds and milled rice grains are prone to be damaged by insect pests. In particularly, milled rice is mostly infested by rice weevils, *Sitophilus oryzae* L. (Coleoptera: Curculionidae), causing heavy economic losses. Rice weevil adults and larvae feed on the carbohydrate in the rice grains leading to weight loss and product contamination [1].

Presently, the control of rice weevils relies on fumigation and residual grain protection by synthetic insecticides such as DDT, lindane, pirimiphos-methyl, and aluminium phosphide (phosphine) [2]. However, these chemicals are costly and some are explosive and hard to handle. Some are potentially mutagens, inducing insect resistance and carcinogenesis to humans [3]. The biological control of weevils on wheat, corn and rice storage using different plants has been evidenced before and after harvest [4-6]. A numbers of plant crude extracts have been investigated for their toxic properties against different stored grain pests. They have been also proved non-toxic to human and environment [7-9].

Some plant extracts from the families of Asteraceae, Piperaceae, Annonaceae, Laminaceae and Rutaceae were demonstrated to produce various biological controls such as antifeedant, repellant, and insecticidal properties to many insect species [10, 11-13].

Rice is one of the most economically important crops of Thailand and many other countries. Stored, milled rice is damaged by rice weevils causing substantially economic loss for household consumption and export. Therefore, searching for new alternative means to protect rice from damaging by insect pests and fungi, which are safe for human and environment, is very essential. In this study, the leaf crude extracts of three edible aromatic plants, mintweed *Hyptis suaveolens* L., Poit., kichen mint *Mentha cordifolia* Opiz, and kaffir lime *Citrus hystrix* DC. were investigated for their toxic protection against the rice weevils infested in stored Thai jasmine, milled rice.

Materials and Methods

Preparation for Plant Extracts

Mintweed, kitchen mint and kaffir lime leaves were collected on Suranaree University of Technology campus and vicinity during 2008-9. The leaves were cleaned, sun dried and ground to powders. The leaf powders were extracted in 80% ethanol and water using a Soxhlets extraction apparatus. The extracts were evaporated, freeze dried and kept refrigerated. The extract powders were redissolved in 40% ethanol or water before use in the experiments.

Insect Rearing

Rice weevils were collected from infested, stored, milled rice and reared in a 600-ml plastic container containing

milled rice, covered with a cotton cloth and kept at 28°C, 65-70% relative humidity and 12 h light : 12 h dark. Two weeks, after oviposition, the insect parents were removed through a 2-mm mesh sieve. In a month, the new adults emerged and were used in the experiments. Thai jasmine rice, KDML 105, was used in all experiments.

Repellency Test

The effects of the extracts on weevil repellence were conducted by a cone bioassay; the setting was designed as in Figure 1. Briefly, 40 grams of milled rice grains were thoroughly mixed with various concentrations of the extracts. The mixed grains were put in a plastic cone strainer with 2 mm pore size. The cone was put on top of the mouth of a bottle which was placed on a glycerol pre-coated plastic plate, wrapped around with nylon cloth and tightly secured with a rubber band. Adult weevils were introduced into the middle of the mixed grains through a long-stemmed funnel. The weevils those escaped from the cone were counted after 15, 30 and 60 minutes, 1, 12, and 24 hours. The tests were done in triplicate and repeated twice in all experiments.

Mortality Test

Twenty grams of milled rice were thoroughly sprayed and mixed with the extracts in a bottle. Twenty-adult weevils were introduced into the mixed grains. The bottle was covered with cotton cloth and secured with a rubber band. The dead weevils, no response to forceps poking, were counted after 5, 10 15 and 20 days. The experiments were done in triplicate and repeated twice. The mortality was calculated using the Abbott formula [14].

Rice Grain Protection Test

Twenty grams of milled rice were thoroughly sprayed and mixed with the extracts. Twenty-adult weevils were introduced; the bottle was covered with cotton cloth and secured with a rubber band. The weevils were cultured, allowed to lay eggs inside the rice grains and then removed after 2 weeks. The treated and control grains were kept to allow weevils to develop. The culture was continued for 35 and 49 days. A hundred of infested grains were taken out and investigated for damage by opaque appearance and weight loss. The grain damage was computed using the method of FAO [15] modified by [16] as follows:

$$\% \text{ Weight loss} = [(UNd \times DNu) / U(Nd+Nu)] \times 100$$

Where:
U = weight of undamaged grain
D = weight of damaged grain
Nu = Number of undamaged grains
Nd = Number of damage grains

Progeny Growth and Development Test

Twenty grams of milled rice were placed in a bottle and 20-adult weevils were introduced into the bottle. The bottle was then covered with cotton cloth. The weevils were cultured, allowed to lay eggs and removed after 2 weeks. The rice grains were then thoroughly sprayed and mixed with the extracts. The culture was continued until weevil progeny emerged. The progeny were counted at 49 days of the culture. Inhibition rate (% IR) or reduction in the number of emerged weevils was calculated by the method of [17] as follows

$$\% \text{ IR} = (Cn-Tn) \times 100 / Cn$$

Where:
Cn is the number of newly emerged insects in the untreated (control) sample.
Tn is the number of insects in the treated sample.

Data Analysis

All data were analyzed by analysis of variance (ANOVA) using Statistics Package for the Social Sciences (SPSS) version 11 and completely randomized design (CRD). The means were compared using the Duncan's Multiple Range Test (DMRT) at 5% significant level. The mortality counts were corrected by Abbott's formula [14]. Probit analysis was used to estimate EC_{50} values.

Results

Repellent Effect

The repellent protection of mintweed, kitchen mint and kaffir lime leaf extracts against adult rice weevils were dose- and time-dependent variables (Tables 1-3). In table 1, the ethanolic and the water extracts of all plants significantly expressed repellent activity against the adult weevils at 24 hours in dose-dependent variable. The ethanolic extracts slightly stronger repelled the weevils than the water extracts. The repellency of ethanolic extracts of mintweed ranged from 49.17% to 72.50%; of kitchen mint ranged from 55% to 75%; and of kaffir lime ranged from 53.33% to 80.00%. All extracts at highest dose of 6.4%, 24 h repelled the weevils about 3-3.4 fold of the control. The repellent protection of the ethanolic extracts compared as kaffir lime > kitchen mint > mintweed and of the water extracts compared as kitchen mint > kaffir lime > mintweed. The repellency of the ethanolic extracts of kaffir lime, kitchen mint and mintweed, expressed as EC_{50} values at 24 h, were 13.23, 15.63, and 18.95 mg/ml, respectively. While the EC_{50} values of repellency of the water extracts were 19.87, 19.04, and 27.13 mg/ml, respectively.

The repellent protection was also time-dependent (Table 2 & 3). Table 2 represents the repellent effects of the ethanolic extracts. The repellent efficacy of the lowest extract concentration, 0.8%, increased approximately from 1.6-1.9 fold (15 min) to 1.7-1.9 fold (1 h) and to 2.1-2.4 fold (24 h) as compared to the controls. While the highest concentration, 6.4%, the repellent efficacy increased approximately from 3.8-4.5 fold (15 min), to 2.6-2.8 fold (1 h) and to 2.1-3.4 fold (24 h).

Table 3 represents the repellent protection of the water extracts, which was also expressed in the time-dependent variable with similar to that of ethanolic extracts. The kitchen mint extract at 6.4%, 24 h, repelled highest insects of 71.66%. However, the repellency of the ethanolic extracts of all plants was slightly higher than of the water extracts of the same plant, as well as of the same concentration. It is concluded that the highest repellent protection against the adult rice weevils by the ethanolic extracts was kaffir lime (Table 2) and by the water extracts was kitchen mint (Table 3).

Mortality Effect

All plant extracts exhibited strongly insecticidal activity against adult rice weevils as dose- and time- dependent variables (Tables 4 & 5). Kitchen mint at highest dose, 6.4%, produced the most potent insecticidal activity by nearly 50% in one day exposure (Table 4) and by 100% in 20 day exposure. Meanwhile, mintweed and kaffir lime extracts affected equally with a high of 90%. The mortality effects of the water leaf extracts were less toxic than the ethanolic leaf extracts (Table 5). The kitchen mint water extract at 6.4% was slightly more potent than the others and reached a high of 76.67% in 10 days.

Rice Grain Protection

Rice grain protection against rice weevils by plant extracts was observed after allowing the weevil embryos to develop and grow inside the extract-sprayed grains for more or less one life cycle. It appeared that all extracts well and similarly protected the rice grain texture and the rice weight as increasing extract doses (Table 6). However, the rice grain protection by kitchen mint extract was slightly higher than the others and much greater than the controls. At day 35, rice weevils infested in rice grains, treatment with the kitchen mint ethanolic extracts caused rice weight loss only 4.09% (0.8% conc.) and 2.62% (6.4% conc.). The rice weight loss by the kitchen mint water extract was similar. At day 49, the kitchen mint ethanolic extract slightly increased the rice weight loss to 14.64% (0.8% conc.) and 10.24% (6.4% conc.). At the same time, the kitchen mint water extracts caused rice weight loss 16.3% (0.8% conc.) and 10.3% (6.4% conc.). In addition, the texture of the extract treated rice grains was very much similar to the control rice.

Progeny Growth and Development Inhibition

Rice weevil progeny was the new generation allowed to develop and grow in rice after treatment with the extracts and being collected in a life cycle. All plant extracts significantly inhibited the F1 progeny growth and development in the dose-dependent variable (Table 7). The kitchen mint extract slightly more potently reduced the emergence of rice weevil new generation than the others The F1 progeny inhibition by kitchen mint ethanolic extract ranged from 71% (0.8% dose) to 89% (6.4% dose). While, the F1 progeny reduction by kitchen mint water extract ranged from 61% (0.8% dose) to 81% (6.4% dose). Therefore, these three edible aromatic plants leaves were high potent to early stop rice weevil life cycle. These would prevent the continuously wide spread of the rice weevils in new stored, milled rice grains.

Discussion

Presently, plants are more favorably exploited as biological control agents to protect stored grain products from insect pests, including rice weevils [10-11, 18-19]. Our study demonstrated that mintweed, kitchen mint and kaffir lime leaf extracts were potentially protective agents against rice weevils infested in milled rice. The kaffir lime ethanolic extract exhibited high repellency against rice weevils, which was similar to neem *Azadirachta indica* extract [20]. and to stinging nettle *Urtica dioica* and dandelion *Taraxacum officinale* extracts [21]. The repellent efficacy of different plants on stored products was also evident [21-22]. The aromatic chemicals in our three edible plant leaf extracts could destroy rice weevils by disrupting the normal respiratory activity causing asphyxiation and subsequent death [23].

It was evident that some plants contained irritant and foul smelling chemicals which strongly repelled stored product insect pests [24-25]. These were in accordance with the repellent efficacy against rice weevils of mintweed, kitchen mint and kaffir lime, which are known containing naturally aromatic chemicals.

The insecticidal activities of mintweed, kitchen mint and kaffir lime extracts on rice weevils were dose and time dependent. The ethanolic extracts of all studied plants produced stronger activities than the water extracts. The most potent activity was obtained from kitchen mint ethanolic extracts. These findings are in agreement with the insecticidal activities of chinaberry *Melia azdarach* and star anise *Illicium verum* on red flour beetle *Tribolium castaneum* infested rice grains [19].

There are reports showing that compounds from plant extracts such as menthone,1,8 cineol, limonene and linalool could act as insecticides against insect-stored products [11, 23, 26-28]. Similarly, there are reports that essential oil of *rosemary Rosmarinus officinalis* inhibited the growth of bean weevil *Acanthoscelides obtectus* [29] and of *Eucalyptus globulus* inhibited the progeny emergence of cowpea weevil *Callosobruchus maculatus* [22]. In addition, different plant powders and extracts were reported to effectively reduce the adult rice weevils and rice grain weight [30]. This is the first study showing that edible aromatic plant, mintweed, kitchen mint and kaffir lime, leaf extracts exhibit strong inhibition on growth and development of rice weevil progeny in milled rice. This is very important in early protection of rice grain texture and weight from the young insects. It also stops the sequential spread of rice weevils in milled rice.

Conclusion

In conclusion, our finding demonstrates that the leaf extracts of mintweed, kitchen mint and kaffir lime, which is aromatic, protected milled rice from rice weevil infestation in a laboratory scale. The crude extracts of these plants are potent repellent, insecticidal and growth inhibitor agents against rice weevils. All extracts well protected rice grain weight loss and grain texture.

Their ethanolic extracts are more potent than the water extracts. Among these three plants, kitchen mint is most potent. Therefore, it is very promising that these three edible aromatic plants are potential candidates as plant-based insecticides for the protection of stored, milled rice. The application in large scales, household and industrial crop grain storages, ought to be further studied.

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Table-1 - Repellent activities of the ethanolic and water extracts of mintweed, kitchen mint and kaffir lime leaves on adult rice weevils in milled rice at 24 hours.

Conc. (%)	% Repellent activity					
	Ethanolic extract			Water extract		
	Mintweed	Kitchen mint	Kaffir lime	Mintweed	Kitchen mint	Kaffir lime
0	23.33±0.10^{a}	23.33±0.10^{a}	23.33±0.10^{a}	20.00±0.57^{a}	20.00±0.57^{a}	20.00±0.57^{a}
0.8	49.17±0.23^{b}	55.00±0.29^{b}	53.33±1.11^{b}	45.83±0.23^{b}	51.67±0.14^{b}	51.33±0.1^{b}
1.6	55.83±0.15^{b}	56.67±0.27^{b}	60.00±0.18^{c}	49.17±0.15^{b}	52.50±0.14^{b}	55.50±0.11^{c}
3.2	64.17±0.15^{c}	65.00±0.41^{c}	66.66±0.08^{c}	57.50±0.15^{c}	66.67±0.15^{c}	62.50±0.10^{d}
6.4	72.50±0.22^{c}	75.00±0.25^{d}	80.00±0.12^{d}	67.50±0.20^{d}	71.67±0.06^{c}	70.83±0.10^{e}
EC_{50} (mg/ml)	18.95	15.63	13.23	27.13	19.04	19.87

Table-2 - Repellent effects of the ethanolic extracts of mimtweed, kitchen mint and kaffir lime leaves on adult rice weevils in milled rice at various times of exposure.

Ethanolic extract	Conc. (%)	% Repellant activity				
		15 Min	30 Min	1 Hr	12 Hr	24 Hr
Mintweed	0.8	21.66±0.11^{b}	30.83±0.24^{b}	39.17±0.19^{b}	45.83±0.26^{b}	49.17±0.23^{b}
	1.6	34.17±0.13^{c}	41.67±0.16^{c}	48.33±0.15^{c}	53.33±0.10^{bc}	55.83±0.15^{b}
	3.2	50.83±0.13^{d}	54.17±0.13^{d}	54.17±0.07^{c}	59.17±0.16^{c}	64.17±0.15^{c}
	6.4	52.50±0.11^{d}	55.83±0.10^{d}	62.50±0.15^{d}	68.33±0.23^{d}	72.50±0.22^{c}
Kitchen mint	0.8	21.67±0.26^{b}	28.33±0.75^{b}	40.83±0.47^{b}	51.67±0.17^{b}	55.00±0.29^{b}
	1.6	35.00±0.60^{c}	36.67±0.42^{c}	44.17±0.15^{b}	51.67±0.28^{b}	56.67±0.27^{b}
	3.2	48.33±0.18^{d}	51.67±0.17^{d}	55.00±0.29^{c}	58.33±0.36^{c}	65.00±0.41^{c}
	6.4	52.50±0.41^{d}	53.33±0.27^{d}	61.67±0.44^{d}	66.67±0.46^{d}	75.00±0.25^{d}
Kaffir lime	0.8	18.33±0.25^{b}	39.17±0.19^{b}	45.00±1.19^{b}	50.83±1.10^{b}	53.33±1.11^{b}
	1.6	31.67±0.21^{c}	40.83±0.12^{b}	49.17±0.19^{b}	54.17±1.13^{bc}	60.00±0.18^{c}
	3.2	34.17±0.20^{c}	44.17±0.15^{b}	50.00±0.09^{b}	59.17±0.09^{c}	66.66±0.08^{c}
	6.4	44.17±0.18^{d}	53.33±0.11^{c}	65.00±0.11^{c}	75.00±0.16^{d}	80.00±0.12^{d}
Control		11.67±0.14^{a}	16.67±0.12^{a}	23.33±0.10^{a}	23.33±0.10^{a}	23.33±0.10^{a}

Table-3 - Repellent effects of water extracts of mimtweed, kitchen mint and kaffir lime leaves on adult rice weevils in milled rice at various times of exposure.

Water extract	Conc. (%)	% Repellant activity				
		15 Min	30 Min	1 Hr	12 Hr	24 Hr
Mintweed	0.8	21.67±0.9^{b}	28.33±0.22^{b}	36.67±0.08^{b}	42.50±0.11^{b}	45.83±0.23^{b}
	1.6	27.50±0.12^{c}	35.83±0.13^{b}	41.67±0.11^{b}	45.83±0.17^{b}	49.17±0.15^{b}
	3.2	32.50±0.16^{d}	42.50±0.10^{c}	50.83±0.13^{c}	54.17±0.16^{c}	57.50±0.15^{c}
	6.4	38.33±0.11^{e}	56.67±0.09^{d}	59.17±0.12^{d}	67.50±0.69^{d}	67.50±0.20^{d}
Kitchen mint	0.8	21.67±0.18^{b}	26.67±0.09^{b}	35.00±0.15^{b}	41.67±0.08^{b}	51.33±0.14^{b}
	1.6	34.17±0.20^{c}	34.17±0.13^{c}	43.33±0.08^{c}	48.33±0.11^{c}	55.50±0.14^{b}
	3.2	46.67±0.12^{d}	48.33±0.07^{d}	55.00±0.12^{d}	61.67±0.13^{d}	66.67±0.15^{c}
	6.4	51.67±1.11^{d}	52.50±0.07^{d}	61.67±0.21^{d}	70.00±0.10^{e}	71.67±0.06^{c}
Kaffir lime	0.8	20.83±0.16^{b}	38.33±0.20^{b}	44.17±1.11^{b}	51.67±0.07^{b}	53.33±0.1^{b}
	1.6	30.00±0.16^{c}	40.00±0.18^{b}	49.17±0.10^{c}	54.17±0.10^{bc}	57.50±0.11^{c}
	3.2	32.50±0.18^{c}	46.67±0.18^{c}	51.67±0.11^{c}	58.33±0.13^{c}	62.50±0.10^{d}
	6.4	43.33±0.12^{d}	53.33±0.07^{d}	63.33±0.13^{d}	65.00±0.11^{d}	70.83±0.10^{e}
Control		11.67±0.57^{a}	16.67±1.52^{a}	20.00±0.14^{a}	20.00±0.14^{a}	20.00±0.14^{a}

Table- 4 - Mortality effects of ethanolic extracts of mimtweed, kitchen mint and kaffir lime leaves on adult rice weevils in milled rice at various days of exposure.

Ethanolic extract	Conc. (%)	% Mortality				
		Day 1	Day 5	Day 10	Day 15	Day 20
Mintweed	0.8	21.67±0.18^{b}	39.17±0.30^{b}	55.83±0.23^{b}	61.67±0.19^{b}	65.00±0.13^{b}
	1.6	25.83±0.30^{b}	41.67±0.27^{bc}	64.17±0.15^{c}	76.67±0.17^{c}	79.17±0.15^{c}
	3.2	35.00±0.19^{c}	51.67±0.21^{ed}	74.17±0.15^{d}	83.33±0.11^{cd}	85.83±0.18^{cd}
	6.4	43.30±0.18^{d}	60.80±0.24^{d}	80.00±0.10^{d}	86.70±0.05^{d}	90.00±0.11^{d}
Kitchen mint	0.8	22.50±0.22^{b}	42.50±0.16^{b}	63.33±0.25^{b}	66.67±0.15^{b}	70.00±0.10^{b}
	1.6	30.83±0.31^{c}	51.67±0.14^{c}	67.50±0.17^{bc}	81.67±0.13^{c}	85.00±0.12^{c}
	3.2	40.00±0.10^{d}	55.83±0.10^{c}	75.00±0.18^{c}	91.67±0.08^{d}	99.17±0.04^{d}
	6.4	45.83±0.11^{d}	72.50±0.18^{d}	85.00±0.06^{d}	95.83±0.12^{d}	100.00±0.00^{d}
Kaffir lime	0.8	17.50±0.25^{b}	38.33±0.14^{b}	51.67±0.09^{b}	61.67±0.18^{b}	65.83±0.14^{b}
	1.6	20.83±0.28^{bc}	51.67±0.23^{b}	59.17±0.14^{bc}	67.50±0.20^{bc}	71.67±0.19^{c}
	3.2	24.17±0.38^{c}	58.33±0.24^{c}	66.67±0.15^{c}	76.67±0.15^{cd}	83.33±0.13^{c}
	6.4	35.00±0.15^{d}	70.00±0.19^{c}	79.17±0.17^{d}	85.00±0.18^{d}	91.67±0.18^{c}
Control		0.00±0.00^{a}	3.33±0.36^{a}	5.00±0.34^{a}	5.00±0.27^{a}	5.00±0.27^{a}

Table-5 - Mortality effects of water extracts of mimtweed, kitchen mint and kaffir lime leaves on adult rice weevils in milled rice at various days of exposure.

Water extract	Conc. (%)	% Mortality				
		Day 1	Day 5	Day 10	Day 15	Day 20
Mintweed	0.8	8.33±0.33^{ab}	40.00±0.57^{b}	45.00±0.57^{b}	53.33±0.66^{b}	53.33±0.66^{b}
	1.6	15.00±0.57^{bc}	43.33±0.33^{bc}	56.67±0.66^{bc}	61.67±0.33^{b}	66.67±0.88^{b}
	3.2	20.00±1.20^{bc}	55.00±0.57^{d}	61.67±1.20^{c}	71.67±0.66^{c}	71.67±0.66^{c}
	6.4	26.00±0.88^{c}	61.67±1.40^{e}	70.00±1.00^{c}	71.67±0.66^{c}	71.67±0.66^{c}
Kitchen mint	0.8	13.33±0.88^{ab}	41.67±0.66^{b}	48.33±0.33^{b}	61.67±1.20^{b}	63.33±0.88^{b}
	1.6	18.33±0.88^{bc}	45.00±0.57^{bc}	55.00±0.57^{bc}	65.00±1.20^{b}	68.33±0.66^{b}
	3.2	21.67±0.57^{bc}	56.67±1.20^{cd}	63.33±0.88^{c}	71.67±0.66^{b}	73.33±0.88^{b}
	6.4	30.00±0.33^{c}	63.33±1.20^{d}	76.67±1.20^{d}	76.67±1.20^{b}	76.67±1.20^{b}
Kaffir lime	0.8	11.67±0.57^{b}	38.33±0.66^{b}	46.67±0.33^{b}	60.00±1.20^{b}	60.00±1.20^{b}
	1.6	15.00±1.20^{b}	46.67±0.33^{b}	58.33±0.66^{c}	63.33±0.88^{bc}	63.33±0.88^{bc}
	3.2	21.67±0.66^{bc}	56.67±0.88^{c}	61.67±0.66^{cd}	71.67±0.33^{c}	73.33±0.33^{c}
	6.4	28.33±1.15^{c}	65.00±0.57^{c}	70.00±0.57^{d}	73.33±0.33^{c}	73.33±0.33^{c}
Control		0.00±0.00^{a}	1.67±0.33^{a}	3.33±033^{a}	5.00±0.00^{a}	5.00±0.00^{a}

Table-6 - Rice grain weight losses produced by adult rice weevils after exposure to mimtweed, kitchen mint and kaffir lime leaf extracts at day 35 and day 49.

Plant	Conc. (%)	% Rice grain weight loss			
		Day 35		Day 49	
		Ethanolic extract	Water extract	Ethanolic extract	Water extract
Mintweed	0.8	4.36 ± 0.44^{b}	6.33 ± 1.10^{b}	14.45 ± 0.51^{a}	16.83 ± 1.05^{b}
	1.6	3.86 ± 0.25^{ab}	4.13 ± 0.27^{a}	13.93 ± 0.70^{a}	13.20 ± 0.64^{a}
	3.2	3.47 ± 0.15^{ab}	3.69 ± 0.26^{a}	13.10 ± 0.24^{a}	11.57 ± 0.94^{a}
	6.4	2.75 ± 0.37^{a}	3.12 ± 0.24^{a}	12.62 ± 0.72^{a}	11.02 ± 0.55^{a}
Kitchen mint	0.8	4.46 ± 0.22^{bc}	5.13 ± 023^{b}	14.26 ± 0.68^{c}	16.33 ± 2.12^{b}
	1.6	3.69 ± 0.25^{ab}	4.47 ± 0.58^{ab}	12.02 ± 0.53^{b}	12.64 ± 0.67^{ab}
	3.2	3.57 ± 0.98^{ab}	4.28 ± 0.35^{a}	11.52 ± 0.43^{b}	12.25 ± 1.02^{a}
	6.4	2.36 ± 0.26^{a}	2.85 ± 0.98^{a}	9.40 ± 0.30^{a}	10.32 ± 0.63^{a}
Kaffir lime	0.8	4.09 ± 0.20^{a}	4.52 ± 0.75^{a}	14.64 ± 0.89^{b}	17.68 ± 2.30^{c}
	1.6	3.39 ± 0.37^{ab}	3.64 ± 0.39^{a}	12.54 ± 0.83^{ab}	16.24 ± 0.53^{bc}
	3.2	2.69 ± 0.25^{a}	3.64 ± 0.29^{a}	11.82 ± 0.74^{a}	13.10 ± 0.39^{ab}
	6.4	2.62 ± 0.19^{a}	3.40 ± 0.57^{a}	10.24 ± 0.70^{a}	12.19 ± 0.29^{a}
Control		6.07 ± 0.50^{c}	7.20 ± 0.82^{b}	19.03 ± 0.77^{b}	24.14 ± 0.71^{c}

Table-7 - Inhibition of emergence rice weevil progeny from milled rice by mimtweed, kitchen mint and kaffir lime leaf extracts.

Plant	Conc. (%)	Progeny emerged			
		Ethanolic extract		Water extract	
		F_1 Progeny	% inhibition	F_1 Progeny	% inhibition
Mintweed	0.8	14.67 ± 0.33^{c}	64.52	19.33 ± 0.33^{c}	60.00
	1.6	12.33 ± 0.88^{bc}	70.16	15.00 ± 0.57^{b}	68.97
	3.2	11.33 ± 0.66^{b}	72.58	13.33 ± 0.88^{b}	72.41
	6.4	7.67 ± 0.88^{a}	81.45	10.67 ± 0.66^{a}	77.93
Kitchen mint	0.8	12.00 ± 1.20^{c}	70.97	18.67 ± 0.33^{c}	61.38
	1.6	10.67 ± 0.33^{c}	74.19	15.00 ± 1.20^{b}	68.97
	3.2	8.00 ± 0.57^{b}	80.65	11.33 ± 0.88^{a}	76.55
	6.4	4.67 ± 0.33^{a}	88.71	9.30 ± 0.33^{a}	80.69
Kaffir lime	0.8	14.33 ± 0.88^{c}	65.32	21.67 ± 1.20^{c}	55.17
	1.6	12.67 ± 0.33^{bc}	69.35	19.33 ± 0.33^{bc}	60.00
	3.2	10.33 ± 0.88^{ab}	75.00	17.67 ± 0.66^{ab}	63.45
	6.4	8.67 ± 0.88^{a}	79.03	15.67 ± 0.33^{a}	67.59
Control		41.33 ± 0.88^{d}	0.00	48.33 ± 0.88^{d}	0.00

Note: *Each value is the mean $\pm$ standard error, n = 6. Numbers with different letters within the same column are significantly different ($P \leq 0.05$).* ***[For Table 1-7]***

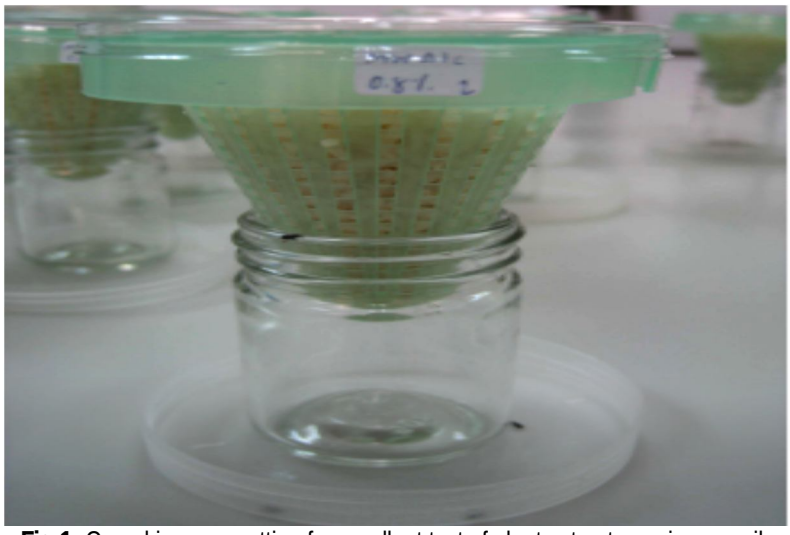

Fig 1- Cone bioassay setting for repellent test of plant extracts on rice weevils.