

Bioefficacy of Organic Extracts of *Ocimum basilicum* against *Sitophilus zeamais*

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Abstract

Ocimum basilicum plant extracts in methanol, hexane and methanol: hexane solvent blend were evaluated for their fumigant toxicities, repellent and adult emergence inhibition activities against *Sitophilus zeamais*. Twenty grams of maize were used for each treatment and four different extract concentrations of 25, 50, 75 and 100% were tested for their activities. The highest mortality (100%) was observed after 72 h at 100% *O. basilicum* blend extract concentration. The methanolic extract recorded mortality rates of 74.36% at highest concentration while 78% mortality was true for hexane extract at 96 hours with 100% extract concentration. The three different solvents extracts of *O. basilicum* recorded high repellent and new adult emergence inhibition activities comparable to actellic (reference pesticide). In conclusion, blend extract of *O. basilicum* was the most effective in maize weevil control and therefore can be used in formulating eco-friendly bio-pesticide against *S. zeamais*.

Keywords: *Sitophilus zeamais*; *Ocimum basilica*; Adult emergence; Fumigant toxicity; Repellent activities

Introduction

Maize weevil (*Sitophilus zeamais*) (Coleoptera; Dryophthoridae), is one of the most important primary pest that attack stored-maize among others like larger grain borer (*Prostephanus truncatus*) [1]. *Sitophilus zeamais* are virtually found in every part of the world, especially Tropical regions where maize is grown [2]. The damage caused by weevils in maize grains reduces its nutritive value, weight and contaminates the stored grain rendering the grain unfit for consumption. The losses attributed to maize weevils are enormous and may lead to diverse effects such as hunger and food insecurity in affected areas [3]. There are a number of conventional methods of controlling weevils. Including, use synthetic pesticides. However, these methods have a number of short comings which include, residual toxicity, death of non-target organism, risk of user's contamination and pest resistance hence not preferable. Plants produce a diverse array of chemicals some of which have insecticidal and repellent activities [4]. This gives prospects of a source of safer, less expensive and easily processed insecticides against weevils after determination of their insecticidal and repellent efficacies [5]. The current study was designed to determine the fumigant toxicities, repellent activity and new adult emergence inhibition activities of methanolic, hexane and methanol: hexane blend extracts of *O. basilicum* to *S. zeamais* as a possible alternative pest control material.

Materials and Methods

Plant material collection and preparation of crude extracts

Fresh leaves of *Ocimum basilicum* (sweet basil) were collected from Siakago division, Mbeere North Sub County of Embu County, Kenya. They were then clean and transported to Kenyatta university biochemistry laboratory. The leaves were air dried indoors at room temperature for ten days until they were completely dry. The dried leaves were then crushed into powder using an electric mill to obtain fine powder. Seven hundred and fifty grams of the powder were soaked in a litre of each of the solvent for 72 h at room temperature. For blend extraction, hexane and methanol were mixed in the ratio 1: 1 followed by extraction. the extracts were then filtered and concentrated using rotary evaporator at 45°C for eight hours and the final concentrates were kept as stock solution (100% concentrate) as suggested by Deshmukh

and Borie [6]. Different extract proportions were then formulated from stock solution, i.e., 75% (3 stock solution: 1 solvent v/v), 50% (1:1) and 25% (3:1 v/v).

Insect culture

Maize weevils *Sitophilus zeamais* were reared at the Kenyatta university biochemistry laboratory growth chambers maintained at 27 ± 2°C and 75% relative humidity. The weevils were fed on corn meal. The jars containing the weevils were covered with muslin cloth to ensure proper ventilation.

Fumigant toxicity assay

Fumigant toxicities of the extracts on *S. zeamais* were carried out using plastic vials each containing twenty grams of whole maize grains divided into six different groups. Each group was separately treated with 1 ml of the different extract concentrates (25, 50, 75 and 100%) and four replicates made for each treatment. One control group was treated with solvent only while the other group with actellic (reference pesticide). The containers were shaken thoroughly and then left open for one hour so that traces of solvents can evaporate. Twenty adult *S. zeamais* (2 to 3 days old) were then placed into each container and ventilation made. The numbers of dead and alive weevils were counted after 6, 24, 48, 72 and 96 h. The insects were confirmed dead when they did not respond to probing with sharp object at the abdomen [7]. Corrected mortality was then computed following Abbott formula [8].

New adult emergence inhibition effect

After 96 h, both dead and live insects were removed from the vials and the set up maintained for 49 days. The total number of *S. zeamais*

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that emerged from each vial was counted and percentage inhibition rates computed using the formula described by Tapondjou et al. [9].

Repellent assay

The repellent activities of *O. basilicum* extracts were carried out following method described by Obeng-Ofori et al. [10]. The test areas were 9 cm diameter filter-paper circles cut into half. 1 ml of each of the extract was uniformly applied to one half paper-discs while the other half disc was treated with solvent only (control). The half-paper discs were then air dried and full discs re-made by attaching the half-paper discs with adhesive paper tape. The full discs were then placed into petri dish followed by release of twenty adult *S. zeamais* at the centre of the filter discs and covered. Four replicates were made for each treatment. The number of insects present on the control half (Nc) and treated half (Nt) were recorded hourly for five hours. Percentage Repellency (PR) was then calculated using the formula described by Thien et al. [11].

Qualitative phytochemical screening

Freshly prepared organic extracts of *O. basilicum* were subjected to qualitative phytochemical screening to check for presence or absence of a number of secondary metabolites that have been have associated with fumigant toxicity and repellent activities of various plants. Particularly, terpenoids, flavonoids, phenolics, alkaloids, saponins, steroids and tannins were screened following the protocol described by Harborne [12] and Kotake [13].

Data analysis

Data obtained from this work were subjected to descriptive statistics to obtain means \pm SEM. One way analysis of variance (ANOVA) was then carried out followed by Tukey's post hoc test to compare and separate the means.

Results

Fumigant toxicity of methanolic extract of *O. basilicum* against *S. zeamais*

Low mortality rates of *S. zeamais* were recorded after exposure to methanolic extracts of *O. basilicum* in the sixth hour at all extract

concentration used. Nonetheless, mortality rates increased in the subsequent time periods. Highest mortality rate of 74.36% was recorded by 100% extract concentration, followed by 65.38% mortality caused by 75% extract concentration within 96 hours (Table 1). The low extract concentrations of 25 and 50% had low fumigant toxicity effects of 30.77 and 33.38% within similar time period of 96 hours. Moreover, the fumigant toxicity effects of actellic (reference pesticide) was significantly higher compared to all extract treatments throughout the experimental period ($p < 0.05$; Table 1).

Fumigant activity of hexane extracts of *Ocimum basilicum* against *Sitophilus zeamais*

The hexane extract of *O. basilicum* showed varied fumigant toxicity effects against *S. zeamais* at all levels of extract concentration. In the 6th h, the acute fumigant toxicities effects of the four different extract concentrations were between 0-18.75% which was comparable to the control (Table 2). However, this was significantly lower than that of actellic treatment. In the 24th h, the actellic treatment still caused a higher acute fumigant toxicities compared to the different extract concentrations. The lowest mortality rate of 42.31% of *S. zeamais* was evoked by 25% extract concentration within the 96 hour period of exposure. The 75% and 100% extract concentrations recorded 66.67% and 78.21% mortality respectively. The fumigant toxicities effects of the extracts were significantly lower than actellic (reference pesticide) at 48, 72 and 96 hours of treatment period ($p < 0.05$; Table 2).

Fumigant toxicity of hexane: methanol blend extract of *Ocimum basilicum* against *Sitophilus zeamais*

When fumigant toxicity effects of hexane: methanolic extract of *O. basilicum* was examined against *S. zeamais*, extract concentration of 25-75% evoked 0-11.25% mortality rates within 6 hours of exposure period, which were not significantly different from effects of the control ($P > 0.05$; Table 3). The 100% extract concentration recorded the highest percentage mortality at the 72nd h and this was comparable to actellic (reference pesticide) ($p > 0.05$; Table 3). The effects of the lowest extract concentration (25%) caused the least mortality (32%) within 96 h of the study. When the extract concentration was increased to 50%, more than double mortality was recorded. The fumigant toxicity effects of the

Concentration	Mean % corrected mortality \pm S.E with exposure period (hours)				
	6 h	24 h	48 h	72 h	96 h
Control	0.00 \pm 0.00 ^c	0.00 \pm 0.00 ^c	0.00 \pm 0.00 ^e	0.00 \pm 0.00 ^d	0.00 \pm 0.00 ^d
25% extract	3.75 \pm 2.39 ^c	20.51 \pm 3.31 ^b	23.08 \pm 3.63 ^{cd}	26.92 \pm 4.38 ^c	30.77 \pm 3.31 ^c
50% extract	5 \pm 2.04 ^b	8.97 \pm 2.45 ^c	20.51 \pm 2.56 ^d	30.77 \pm 4.44 ^c	33.33 \pm 2.69 ^c
75% extract	8.75 \pm 2.39 ^c	21.79 \pm 3.23 ^b	34.62 \pm 3.85 ^c	65.38 \pm 4.38 ^b	65.38 \pm 4.38 ^b
100% extract	12.5 \pm 3.23 ^b	26.92 \pm 1.28 ^b	48.72 \pm 2.96 ^b	67.95 \pm 4.38 ^b	74.36 \pm 2.09 ^b
Actellic	91.25 \pm 5.15 ^a	100 \pm 0.00 ^a	100 \pm 0.00 ^a	100 \pm 0.00 ^a	100 \pm 0.00 ^a

Values followed by the same superscript within the same column are not significantly different by one-way ANOVA ($P \leq 0.05$) followed by Tukey's test.

Table 1: Fumigant toxicity effect of methanolic extract of *Ocimum basilicum* on adult *Sitophilus zeamais*.

Concentration (% extract)	Mean % corrected mortality \pm S.E with exposure period (hours)				
	6 h	24 h	48 h	72 h	96 h
Control	0.00 \pm 0.00 ^c	0.00 \pm 0.00 ^e			
25	0.00 \pm 0.00 ^c	10.90 \pm 4.84 ^{de}	28.21 \pm 2.09 ^d	35.90 \pm 4.44 ^d	42.31 \pm 3.23 ^d
50	1.25 \pm 0.25 ^c	25.64 \pm 1.48 ^{cd}	44.87 \pm 2.45 ^c	56.41 \pm 1.48 ^c	62.82 \pm 2.45 ^c
75	2.50 \pm 1.44 ^c	26.92 \pm 6.74 ^c	52.56 \pm 1.28 ^c	61.54 \pm 1.48 ^{bc}	66.67 \pm 3.31 ^c
100	18.75 \pm 4.27 ^b	48.72 \pm 2.09 ^b	62.82 \pm 2.45 ^b	70.51 \pm 2.45 ^b	78.21 \pm 1.28 ^b
Actellic	91.25 \pm 5.15 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a

Values followed by the same superscript within the same column are not significantly different one-way ANOVA ($P \leq 0.05$) followed by Tukey's test.

Table 2: Fumigant toxicity effect of hexane extract of *Ocimum basilicum* on adult *Sitophilus zeamais*.

extract at 75% and 100% concentration were not significantly different from actellic (reference pesticide) 96 hours exposure period ($p > 0.05$; Table 3). In general, the extract activity was dose dependent. Again, the hexane; methanolic blend extract of *O. basilicum* showed greater fumigant toxicity than individual solvent extracts. The difference in toxicities was even more marked with higher concentrations of the extracts (Figures 1 and 2).

Repellence activity of methanolic extracts of *Ocimum basilicum* against *Sitophilus zeamais*

The methanolic extract of *O. basilicum* at all tested concentrations recorded repellence activities of 72.5% and above by the end of the fifth hour against *S. zeamais*. All the treatment tested showed activity above 57% during the first hour. The 25% extract concentration recorded upto 72.5% activity by the end of the fifth hour of exposure. A slightly higher repellence effect of 82.5% was realized when treatment concentration was increased to 50% extract. Both 75% and 100% extract concentration achieved greater repellence activities of 80% and 87.5% respectively. The mean Percentage Repellence (PR) for all extracts was above 68%. Among all the extract concentrations tested, the repellence activities were not significant difference in the first, third, fourth and fifth hours of exposure ($p > 0.05$; Table 4). The repellent activities of actellic control was significantly higher than that of extracts in the first hour. However, in the following hours the repellent activities of actellic was comparable to that of the higher concentration of extracts (Table 4).

Repellent activity of hexane extracts of *Ocimum basilicum* against *Sitophilus zeamais*

The hexane extract of *O. basilicum* demonstrated repellence activity on *S. zeamias* at different concentrations (Table 5). In the first hour of experimental period, all the extract concentrations tested caused repellent activities greater than 67%. The high repellent effect of 90% was caused by 100% concentration during the fifth hour which was not significant different from that caused by control pesticide. The 25% and 75% extract concentrations caused repellence activities of between 67- 80% during the entire experimental period, while 50% concentration caused repellence activities of between 65% and 77.5%. The repellence activities of all extract concentrations tested were not significantly different in the fourth hour of exposure ($p > 0.05$; Table 5). Mean percentage repellence effects for the 5 hours experimental period were between 73 to 90.50%. The repellent activities of actellic were compared to that of the extract at higher doses (Table 5).

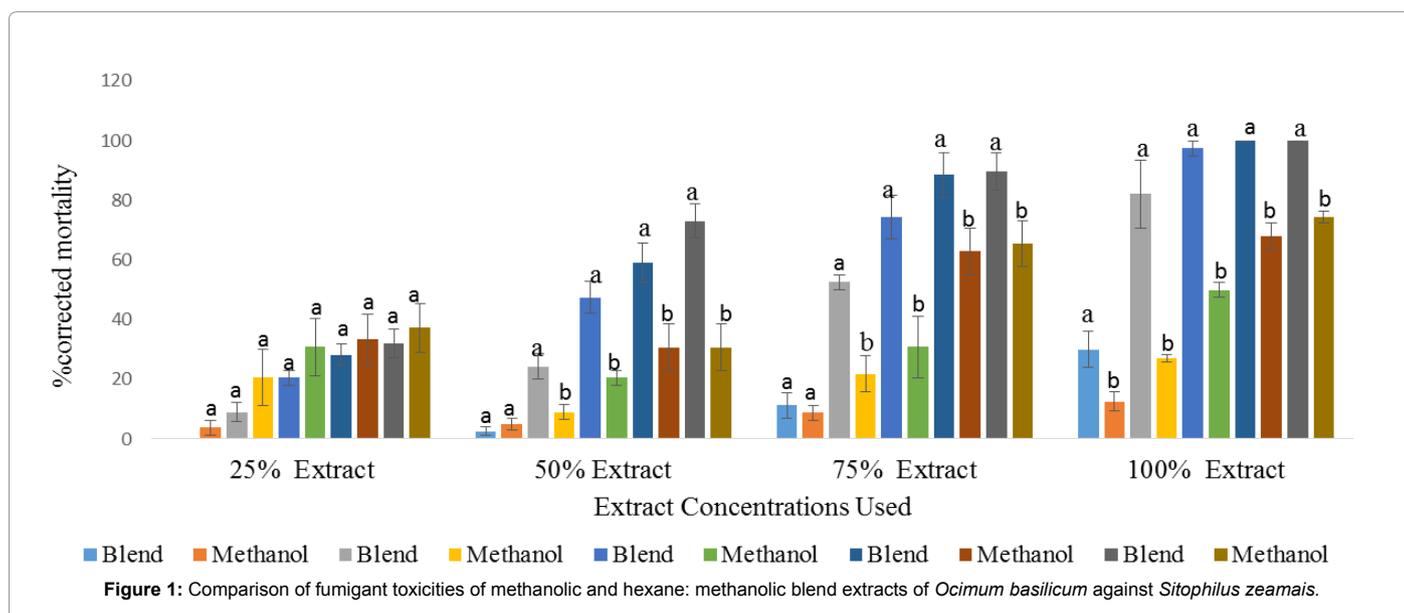
Repellent activity of hexane: methanolic blend extracts of *Ocimum basilicum* on *Sitophilus zeamais*

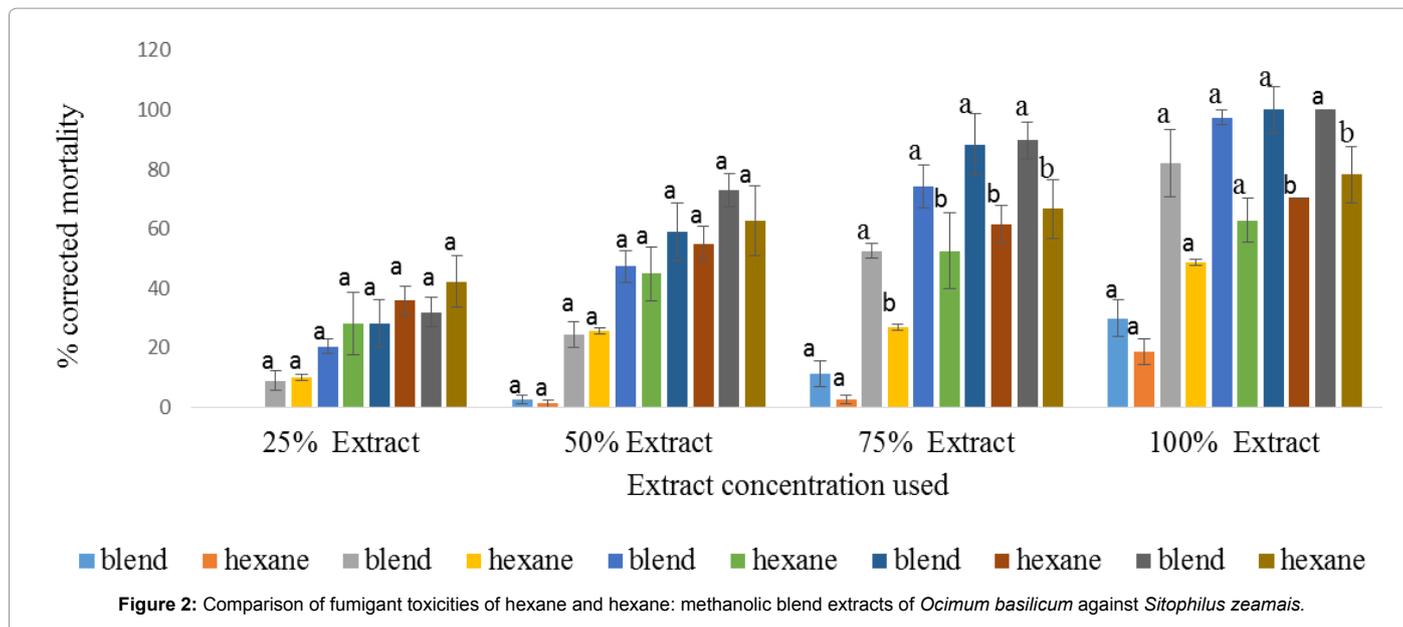
The blend extract concentrations of *O. basilicum* strongly repelled *S. zeamais* as indicated by results in Table 6. At the lowest extract concentration (25%), a repellence activity of 80% was achieved within the first hour, and then it decreased to 60% in the third hour but slightly increased to 75% and 72.5% by fourth and fifth hour respectively. When extract concentration was increased to 50%, the repellence effect increased to 95% in the end of fifth hour. Similarly, 75% extract

Concentration (% extract)	Mean % corrected mortality \pm S.E with exposure period (hours)				
	6 h	24 h	48 h	72 h	96 h
Control	0.00 \pm 0.00 ^c	0.00 \pm 0.00 ^d	0.00 \pm 0.00 ^e	0.00 \pm 0.00 ^d	0.00 \pm 0.00 ^d
25	0.00 \pm 0.00 ^c	8.97 \pm 3.23 ^{cd}	20.51 \pm 2.56 ^d	28.21 \pm 3.63 ^c	32.05 \pm 4.85 ^c
50	2.50 \pm 1.44 ^c	24.36 \pm 4.38 ^c	47.44 \pm 5.29 ^c	58.97 \pm 6.62 ^b	73.08 \pm 5.69 ^b
75	11.25 \pm 4.27 ^c	52.56 \pm 2.45 ^b	74.36 \pm 7.25 ^b	88.46 \pm 7.36 ^a	89.74 \pm 6.28 ^a
100	30.00 \pm 6.12 ^b	82.10 \pm 11.40 ^a	97.44 \pm 2.56 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a
Actellic	91.25 \pm 5.15 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a	100.00 \pm 0.00 ^a

Values followed by the same superscript within the same column are not significantly different one-way ANOVA ($P \leq 0.05$) followed by Tukey's test.

Table 3: Fumigant toxicity effect of mortality of hexane; methanolic blend extract of *Ocimum basilicum* on adult *Sitophilus zeamais*.





Concentration (%extract)	PR (mean% ± S.E) ^m with time					PR (mean%) ⁿ
	1 h	2 h	3 h	4 h	5 h	
25	62.50 ± 4.79 ^{cb}	65.00 ± 2.89 ^b	65.00 ± 2.89 ^b	70.00 ± 4.08 ^b	72.50 ± 4.79 ^b	69.00
50	67.50 ± 4.79 ^b	57.50 ± 2.50 ^b	62.50 ± 4.79 ^b	72.50 ± 4.08 ^b	82.50 ± 2.89 ^a	68.5
75	57.50 ± 2.50 ^c	72.50 ± 2.50 ^a	75.00 ± 2.89 ^a	80.00 ± 4.08 ^{ab}	77.50 ± 4.79 ^{ab}	70.5
100	65.00 ± 6.45 ^{cb}	75.00 ± 8.66 ^a	75.00 ± 6.45 ^a	82.50 ± 4.79 ^a	87.50 ± 4.79 ^a	77
Actellic (control)	87.50 ± 4.79 ^a	87.50 ± 4.79 ^a	85.00 ± 6.45 ^a	97.50 ± 2.50 ^a	95.00 ± 5.00 ^a	90.50

Values followed by the same superscript within the same column are not significantly different ($P \leq 0.05$) determined by one way ANOVA following Tukey's test. Superscript m values were based on four extract concentrations, four replicates. Superscript n values were means obtained over the 5 hour duration

Table 4: Repellent activity of methanolic extract of *Ocimum basilicum* on *Sitophilus zeamais*.

Concentration (%extract)	PR (mean% ± S.E) ^m with time					PR (mean%) ⁿ
	1 h	2 h	3 h	4 h	5 h	
25	80.00 ± 0.00 ^{ab}	70.00 ± 4.08 ^b	67.50 ± 2.50 ^c	77.50 ± 4.79 ^b	75.00 ± 2.89 ^b	74.00
50	70.00 ± 4.08 ^b	72.50 ± 4.79 ^{ab}	80.00 ± 4.08 ^{ab}	72.50 ± 2.50 ^b	77.50 ± 4.79 ^b	73.00
75	80.00 ± 4.08 ^{ab}	77.50 ± 4.79 ^{ab}	70.00 ± 4.08 ^b	67.50 ± 4.79 ^b	75.00 ± 2.89 ^b	74.00
100	85.00 ± 2.89 ^a	87.50 ± 2.50 ^a	82.50 ± 6.29 ^{ab}	75.00 ± 2.89 ^b	90.00 ± 0.0 ^a	84.00
Actellic (control)	87.50 ± 4.79 ^a	87.50 ± 4.79 ^a	85.00 ± 6.45 ^a	97.50 ± 2.50 ^a	95.00 ± 5.00 ^a	90.50

Values followed by the same superscript within the same column are not significantly different ($P \leq 0.05$) determined by one way ANOVA followed by Tukey's test. Superscript m values were based on four concentrations, four replicates. Superscript n values were means obtained over the 5 h duration.

Table 5: Repellence activity of hexane extract of *Ocimum basilicum* on *Sitophilus zeamais*.

concentration also had a strong repellence effect of 95.5% in the fourth hour. At the highest extract concentration (100%) repellence effect of 97.5% was recorded in the fourth and fifth hour. The repellent effects of 50, 75 and 100% extract concentration were not significantly different in the first and fourth hour of extract exposure ($p > 0.05$). The mean percentage repellence of the extracts for five hour during was between 71.5 and 86.50 %. The repellent activities of actellic were significantly higher than extract in the first hour, but compared in the following hours (Table 6).

Qualitative phytochemical screening

Methanolic extract of *O. basilicum* contained phenolics, alkaloids, terpenoids, flavonoids, saponins and steroids. Hexane extract of *O. basilicum* contained phenolics, alkaloids, terpenoids, flavonoids, saponins and steroids.

Discussion

When methanolic extracts of *O. basilicum* were tested against *S. zeamais*, the results obtained revealed that the extract had distinct effect on the mortality of the tested pest on treated maize. The methanolic extract was able to cause up to 74% mortality at highest applied concentration and 37% mortality at lowest applied concentration. This corroborates with the work done by Mwangangi and Mutisya [14], who found out that *O. basilicum* leaf powder caused up to 90% mortality of maize weevils within two weeks when applied at 2 g powder per 100 g of maize grains. Other works by Boeke et al. [15] showed much greater effect of *O. basilicum* essential oils on closely related coleopteran, *C. maculatus* with a record of 49% mortality within 24 h of exposure.

The effectiveness of this extract in causing mortality could be due to the presence of active compounds such as terpenoids, alkaloids, steroids,

Concentration (%extract)	PR (mean% ± S.E) ^m with time					PR (mean%) ⁿ
	1 h	2 h	3 h	4 h	5 h	
25	80.00 ± 4.08 ^{ab}	70.00 ± 0.00 ^b	60.00 ± 4.08 ^b	75.00 ± 5.0 ^b	72.50 ± 4.79 ^b	71.50
50	70.00 ± 4.08 ^{bc}	85.00 ± 2.89 ^a	87.50 ± 4.79 ^a	92.50 ± 2.50 ^a	95.00 ± 2.89 ^a	86.00
75	75.00 ± 2.89 ^{ab}	82.5 ± 2.50 ^a	87.50 ± 4.79 ^a	95.00 ± 5.00 ^a	87.50 ± 2.50 ^a	84.00
100	67.50 ± 4.08 ^c	82.50 ± 2.89 ^a	87.50 ± 2.50 ^a	97.50 ± 2.50 ^a	97.50 ± 2.50 ^a	86.50
Actellic (control)	87.50 ± 4.79 ^a	87.50 ± 4.79 ^a	85.00 ± 6.45 ^a	97.50 ± 2.50 ^a	95.00 ± 5.00 ^a	90.50

Values followed by the same superscript within the same column are not significantly different ($P > 0.05$) determined by one way ANOVA followed by Tukey's test. Superscript m values were based on four concentrations, four replicates. Superscript n values were means obtained over the 5 h duration.

Table 6: Repellent activity of hexane; methanolic extract *Ocimum basilicum* on *Sitophilus zeamais*.

glycosides and flavonoids that tested positive in the phytochemical analysis. Triterpenoids of various plant extract have been proven to have toxic effect against coleopterans [16,17]. Moreover, aromatic compounds such as glycosides, saponins, flavonoids and phenols have toxic effects on coleopterans too [18]. It is also possible that some of the extract came into contact with the insects' spiracles contributing to further mortality by suffocation. Since coating the grains with the extracts minimized contact between grains and weevils, some weevils might have died as a result of starvation [7]. Glycosides, terpenoids, tannins and certain monomeric flavonoids found among lamiaceae are excellent feeding deterrents against pest insect [18,19]. Therefore, could have enhanced more mortality again due to starvation.

Hexane extracts of *O. basilicum* had potent toxic activity against *S. zeamais*. The highest application rates caused 48% and 78% mortality at within 24 and 96 hours respectively, while the lowest application rates showed 10% and 42% mortality of the maize weevils within the same assessment period. The information available on the use of hexane extract of *O. basilicum* against insect pest is scanty. However, these results are in agreement with the findings of related studies done by Popović et al. [20] that reported 21.8% mortality of *S. oryzae* within 24 hours of exposure to *O. basilicum* essential oils at lower doses. Other studies done by Kerchoechuen et al. [21] showed higher mortality rates of *S. zeamais* when subjected to *O. basilicum* essential oil treatment.

A range of phytochemical compounds such as glycosides, alkaloids, flavonoids and saponins were found to be present in this extract which could be responsible for its toxic activity against the tested pest. Saponins for example, have been shown to impair ecdysteroid synthesis [22]. Terpenoids especially monoterpenes have also been previously reported to possess insecticidal activity against coleopterans [23-25]. A combination of several mechanisms both physical and biological could have attributed to the efficacy of the plant extract.

The hexane: methanolic blend extract of *O. basilicum* applied was found effective in controlling maize weevils. Higher efficacy rates of up to 100% mortality within 72 hour were recorded at the highest applied concentration. The extract also showed acute toxicity against the pest at higher dosage application. The findings of this present study were in agreement with earlier studies by Bekele and Hassanali, [26] that also recorded 100% mortality against *S. zeamais* and *Rhyzopertha dominica* when subjected to blend of various component of *Ocimum kilim* and *scharica* and *Ocimum kenyense*. Related studies by Ranger et al. [27] also revealed acute toxicities of blends of various plant components to coleopteran larvae. Toxicity of the blend extract could be attributed to presence of active constituents such as alkaloids, terpenoids, cardiac glycosides, saponins, steroids, tannins and phenols that are reported to be toxic to post harvest pest in several ways [18,28,29]. For example, alkaloids and tannins have been reported to impart toxicity by iron chelation and enzyme inhibition [30].

A complex mixture of these active compounds also contributes to synergism to greater extent which could have promoted much activity

against the tested pest [29]. The greater toxicity of the blend extract *O. basilicum* could be in line with fact that higher concentration levels of the active constituents were obtained with blend maceration. Other factors such as suffocation and starvation might also have equally led to more mortality of *S. zeamais* within the treated grains [7].

In this study, hexane, methanolic and blend extracts of *O. basilicum* showed considerable potential as repellent against maize weevils. At low concentration of 25% extracts, above 68% mean repellency was true for all the tested combination of sweet basil. Similar observation has been reported on number of plant extract tested against a range of insect pest. Asawalam et al. [31] described moderate repellent activity of *O. grattissium* to *S. zeamais*. Essential oils of *Eucalyptus globulus* and *O. basilicum* have showed strong repellency against *S. oryzae* and *T. castaneum* at remarkably low concentration [32]. This supports the findings of this study.

Padin et al. [33] work on aqueous and methanolic extracts of *Jacaranda mimisifolia*, *matricaria chamomilla* and *T. minuta* also recorded high repellency index of these extracts against *T. castaneum* (Coleopteran). Many other related studies have also documented much on repellent potential of various plants against post-harvest pest [34-39].

A number of secondary metabolites are linked to repellent activities of plants in which they occur. Hydrocarbons especially monoterpenes and oxygenated compounds like phenols and esters determine distinctive odor of plants [37]. Monoterpenes such as eugenol, limonene, camphor and thymol commonly found in basil have strong repellent activity against insects [40]. Therefore the activity of *O. basilicum* extracts could have been due presence of these monoterpenes. Odalo et al. [41] also found out alcohol components of basil (labiate) as effective repellents against *A. gambiae* (Diptera). Other studies have also indicated terpenoids as Arthropod-repellent compounds [37]. As much as repellent properties of these extracts could be attributed to specific compounds, a synergistic effect as a result of combination and interaction between various active phytochemicals could also have contributed to a greater activity of the extracts against the tested pest [42,43].

Adult emergence of *S. zeamais* was also affected by different *O. basilicum* extracts at all the tested extract of concentrations. High inhibition rate ranging between 86 and 100% were recorded in every study treatment. These results are in agreement with previous studies that showed various labiate plants as valuable source of potential grain protectant against development of all life stages of a number of post-harvest grain pests. Keita et al. [44] observed zero emergence of *C. maculatus* F1 progeny in cowpea treated with *O. basilicum* extracts. A closely related study conducted by Vanmathi et al. [45] also reported that aqueous extracts of *O. tenuiflorum* greatly reduced F1 adult emergence of coleopterons. However, studies carried out by Vanmathi et al. [45] recorded much lower inhibition rates of *O. tenuiflorum*

extracts against *C. maculatus*. A number of botanicals have also been shown to inhibit adult emergence of *S. zeamias* in treated grains [46].

The reduction in adult emergence could be as a result of high adult mortality of *S. zeamias* in treated grain. In addition, active phytochemicals such as alkaloids have been found to disrupt growth and reduce larval survival by hindering loss of exoskeleton during larval development [47]. Other active principles such as isoflavonoids, flavonoids and terpenoids have also been reported to inhibit reproduction and fertility among coleopterons [29,48].

Other studies have also shown phenolic compounds of basil to have ovicidal, larvicidal and nymphicidal properties [49]. Change in behavior and physiology of the insects following extract treatment due to chemical nature of the extract might have also led to low egg laying capacity of *S. zeamais* within the grain and subsequently few hatch adults [29]. These factors collectively may have led to high inhibition of rates F1 adult emergence within the treated grains.

Conclusion

This study recommends the use of hexane; methanolic blend extracts of *Ocimum basilicum* in control of *Sitophilus zeamais*. However further research should be undertaken to determine the mechanism of action of each active compound of *O. basilicum* extract.

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