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Evaluation of Twenty Botanical Extracts and Products as Sources of Repellents, Toxicants and Protectants for Stored Grains against the Almond Moth, *Cadra cautella*

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ABSTRACT

Management of stored product pests using substances of natural origin is nowadays the subject of much research. The effectiveness of 20 botanical extracts and products was evaluated for protecting stored corn meal against *Cadra cautella* Walker (Lepidoptera, Pyralidae) infestation. Toxicity of the botanical materials was evaluated through screening of the tested botanicals on adults' oviposition preference and the mortality of eggs and larvae. Besides, the repellency effect of the tested plant materials was evaluated against *C. cautella* larvae (20-days old). Repellency tests were carried out through food and area preference tests. Results showed that cedar wood oil, clove buds powder and orange oil were the most promising materials in protecting stored corn meal against *C. cautella* infestation.

Keywords: area-preference, food-preference, Lepidoptera, repellency, screening, toxicity
Abbreviations: PR, percentage repulsion; **RH**, relative humidity

INTRODUCTION

The almond moth, *Cadra cautella* Walker (*Ephestia cautella*) (Pyralidae: Lepidoptera), is one of the most economically important stored-product pests in many parts of the world. The larvae are the very destructive stage. They spin silken threads while they are feeding and crawling. Thus, webbing food particles together rendered them unfit for human or animal consumption. Moreover, the feeding of larvae on the seed germ destroys the germination power of seed. Webbing produced by the larvae is often responsible for damage to milling and conveying equipment. Larvae are known to feed on a wide variety of foods and foodstuffs such as maize, wheat, dried beans, nuts, bananas, raisins, fresh and dried dates, dried fruits, cocoa beans, oilseed flours and mixtures, chocolate, cotton seeds, etc. (Hill 1987; Sedlacek *et al.* 1996).

The control of these pests in storage systems mainly depends on fumigants such as methyl bromide or phosphine. However, methyl bromide was banned in many countries starting in 2004 because of its ozone-depleting properties (Ayvaz *et al.* 2010). Plant materials have played an important part in traditional methods of protection against insect infestation in Africa since time immemorial and the protection of stored products has generally involved mixing grains with plant-based protectants (Levinson and Levinson 1998). The precise strategy used varies from place to place and appears to depend partly on the type and efficacy of suitable flora available in different locations. Prakash and Rao (1997) described 866 different plant species that produced chemicals useful against insects and listed their 256 biologically active chemical components. In spite of the wide recognition that many plants possess insecticidal properties, the use of these materials is limited to small-scale traditional farming and not to large-scale commercial crop protection. Botanicals used as insecticides presently constitute 1% of the world insecticide market (Rozman *et al.* 2007).

Little work has been done to manage *C. cautella* by using plant materials, although the efficacy of plant-derived materials against stored-product insects has been well described by many authors: El-Sabaay (1998) investigated the efficiency of 10 vegetable oils namely cottonseed, sesame, castor, sunflower, lettuce, olive, soybean, fenugreek, maize and habet-el-baraka as grain protectants against the granary weevil, *Sitophilus granarius* and lesser grain borer, *Rhyzopertha dominica*; Tripathi *et al.* (2002) investigated essential oil extracted from the leaves of turmeric, *Curcuma longa*, for contact and fumigant toxicity and its effect on progeny production in three stored-product beetles, *Rhyzopertha dominica* (lesser grain borer), *Sitophilus oryzae* (rice weevil) and *Tribolium castaneum* (red flour beetle); Demissie *et al.* (2008) evaluated the uses of some cooking oils (noug, soybean, sunflower, corn, olive oils) against maize weevil, *Sitophilus zeamais*, in stored maize grain under storage conditions; Ayvaz *et al.* (2009) tested five essential oils against the eggs of *Ephestia kuehniella* and *Plodia interpunctella* for their fumigant toxicity.

Botanicals have an array of properties including insecticidal activity, repellency, antifeedancy, insect growth regulation, and toxicity to nematodes, mites and other agricultural pests (Nerio *et al.* 2010). Many botanicals proved antifungal and antibacterial properties against pathogens (Montes-Molina *et al.* 2008). Besides, they are renewable, non-persistent in the environment and relatively safe to natural enemies, non-target organisms and human beings (Kéita *et al.* 2001), also, no development of insect resistance to these materials and no adverse on seed germination have been reported.

The goal of this work was to detect some good alternatives to conventional methods of insect control in storage. Any positive finding can pave the way for the development of a safe, potent and cheaper plant protection component for the future. Therefore, the efficiency of 20 available botanical products and extracts was evaluated against the almond moth. The principal criteria in the selection of the tested plant species were their insecticidal properties against vari-

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Table 1 General information about the tested plants and the used part of each plant.

No.	English name	Family name	Scientific name	Arabic name	Used parts
1	Lupine	Fabaceae	*Lupinus termis* (L.)	Termes	Seeds
2	Fenugreek		*Trigonella foenum-graecum* (L.)	Helba	
3	Camphor	Myrtaceae	*Eucalyptus* spp.	Kafour	Leaves
4	Clove		*Syzygium aromaticum* (L.)	Kuronfil	Flower buds
5	Guava		*Psidium guajava* (L.)	Jawafa	Leaves
6	Nutmeg	Myristicaceae	*Myristica fragrans* (Houtt)	Jawzat Atteeb	Seeds
7	Rosemary	Lamiaceae	*Rosemarinus officinalis* (L.)	Hasalban	Leaves
8	Spearmint		*Mentha spicata* (L.)	Naanaa	
9	Sweet basil		*Ocimum basilicum* (L.)	Rehan	
10	Ginger	Zingiberaceae	*Zingiber officinale* (Rosc.)	Zanjabeel	Rhizome
11	Turmeric		*Curcuma longa*	Kurkum	
12	Sesame	Pedaliaceae	*Sesamum indicum* (L.)	Simsim	Seeds
13	Black seed	Ranunculaceae	*Nigella sativa*	Habbet El-baraka	
14	Chamomile	Compositae	*Matricaria chamomilla*	Babung	Flower heads
15	Cinnamon	Lauraceae	*Cinnamomum zeylanicum* (L.)	Kerfah	Bark
16	Dill	Apiaceae	*Anethum graveolens* (L.)	Shabat	Leaves
17	Sweet orange	Rutaceae	*Citrus sinensis* (L.)	Bortokal	Peel and oil
18	Castor bean	Euphorbiaceae	*Ricinus communis* (L.)	Kharwaa	Oil
19	Olive	Oleaceae	*Olea europaea* (L.)	Zaytoon	
20	Cedar	Pinaceae	*Cedrus* spp.	Al'arz	

ous stored grain insect pests.

Plant species selected for the present work are consumed by humans (lupine, sesame, dill, olive and fenugreek), used as flavouring in foods (clove, orange, sweet basil and cinnamon), spices (rosemary, ginger, nutmeg and turmeric), used either directly as folk medicine (spearmint, guava and chamomile) or as ingredient of pharmaceutical preparations (camphor, black seed, castor bean and cedar).

MATERIALS AND METHODS

Maintenance of insect culture in the laboratory

A stock culture of the insect was established from a single pair (male and female), to keep the genetic homogeneity of the subsequent generations. The stock culture was established and maintained in the incubator on sterilized corn meal (*Zea mays*) (Siruno *et al*. 1986), at optimum conditions of 28 ± 2°C and 60-70% relative humidity. The rearing incubator was adjusted to provide a continuous 16-h photoperiod to prevent insect diapause (Bell 1977).

Tested plants

The tested plants selected for this study are listed in **Table 1**. They include 20 plant species belonging to 14 different families. The part of each plant used is also indicated.

Screening for the effectiveness of botanical extracts and products on eggs, larvae and adults

In line with the normal practices carried out traditionally by small-scale farmers, 0.5 g of dried plant powders were mixed thoroughly with 50 g of sterilized corn meal in 250 ml plastic cups. For tested oils, 0.5 ml of the tested oil was dissolved in 4.5 ml acetone (as a solvent), then mixed with 50 g sterilized corn meal. They were left for 30 min at room temperature for the solvent to evaporate. Also, the check cup was prepared in the same manner using 5 ml acetone, then left to dry at the room temperature. Control cups were prepared without any treatment.

1. Screening of adults (oviposition preference)

The prepared cups were randomly arranged in a choice-test cage. About 150–160 newly emerged adults (mixed-sexes) of *C. cautella* (1–2 days old) were collected from the rearing jars, and then introduced into the cage for oviposition. After 72 h, the adults were discarded and the plastic cups were tightly covered. Cups were incubated at favorable conditions until the emergence of new adults. The procedure was repeated four times. All treatments were observed daily and the number of emerged adults was recorded until no more adults emerged from the controls.

2. Screening of eggs

Eggs collected from the oviposition jars during 24 h were counted and groups each of 25 eggs were prepared using a fine brush. Each group was carefully transferred into the previously prepared treated, check and control cups. Cups were covered and incubated until adults emerged. Each treatment was replicated 4 times. The treatments were observed daily and the number of emerged adults was recorded until no more adults emerged from the controls. The mortality percentages were calculated from the differences between the number of tested eggs and those of emerged adults.

3. Screening of larvae

This experiment was done on larvae at two different ages (10- and 20-days old). The larvae were collected from the standard laboratory culture at the same age. The collected larvae were divided into groups in Petri dishes. The number of each group of larvae was 15 and 20 for 10-day-old and 20-day-old larvae, respectively. Randomly, each previously- prepared cup received a group of larvae. All treatments were covered and incubated. Each treatment was replicated 4 times. Mortality percentages were calculated as mentioned before.

Determination of repellency effect

The repellency effect of the tested botanical extracts and products were evaluated against *C. cautella* larvae (20-days old). For determination of potential repellency, two kinds of test methods were used.

1. Food preference tests

Multiple-choice bioassay: Trials, which assess repellency, usually incorporate modifications of Loschiavo (1952) food preference tests which were developed to assess the repellency of pyrethrum applied to maize (Golob *et al*. 1999), were adopted in the present study. Food preference compartments (bags) were used to conduct multiple-choice bioassays. A number of 22 bags were made of net cloth in triangular shapes and arranged in a circle in a 34 cm diameter high-edged plate. Bags were randomly selected and each was filled with about 20 g treated corn meal as follows: twenty bags contained corn meal each was treated with one of the twenty tested plant materials, one bag treated with acetone only as a check and the last one was untreated as a control. In acetone-treated bags, acetone was allowed to evaporate for 30 min. 100 larvae (20-days old) were introduced into the center of the circular plate, confined by a brass ring. After 15 min confinement, to allow time for larvae to return to normal activity, larvae were released by raising the brass ring without interrupting their activity, and the plate was covered tightly by stretching and fixing cling film. The plate was incubated for 48 h. The content of each bag was then gently obtained and the larvae were counted. Those larvae which stayed out the bags were not taken into account. The experiment was repeated three times.

Double-choice bioassay: The same general procedure that was used for the multiple choice experiment was used with double-choice bioassay. The bags were made of net cloth in half-circle shapes and arranged parallel to each other in a Petri dish (14 cm diameter) with tight-fitting lids. Two kinds of treatments were always compared in each Petri dish. For each Petri dish, one bag was filled with about 50 g corn meal treated with plant powder or oils, and the other was untreated as a control. Twenty larvae (20-day old) were placed in the center of the Petri dish between the two bags. The larvae were allowed to make a choice between treated and untreated corn meal for 24 h in the dark, after which, larvae settled in each half were counted. Those larvae which stayed out the two halves were not taken into account. Experiment was repeated three times.

2. Area-preference test

The other repellency test was an area-preference test adopted after Laudani *et al.* (1955). Substrates were prepared from 9 cm diameter filter papers (Whatman No. 1) cut in half. A quantity of 0.3 ml of the desired plant product dissolved in water or acetone was uniformly applied to a half filter paper. The treated half discs were then air-dried to evaporate the solvent completely. Full discs were then remade by attaching treated halves to untreated (treated with solvent only) halves of same dimensions with cellotape. Precautions were taken so that an attachment did not prevent the free movement of larvae from one half to another but the distance between the two halves was kept sufficient to prevent seepage of test samples from one half to another. Each filter paper was then placed in a 9 cm Petri dish with the same orientation in one of four randomly selected different directions to avoid any incidental stimuli affecting the distribution of larvae. Ten larvae (20-day old) were released at the center of each filter paper disc and the Petri dish was covered. Petri dishes were incubated. For each plant extract or product, five replicates were used. Counts of the larvae present on each half were made after 1h and at hourly intervals up to the sixth hour and then after 24 h.

The data were converted to express percentage repulsion (PR) by the formula of Talukder and Howse (1993):

$$PR\% = [(N - C)/ C] \times 100$$

where N = number of larvae present in the control half; C = total number of larvae present.

Positive values (+) expressed repellency and negative values (-) expressed attractancy.

The mean repellency from the five replications was averaged for 1 to 6 h and 24 h examinations. The overall average of these averages was calculated for each tested plant extract or product. Percent repellency values were assigned repellency classes according to the scale of Juliana and Su (1983): Repellency classes, (repellency rate = class): (< 0.1 = 0), (0.1-20 = I), (20.1-40 = II), (40.1-60 = III), (60.1-80 = IV) and (80.1-100 = V).

Statistical analysis of data

Results were expressed as mean ± standard deviation, by using Excel program 2003. The statistical significance of differences between means was determined by student's *t*-test for paired observations. The level of significance was stated to be highly significant ($P < 0.01$), significant ($P < 0.05$) or insignificant ($P > 0.05$). In all cases, the percentage of change was calculated using the following equation:

$$\text{Percentage of change} = \frac{\text{test - control}}{\text{control}} \times 100.$$

RESULTS AND DISCUSSION

Screening for the effectiveness of botanical extracts and products on adults, eggs and larvae

1. Screening on adults (oviposition preference)

Clove buds and orange peel powders and cedar wood oil were the most effective in repelling the oviposition of *C. cautella* female moths in the treated corn meal (**Table 2**). The female moths avoid egg deposition in corn meal treated with those plant materials. Results are in agreement with the findings of previous studies. Behal (1998) found that oils of clove and cedar wood were effective repellents at higher concentrations against *Corcyra cephalonica*, and Allotey and Azalekor (2000) found that *Citrus sinensis* peel powder, at higher dosage, was more effective and reduced *Corcyra cephalonica* population by half, as compared with control over 1.5 months.

The location of suitable oviposition sites by female Lepidoptera is very important for the survival of their progeny. Nansen and Phillips (2003) reported that stimuli, most likely volatile chemicals, were perceived at a distance above the food, and Lepidopteran females assess the suitability of oviposition sites based on chemical and physical stimuli. For example, female *Plodia interpunctella* flew upwind in response to volatile from suitable oviposition substrates that incorporate corn meal-based laboratory rearing diet (Phillips and Strand 1994). As insect fecundity depends much on host-plant stimuli, modifications of the microenvironment of the oviposition site can lead to a blockage of oogenesis and egg retention in the lateral oviduct (Pouzat 1978). In addition, the plant material vapours can act indirectly by masking the stimulating action of the host plant (Papachristos and Stamopoulos 2002).

Another explanation for the significant reduction in the number of emerged adults of *C. cautella* from treated corn meal is that the plant materials may have toxic effects against deposited eggs or the newly emerged larvae. As a result no adults emerged from clove-treated corn meal and about 1.45 and 19.50% adults emerged from cedar- and orange-treated corn meal, respectively. This assumption was previously affirmed by Ho *et al.* (1995) and Alrubeai *et al.* (2001) with the effects of those plant materials against other insect species.

2. Screening of eggs

The results showed that fenugreek seeds, clove buds, guava leaves, black seed, cinnamon and orange peel powders and cedar wood oil produced a highly significant increase in the mean mortality percent of emerged adults of *C. cautella* previously treated as eggs (**Table 3**). The efficiency of fenugreek in reducing progeny production of *C. cautella* treated as eggs was in harmony with the findings of Afifi *et al.* (1988) and Pemonge *et al.* (1997). Also, the toxic effects of clove were reported in previous studies against other insect species (Reuben *et al.* 2006). The efficacy of sweet orange peel powder for the control of some insect species was reported by Allotey and Azalekor (2000) and Ezeonu *et al.* (2001). The efficiency of cedar wood oil was previously reported by Zhu *et al.* (2001).

In addition, nutmeg, rosemary and spearmint powders significantly increased the percent mortality of *C. cautella* adults. These results are in harmony with the findings of El-Shazly (1997) and Anju and Srivastava (2006).

The increasing mortality percentages of adult *C. cautella* after treatment as eggs could be attributed to the toxic effects of these materials on the eggs or the hatched larvae. The toxic effects may be due to inhibition of embryonic development by disturbing the physiological and biochemical processes inside eggs (Raja *et al.* 2001). On the other hand, the toxic effects of the plant materials on emerged larvae may came through inhibiting larval feeding (Rodriguez and Vedramin 1998), or through destroying the larval mid-

Table 2 The influence of selected plant extracts and products on oviposition preference of adult almond moth, *C. cautella*, as indicated by adult emergence.

Treatment	Number of emerged adults		Mean[1] ± SD	% Change	*t*-test	
	Min.	Max.			*P*-value	Significance level[2]
Normal	25	55	39.75 ± 14.50			
Lupine	5	67	31.75 ± 26.70	-20.13	0.617	ns
Fenugreek	11	100	64.75 ± 42.27	62.89	0.306	ns
Camphor	20	85	50.50 ± 26.64	42.27	0.505	ns
Clove	0	0	0.00 ± 0.00	-100.00	0.002	**
Guava	17	110	63.50 ± 41.17	59.75	0.318	ns
Nutmeg	2	98	47.00 ± 57.88	18.24	0.816	ns
Rosemary	2	70	39.50 ± 32.46	-0.63	0.989	ns
Spearmint	8	31	12.75 ± 12.31	-67.93	0.030	*
Sweet basil	11	39	25.75 ± 12.04	-35.22	0.188	ns
Ginger	18	53	33.75 ± 18.41	-15.09	0.627	ns
Turmeric	2	52	25.50 ± 25.21	-35.85	0.365	ns
Sesame	43	63	49.50 ± 9.11	24.53	0.298	ns
Black seed	33	88	54.00 ± 24.10	35.58	0.350	ns
Chamomile	4	70	30.50 ± 29.14	-23.27	0.590	ns
Cinnamon	24	103	64.25 ± 40.02	61.63	0.293	ns
Dill	1	92	29.50 ± 43.05	-25.79	0.668	ns
Sweet orange	2	18	7.75 ± 7.32	-80.50	0.008	**
Control (acetone)	15	60	34.50 ± 18.73			
Castor bean oil	18	38	28.00 ± 8.52	-18.84	0.551	ns
Olive oil	35	66	49.50 ± 15.33	43.48	0.261	ns
Cedar oil	0	1	0.50 ± 0.58	-98.55	0.011	*

1, Four replicates for each plant extract or botanical product; 150-160 moths per replicate

2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

Table 3 The toxic effect of selected plant extracts and products on the eggs of the almond moth, *C. cautella*.

Treatment	% Mortality		Mean[1] ± SD	% Change	*t*-test	
	Min.	Max.			*P*-value	Significance level[2]
Normal	20	28	24.00 ± 4.00			
Lupine	28	56	41.33 ± 14.05	72.22	0.055	ns
Fenugreek	32	44	38.67 ± 6.11	61.11	0.007	**
Camphor	28	72	44.00 ± 24.33	83.33	0.156	ns
Clove	44	52	49.33 ± 4.62	105.55	0.000	**
Guava	44	56	48.00 ± 6.93	100.00	0.000	**
Nutmeg	36	64	49.33 ± 14.05	105.55	0.013	*
Rosemary	40	72	53.33 ± 16.65	122.22	0.014	*
Spearmint	32	52	40.00 ± 10.58	66.67	0.030	*
Sweet basil	16	48	32.00 ± 16.00	33.33	0.369	ns
Ginger	14	40	23.67 ± 14.22	-1.39	0.966	ns
Turmeric	20	56	37.33 ± 18.04	55.55	0.199	ns
Sesame	28	48	34.67 ± 11.55	44.45	0.131	ns
Black seed	44	60	52.00 ± 8.00	116.67	0.000	**
Chamomile	24	28	25.33 ± 2.31	5.55	0.586	ns
Cinnamon	48	68	54.67 ± 11.55	127.78	0.002	**
Dill	32	60	42.67 ± 15.14	77.78	0.054	ns
Sweet orange	40	72	54.67 ± 16.17	127.78	0.009	**
Control (acetone)	36	40	37.33 ± 2.31			
Castor bean oil	32	60	42.67 ± 15.14	14.29	0.512	ns
Olive oil	28	40	33.33 ± 6.11	-10.71	0.267	ns
Cedar oil	88	100	94.67 ± 6.11	153.58	0.000	**

1, Three replicates for each plant extract or botanical product; 25 eggs per replicate.

2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

gut (Zapata 2006) reducing the food ingested by larvae, causing retardation in growth, and finally, a reduction in adult emergence (Richter *et al.* 1997).

3. Screening of larvae

Ten-day-old larvae: The results showed that clove buds and nutmeg powders were the most effective materials in increasing the mortality of *C. cautella* larvae, followed by dill, fenugreek, lupine and chamomile powders (**Table 4**). The present results are in agreement with that of Pemonge *et al.* (1997) who found that Fenugreek seed appeared moderately toxic to young larvae of *Tribolium castaneum*, Alrubeai *et al.* (2001) who proved the toxicity of clove flower buds to *Phthorimaea operculella* larvae, and Reuben *et al.* (2006) who found that clove buds exhibited high efficacy against *Plutella xylostella* larvae.

Twenty-day-old larvae: The results revealed that the cedar wood oil was the most effective material in increasing the mortality of *C. cautella* larvae (**Table 5**). Young larvae were more susceptible than older ones, as some tested botanicals proved toxic against insects treated as 10-day old larvae; while did not affect that treated as 20-day old larvae. It is expected that larvae younger than 10 days would be more susceptible, as susceptibility tended to decrease with age (Ho *et al.* 1995). These findings agree with that of Erler (2005) and Qin *et al.* (2010).

By screening a large number of natural plant extracts and products, it was clear that few numbers of the tested materials had a significant ability to protect the stored corn meal against *C. cautella* infestation. Only clove buds, orange peel powders and cedar wood oil showed the highest toxicity effects against *C. cautella* treated initially as adults or as eggs. Concerning insects initially treated as larvae,

Table 4 The toxic effect of selected plant extracts and products on the almond moth, *C. cautella*, treated as larvae (10-days old).

Treatment	% Mortality		Mean[1] ± SD	% Change	*t*-test	
	Min.	Max.			*P*-value	Significance level[2]
Normal	0	6.67	2.22 ± 3.85			
Lupine	13.33	33.33	20.00 ± 11.55	800.09	0.027	*
Fenugreek	6.67	13.33	11.11 ± 3.85	400.05	0.017	*
Camphor	0	33.3	13.33 ± 17.64	500.05	0.265	ns
Clove	20.00	40.00	26.67 ± 11.55	1100.14	0.007	**
Guava	0	33.33	20.00 ± 17.64	800.09	0.096	ns
Nutmeg	20.00	46.67	31.11 ± 13.88	1300.14	0.007	**
Rosemary	6.67	13.33	8.89 ± 3.85	300.05	0.050	ns
Spearmint	0	6.67	4.45 ± 3.85	100.05	0.444	ns
Sweet basil	0	6.67	4.45 ± 3.85	100.05	0.444	ns
Ginger	6.67	26.67	15.56 ± 10.18	600.09	0.050	ns
Turmeric	0	13.33	8.89 ± 7.70	300.05	0.155	ns
Sesame	0	13.33	6.67 ± 6.67	200.05	0.292	ns
Black seed	0	26.67	13.33 ± 13.33	500.05	0.160	ns
Chamomile	13.33	40.00	28.89 ± 19.25	1200.14	0.035	*
Cinnamon	0	33.33	11.11 ± 19.25	400.05	0.400	ns
Dill	13.33	26.67	17.78 ± 7.70	700.09	0.011	*
Sweet orange	0	40.00	17.78 ± 20.37	700.09	0.184	ns
Control (acetone)	6.67	26.67	17.78 ± 10.18			
Castor bean oil	0	13.33	8.89 ± 7.70	-50.00	0.213	ns
Olive oil	13.33	33.33	24.44 ± 10.18	37.50	0.391	ns
Cedar oil	20.00	33.33	28.89 ± 7.70	62.50	0.132	ns

1, Three replicates for each plant extract or botanical product; 15 larvae per replicate.
2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

Table 5 The toxic effect of selected plant extracts and products on the almond moth, *C. cautella*, treated as larvae (20-day-old).

Treatment	% Mortality		Mean[1] ± SD	% Change	*t*-test	
	Min.	Max.			*P*-value	Significance level[2]
Normal	15	30	20.00 ± 8.66			
Lupine	10	25	18.33 ± 7.64	-8.34	0.782	ns
Fenugreek	0	35	21.67 ± 18.93	8.34	0.878	ns
Camphor	0	10	6.67 ± 5.77	-66.67	0.043	*
Clove	10	40	25.00 ± 15.00	25.00	0.585	ns
Guava	20	40	28.33 ± 10.41	41.67	0.265	ns
Nutmeg	5	30	18.33 ± 12.58	-8.34	0.834	ns
Rosemary	10	20	16.67 ± 5.77	-16.67	0.546	ns
Spearmint	15	30	20.00 ± 8.66	0.00	1.000	ns
Sweet basil	20	25	21.67 ± 2.89	8.34	0.727	ns
Ginger	10	50	25.00 ± 21.79	25.00	0.685	ns
Turmeric	10	25	18.33 ± 7.64	-8.34	0.782	ns
Sesame	0	25	13.33 ± 12.58	-33.34	0.416	ns
Black seed	0	10	5.00 ± 5.00	-75.00	0.024	*
Chamomile	10	45	25.00 ± 18.03	25.00	0.635	ns
Cinnamon	10	25	16.67 ± 7.64	-16.67	0.585	ns
Dill	5	35	20.00 ± 15.00	0.00	1.000	ns
Sweet orange	20	50	31.67 ± 16.07	58.34	0.248	ns
Control (acetone)	10	20	13.33 ± 5.77			
Castor bean oil	10	50	35.00 ± 21.79	162.51	0.103	ns
Olive oil	15	40	25.00 ± 13.23	87.51	0.157	ns
Cedar oil	25	35	30.00 ± 5.00	125.01	0.005	**

1, Three replicates for each plant extract or botanical product; 12 larvae per replicate.
2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

Clove and nutmeg powders proved toxic against 10-day old larvae; while cedar wood oil showed high toxicity to 20-day old larvae.

Determination of repellency effect

1. Food-preference tests

Multiple-choice bioassay: Lupine seeds powder and cedar wood oil were the most effective plant materials in prevention the larval presence in the treated sections (100% prevention) as seen in **Table 6**. Clove buds powder came in the second order (95.57%). These findings are compatible with their effects on other lepidopterous species. Behal (1998) tested the repellent effect of some oils on the larvae of rice moth *Corcyra cephalonica*, and he found that sweet flag oil repelled the larvae at all the concentrations, whereas clove, cedar wood, citronella and eucalyptus oils were effective at the higher concentrations. Ruiz-Moreno *et al.* (2004) evaluated the effects of 6 lupine species on the growth, development and viability of fall armyworm *Spodoptera frugiperda*. They reported that foliage extract of *Lupinus Mexicans* and the seed extract of *L. mexicanus*, *L. montanus* and *L. rotundiflorus* deterred feeding and inhibited growth.

Double-choice bioassay: Cedar wood oil was the most effective repellent against *C. cautella* larvae with 100% repellency followed by clove buds powder (**Table 7**). Behal (1998) reported that cedar wood and clove oils were effective repellents against *Corcyra cephalonica* larvae. Besides, results showed that lupine, fenugreek, camphor, nutmeg, rosemary, cinnamon, dill and sweet orange powders and olive oil had a considerable repellent effect in the treatments. The same was reported by many authors for various

Table 6 The influence of selected plant extracts and products on food preference of *C. cautella* larvae as experimented by using the multiple-choice method.

Treatment[1]	Larvae found in sections (%)			% Change	*t*-test	
	Min.	Max.	Mean ± SD		*P*-value	Significance level[2]
Control	4.55	12.00	8.55 ± 3.54			
Lupine	0.00	0.00	0.00 ± 0.00	-100.00	0.003	**
Fenugreek	0.00	8.00	4.25 ± 3.50	-50.31	0.135	ns
Camphor	3.00	12.12	7.70 ± 4.39	-10.01	0.779	ns
Clove	1.52	0.00	0.38 ± 0.76	-95.57	0.004	**
Guava	0.00	7.00	3.22 ± 3.16	-62.35	0.066	ns
Nutmeg	0.00	4.00	1.92 ± 1.77	-77.59	0.015	*
Rosemary	1.00	2.00	1.46 ± 0.42	-82.91	0.007	**
Spearmint	0.00	1.52	0.88 ± 0.63	-89.72	0.005	**
Sweet basil	1.52	8.00	5.13 ± 2.71	-40.03	0.176	ns
Ginger	0.00	8.00	2.50 ± 3.79	-70.77	0.058	ns
Turmeric	1.33	3.03	2.34 ± 0.82	-72.63	0.014	*
Sesame	2.00	8.00	5.02 ± 2.59	-41.37	0.159	ns
Black seed	0.00	6.00	3.89 ± 2.66	-54.57	0.080	ns
Chamomile	0.00	9.00	4.58 ± 4.57	-46.42	0.219	*
Cinnamon	0.00	9.00	2.58± 4.32	-69.80	0.076	ns
Dill	1.52	7.00	3.96 ± 2.64	-53.68	0.083	ns
Sweet orange	0.00	3.00	1.80 ± 1.36	-79.00	0.012	*
Acetone	3.00	13.33	7.97 ± 4.98			
Castor bean oil	0.00	24.24	7.56 ± 11.24	5.14	0.949	ns
Olive oil	7.00	21.21	11.72 ± 6.51	47.05	0.395	ns
Cedar oil	0.00	0.00	0.00 ± 0.00	-100.00	0.019	*

1, Four replicates for each plant extract or botanical product; 100 larvae per replicate.
2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

Table 7 The influence of selected plant extracts and products on food preference of *C. cautella* larvae as experimented by using double-choice method.

Treatment[1]	Percentage of larvae (Mean ± SD)		*t*-test	
	Control	Treated	*P*-value	Significance level[2]
Lupine	83.33 ± 15.28	16.67 ± 15.28	0.000	**
Fenugreek	76.67 ± 15.28	23.33 ± 15.28	0.003	**
Camphor	70.00 ± 10.00	30.00 ± 10.00	0.001	**
Clove	86.67 ± 5.77	13.33 ± 5.77	0.000	**
Guava	53.33 ± 15.28	46.67 ± 15.28	0.560	ns
Nutmeg	73.33 ± 11.55	26.67 ± 11.55	0.001	**
Rosemary	80.00 ± 10.00	20.00 ± 10.00	0.000	**
Spearmint	63.33 ± 11.55	36.67 ± 11.55	0.017	*
Sweet basil	70.00 ± 17.32	30.00 ± 17.32	0.017	*
Ginger	53.33 ± 5.77	46.67 ± 5.77	0.154	ns
Turmeric	70.00 ± 20.00	30.00 ± 20.00	0.030	*
Sesame	70.00 ± 17.32	30.00 ± 17.32	0.017	*
Black seed	63.33 ± 25.17	36.67 ± 25.17	0.185	ns
Chamomile	63.33 ± 15.28	36.67 ± 15.28	0.049	ns
Cinnamon	73.33 ± 15.28	26.67 ± 15.28	0.005	**
Dill	76.67 ± 11.55	23.33 ± 11.55	0.000	**
Sweet orange	76.67 ± 5.77	23.33 ± 5.77	0.000	**
Control (acetone)	43.33 ± 5.77	56.67 ± 5.77	0.183	ns
Castor bean oil	66.67 ± 32.15	33.33 ± 32.15	0.193	ns
Olive oil	73.33 ± 11.55	26.67 ± 11.55	0.001	**
Cedar oil	100.00 ± 0.00	0.00 ± 0.00	0.000	**

1, Three replicates for each plant extract or botanical product; 10 larvae per replicate.
2, Level of significance: ns, insignificant ($P > 0.05$); *, significant ($P < 0.05$); **, highly significant ($P < 0.01$).

insect species. Devaraj and Srilatha (1993) reported that *Eucalyptus* extract was the most repellent against the pyralid, *Corcyra cephalonica*, followed by mustard, neem and datura extracts. Swidan (1994) screened the extracts of 15 plants from the Egypt flora as well as 9 plants commonly used in popular medicine for their antifeedant activity against 4th instar larvae of *Spodoptera littoralis*, and the study revealed that *Trigonella foenum-graecum* had a significant activity at 1-0.25%, El-Shazly (1997) found that the leaf powder of *Rosmarinus officinalis* was repellent against *Acanthoscelidus obtectus* and *Zobratus subfasciatus*, Behal (1998) reported that clove, cedar wood, citronella and eucalyptus oils were effective at the higher concentrations against larvae of rice moth *Corcyra cephalonica*, Ruiz-Moreno *et al.* (2004) found that the foliage extract of *Lupinus Mexicans* and the seed extract of *L. mexicanus*, *L. montanus* and *L. rotundiflorus* deterred feeding and inhibited growth of fall armyworm *Spodoptera frugiperda*. Tooba *et al.* (2005) stated that leaves of five plants (*Eucalyptus* sp., *Bougainvillea glabra*, *Azadirachta indica*, *Saraca indica* and *Ricinus communis*) showed 78-76% repellency against *Tribolium castaneum*.

The double-choice test also showed that spearmint, sweet basil, turmeric and sesame produced a significant repellency against tested larvae. These results were in agreement with that of El-Shazly (1997) found that the leaf powder of *Ocimum basilicum* has a repellency effect against *Acanthoscelidus obtectus* and *Zobratus subfasciatus*. Jagadeeswari and Pandian (2004) reported that *Curcuma longa* paste exhibited a better protection time (7.6 h) and suppression of biting activity (82.2%) than the synthetic products against the mosquito (*Culex quinquefasciatus*), and Britto *et al.* (2005) *found that Zingiber officinale* and *Ocimum sanctum* possess antifeedant properties on the adult of *Tribolium castaneum*.

Food-preference tests revealed that lupine, clove, nut-

Table 8 Repellency effect of selected plant extracts and products on *C. cautella* larvae as experimented by using the area-preference test.

Treatment	Percentage[1] of the observed larvae after 7 time intervals							Overall average	Repellency class[2]
	1 h	2 h	3 h	4 h	5 h	6 h	24 h	(%)	
Lupine	25	12.5	0.0	12.5	25	37.5	0.0	16.07	I
Fenugreek	0.0	12.5	25	25	0.0	-12.5	62.5	16.07	I
Camphor	25	-12.5	12.5	0.0	12.5	-12.5	62.5	12.50	I
Clove	37.5	0.0	12.5	12.5	12.5	12.5	87.5	25.00	II
Guava	62.5	25	0.0	25	25	12.5	62.5	30.36	II
Nutmeg	25	25	25	0.0	0.0	37.5	12.5	17.86	I
Rosemary	62.5	25	12.5	0.0	25	37.5	37.5	28.57	II
Spearmint	25	37.5	50	37.5	37.5	37.5	37.5	37.50	II
Sweet basil	0.0	25	50	37.5	50	25	25	30.36	II
Ginger	-25	0.0	-12.5	-12.5	25	12.5	-12.5	-3.57	0
Turmeric	62.5	92.5	50	37.5	37.5	12.5	50	48.93	III
Sesame	12.5	-50	-25	-37.5	-25	0.0	-12.5	-19.64	0
Black seed	-25	12.5	0.0	0.0	0.0	0.0	-37.5	-7.14	0
Chamomile	12.5	-12.5	0.0	0.0	0.0	0.0	-12.5	-1.79	0
Cinnamon	25	12.5	0.0	62.5	50	37.5	12.5	28.57	II
Dill	37.5	37.5	12.5	37.5	50	50	37.5	37.50	II
Sweet orange	0.0	12.5	-25	-25	-37.5	0.0	12.5	-8.93	0
Castor bean oil	0.0	37.5	0.0	50	37.5	37.5	50	30.36	II
Olive oil	25	12.5	-37.5	-12.5	12.5	0.0	-50	-7.14	0
Cedar oil	62.5	50	100	62.5	100	75	100	78.57	IV

1, Average of 3 replicates; 10 larvae per replicate.
2, Repellency classes, (repellency rate=class): (< 0.1 = 0), (0.1-20 = I), (20.1-40 = II), (40.1-60 = III), (60.1-80 = IV), (80.1-100 = V).
- Negative figures indicate attractancy.

meg, rosemary, spearmint, turmeric, orange peel powders and cedar oil proved good repellency against *C. cautella* larvae in both multiple-choice and double-choice bioassays. While, other plant materials as Fenugreek, camphor, sweet basil, sesame, cinnamon, dill powders, and olive oil, showed obvious repellent activity against tested larvae in double-choice bioassay, however, in multiple-choice bioassay, they had no repellent effect. These findings indicate that *C. cautella* larvae when given a choice among numerous treatments, such as the multiple-choice experiments, larvae were present in some treatments that have repellent effects under double-choice conditions.

2. Area-preference test

As shown in **Table 8**, cedar wood oil was the most effective repellent against *C. cautella* larvae, giving repellency of class IV by 78.57%. The results are in agreement with the findings of Behal (1998) with *C. cephalonica* larvae. Turmeric powder produced a repellency of class III (48.93% repellency) against tested larvae. Cedar wood oil and turmeric rhizome powder exhibited promising repellents against *C. cautella* larvae according to the role stated by Egwunyenga *et al.* (1998) who stated that at least repellency of class III (40.1-60% repellency) is the standard for promising repellents, in filter paper tests. Area-preference tests also showed that spearmint, dill, guava, sweet basil, castor bean oil, rosemary, cinnamon and clove generated a repellency of class II (20.1-40% repellency) against *C. cautella* larvae. The present results revealed that those plants are under the standard level of promising repellents. However, some authors found that fenugreek, dill, clove and castor bean showed repellency of class IV (60.1-80% repellency) against other insect species. Su (1985) found that application of powder of dill (*Anethum graveolens* L.) on filter paper produced a repellency of 75% over a two month period against *Tribolium confusum*, equivalent to a class IV repellent, and Tooba *et al.* (2005) found that leaves of *Eucalyptus* sp. and *Ricinus communis* showed 78-76% repellency against *Tribolium castaneum*. The remaining plant materials: ginger, sesame, black seed, chamomile, sweet orange and olive oil produced repellency of class 0, i.e., they showed somewhat attractancy towards *C. cautella* larvae in area-preference test. The attractancy behaviour of orange peel in area-preference tests against tested larvae is in accordance with the findings of Ranjana and Beenam (1999). They found that sweet orange peel extract, when applied to strip of filter paper, instead of showing repellency behaviour exhibited attractancy toward *C. maculatus*.

Results obtained from both screening and repellency tests showed that toxicity and repellency of both cedar wood oil and clove buds powder were correlated. These observations are in accordance with Regnault-Roger (1997) who stated that the activities of natural plant extracts are manifold, and they induce fumigant and topical toxicity as well as antifeedant or repellent effects. However, a close relation between toxicity and repellency is not always the case. Although turmeric had significant repellent effects in food-preference tests against tested larvae, it had no toxic effects at all on different developmental stages of *C. cautella*. On the other hand, guava and black seed exhibited significant toxicity against *C. cautella* initially treated as eggs, but they were not repellent for larvae. These findings are in harmony with those of Talukder and Howse (1993) who found that pithraj (*Aphanamixis polystachya*) seed extract was highly toxic to pulse beetle, *Callosobruchus chinensis*, but was a weak repellent for this insect. Also, Wang *et al.* (2001) found that, among six essential oils tested, *Cupressus funebris* oil had highly repellency effects on *Liposcelis bostrychophila* adults, but its fumigant toxicity was significantly lower than those of other five plant oils; thus, authors suggested that active compounds that acted as repellents and fumigants might be chemically different.

CONCLUSIONS

Results obtained from both screening and repellency tests showed that the most promising plant materials, with both toxic and repellent activities, against *C. cautella* were cedar wood oil and clove buds powder. Their toxicity and repellency effects make these materials good candidates as stored-grain protectants against almond moth infestation. Besides, the repellent effect of orange peel powder is less profound, but its toxic effects against eggs and first larval instars add to its efficacy against *C. cautella* in storage. In general, the botanical extracts and products used in the present study are available in Egypt and potentially could offer a cheap and easy control method for farmers. Although the use of oils for large-scale treatment may be impractical, it may be practical when small amount of grains are to be stored. The use of formulations based on these plant materials could reduce the use of residual insecticides in commodities meant for human consumption. Further research is needed to identify the chemical compounds responsible for the toxic effects and to evaluate whether they could be useful for the control of *C. cautella* infestation in stores.

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