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EFFICACY OF DIATOMACEOUS EARTH DUST UNDER MODIFIED ATMOSPHERES AGAINST SOME STORED GRAIN INSECTS

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ABSTRACT

Studies were conducted to determine the efficacy of Diatomaceous earth (DE) alone and under three modified atmospheres (MAs) of carbon dioxide (CO_2) and high Nitrogen (N_2) content on four insect species infesting stored grains in Egypt. DE was tested at 0.3% and 0.6% w/w alone and under MAs of 30, 60 and 80% CO_2 and 99% N_2 against adults of *Sitophilus oryzae* (L.). *Rhizopertha dominica* (F.). *Tribolium castaneum* (Herbst.) and *Trogoderma granarium* (Everts) larvae. Investigations were conducted inside gas-tight steel bins (each of 0.5 m3). which were situated at premises of Faculty of Agriculture, Moshtohor. Zagazig University Obtained results revealed that. the effectiveness depends on the dust concentration. exposure period and tested insect species and the type of the tested MA. *T granarium* larvae were found more tolerant to DE compared to other tested insect species. In respect to MAs of 30, 60 and 80 % CO_2 and 99% N_2 alone. the efficacy was depending on gas concentration. exposure period and insect species. which the effectiveness increased with increasing gas concentration and exposure period. *T.granarium* larvae (active and diapaused) were found more tolerant than the adults of the other tested insects. The combined action of DE with the four MAs figures used depends mainly on dust concentration, exposure time. insect species and type of MA. The results of the combined effect of the DE dust under MAs to the tested insects. showed improved mortality values than those achieved with each component separately at all the exposure periods. With DE at 0.3 and 0.6% under MAs of 30% and 60% of CO_2. the resultant effect was synergistic or additive with adults of the tested insects. while with MA of 80% CO_2, the effect was synergistic after the shorter exposure periods. With longer periods of exposure. the effect changed to additive. MA of 99% N_2 showed complete mortality of *S. oryzae* after 1 week and it was 48, 24, 8 and 6 for *R. dominica*. *T.castaneum*. active and diapaused larvae of *T.granarium*. respectively The combined action of DE+ MA of 99% N_2 also produced generally enhanced mortalities than each material separately. with all the tested insects. Co-toxicity values of this mixture. indicated potentiation/ or additive effect Synergistic effects were observed after shorter exposure periods with all insects while additive action was noticed with longer exposure periods The previous results showed that insect susceptibility to MAs of CO_2 or N_2 is varied depending on insect type, insect stage type and concentration of MA as well as concentration of DE. Our results indicated that the combined effect of DE+ MA increased insect mortalities. CO_2 was found more effective at higher concentration with higher DE (0.6%) against the tested insects. MA of either CO_2 or N_2 with DE dust enhanced toxicity of tested insects. Thus, the results showed importance of these combined treatments as safe, non-chemical method and accepted by people as alternative method to control insect pest populations. Thus, this method could be considered as potential and effective alternative for methyl bromide fumigation of stored grain insects.

INTRODUCTION

The stored cereals as wheat, maize, rice, barley and sorghum are vulnerable to damage by adults and immature stages of stored grain insects as *Sitophilus spp.* The infested grains are being bored and reduced in their qualities and of reduced weight and so become unfit for human or animal consumption. The search for control measures that don't require toxic chemicals and used as an alternative of the popular chemical fumigant methyl bromide for post harvest insect control is obligatory. Of these alternatives, modified atmosphere (MA) and this method depends mainly on changing the normal atmospheric gaseous constituents as carbon dioxide and oxygen necessary for insect life. This practically was obtained by addition of toxic levels of carbon dioxide (hypercarbia) (El-Lakwah, *et al.*, 2001) or a reduction of oxygen content (hypoxia or anoxia). CO_2 has been investigated as a fumigant and a principal component of MA to control many insects of stored grains (Jay and Pearman, 1973; Navarro *et al.*, 1979), fruits (Soderstrom and Brandl, 1982), stored peanuts (Press and Harein, 1967; Jay *et al.*, 1970 and Marzke and Pearman, 1970) and stored tobacco (Childs and Overby, 1982; Keever, 1989). MAs thus, provide safe, non-chemical treatment; leave no residues in the commodities as well as effective against many insects and mites (McGaughey and Akins, 1989; Fleurat-Lessard, 1990; Hashem and Reichmuth, 1993 and Hashem *et. al.*, 1993;; Banks and Fields, 1995; Annis and Morton, 1997; El-Lakwah *et al.*, 1997 and 2001; Ofuya and Reichmuth, 2002). The effectiveness of MAs depends mainly on exposure time, insect species and the environmental temperature (Jay, 1984). Diatomaceous earth (DE) dust formulations have a long history in protecting stored grains against various insect pests (Ebling, 1971). The present study investigates effects of DE dust alone and under different modified atmospheres against some stored grain insects.

MATERIALS AND METHODS

1. Insects:

Four different insect species infesting stored grains in Egypt were used: adults of the rice weevil, *Sitophilus oryzae* (L.); the lesser grain borer, *Rhizopertha dominica* (F.); the red flour beetle, *Tribolium castaneum* (Herbst.) and the khapra beetle, active and diapaused larvae of. *Trogoderma granarium* (Everts). Insects were maintained at Laboratory of Stored Grain Insects, Plant Protection Dept., Faculty of Agriculture, Moshtohor, Zagazig University, Tukh, Qualubia, Egypt. About 100 insects of 1- 2 weeks old, of each species were introduced into glass jars of 250 ml capacity, each contained about 250 gm of wheat kernels for *S.oryzae*, *R.dominica* and *T. granarium* or wheat flour for *T. castaneum* and covered well by muslin cloth held by rubber bands, under conditions of 28±1 C and 60±5%RH. Wheat grains were sterilized by deep-freezing at -18 C for 2 weeks before application to eliminate any possible hidden infestation. The adults used for tests were 1- 2 weeks old.

2. Diatomaceous earth (DE) dust:

DE is a natural plant dust, which is extracted from deposits of marine plants called diatoms. The used formulation contained 97% silicon dioxide and is produced by Fabrique Per Hadley Pacific Ventures, LTD, Vancouver, Canada. DE was tested at 0.3 and 0.6 % w/w mixed with the insect food. Three replicates of 100 gm of either wheat grains or wheat flour were prepared for each concentration of DE/ species. Thirty adults of each insect species (*S.oryzae*, *R.dominica* and *T.castaneum*) or thirty larvae (active and diapaused) of *T. granarium* were introduced into each jar. Treated jars were kept at 26±1 C and 55±5 %RH. Mortality of adult insects and larvae assessed after 2, 3, 5, 7, 10 and 14 days post treatment.

3. Effect of modified atmospheres (MA):

Carbon dioxide (CO_2) and Nitrogen gases were provided as pure gases in pressure steel cylinders. Each cylinder was connected with a pressure regulator. Batches of 30 adults or 30 active and diapaused larvae of *T.granarium* were confined in cloth bags (10x16 cm), each contained 50 gm wheat kernels for *S. oryzae*, *R. dominica*, *T. castaneum* and *T. granarium* (active and diapaused larvae). Three replicates were conducted for each insect in the various treatments. Experiments were conducted inside gastight steel bins, each of 0.5-m3 volume, and filled with approximately 450 kg wheat grains. After inserting insect samples, the cover of the bin was well closed. MA of 30±5%, 60±5% and 80±5% of CO2 gas or 99% N_2 were tested on the selected insects after varying periods of exposure.

4. Purging the gas inside the steel bins:

For obtaining 30±5% CO_2 concentration, the gas containing the steel cylinders was connected with the upper valve of the steel bins through polyethylene tube. The gas cylinder valve was opened for one and half minute, while the bottom valve of the bin was opened and closed after one minute for inserting the gas. Grain temperature and the relative humidity inside the bins were recorded during the tests. A bin without treatment served as control. The nitrogen gas was introduced in a similar method. Determination of CO_2 gas concentrations was monitored using a carbon dioxide gas Analyzer, Model 200-600 (Gow-Mac-Instuments Company, USA). For the atmosphere of nearly pure nitrogen, the valve of the cylinder was opened for two minutes to flush the bin with the gas. Nitrogen concentration was determined by measuring the oxygen content with the Oxygen Analyzer 572, Servomex, England. After the desired exposure time, the storage facility was opened and aerated. Insect samples were taken out and transferred to the laboratory for mortality assessment after 2, 3, 5, 7, 10, and 14 days and corrected by Abbott's equation (1925).

Joint action of DE under modified atmospheres (MAs):

Cloths bags containing treated grains with DE dust at 0.3 and 0.6 % w/w and infested with the insects as mentioned before, were transferred to the steel bin to be treated with previously mentioned atmospheres. Testes were conducted inside the bin during summer time for varying periods of exposure. Grain temperature averaged 26±2 C and 55±5%RH. The evaluation of the joint effect of DE with the MA was calculated by co-toxicity factor using the equation mentioned by Mansour *et al.* 1966 as follows:

$$\text{Co-toxicity Factor} = \frac{\text{Observed mortality (\%)} - \text{Expected mortality (\%)}}{\text{Expected mortality (\%)}} \times 100$$

The obtained values were ranked into three categories: A positive value of 20 or more means potentiation (P) or synergistic effect (S) a negative factor of -20 or less means antagonism (A) and the intermediate values, i.e. between +20 and -20 was considered as additive effect (D).

RESULTS AND DISCUSSIONS

Data of efficacy of DE dust at 0.3 and 0.6 % w/w alone and under MA of 30±5%CO_2 to the tested insects at grain temperature of 26±2 C and 55±5 %RH. are given in Table 1 and 2. Insect mortalities resulted from DE alone were concentration-and exposure period-dependent. Mortality (%) of the insects increased by rising both the concentration and period of exposure. Adults of *T. castaneum* were found less affected at 0.3% DE followed by *S.oryzae* while *R.dominica* was the most susceptible, which its mortality reached 86%. Diapaused larvae of Khapra beetle were found the most tolerant to DE than adults of other insect species, since its larval mortality reached 33% after two weeks compared to 23% of the active ones.

In MA of 30 % CO_2, the adult mortality demonstrated 97, 79, 78, 34, and 26% for *S. oryzae, R.dominica, T. castaneum* and active as well as diapaused larvae of *T. granarium* after one week of exposure respectively. The combined effect of the DE dust at 0.3 and 0.6 % w/w under MA of 30±5% CO_2 (Table 2) to tested insects, showed in general, improved mortality values than those achieved with each component separately at the two tested concentrations of DE and for all the exposure periods. Co-toxicity values indicated also that synergistic / or additive effects for the three insect species at all the periods of exposure and at the two DE application rates. While in case of *T. granarium* larvae, additive effects were noticed only at the highest application rates (0.6%) for the active and diapause larvae at all the exposure periods (5- 14 days). On the other hand, antagonistic effects were observed at the lower used rates (0.3%) of DE under MA, at all the exposure periods for the active larvae while in case of the diapaused larvae, an additive effect was observed after 5 and 7-day exposure. This effect turned to antagonistic action after the longer exposure periods (10 and 14 days).

Table (1): Mortalities of some stored grain insects after Diatomaceous earth (DE) treatment at two concentrations and different exposure periods.

Exposure periods (days)	Mortalities (%) of the tested insects after Diatomaceous earth dust treatment									
	S.oryzae (Adults)		*R.dominica* (Adults)		*T. castaneum* (Adults)		*T. granarium*			
							Active larvae		Diapaused larvae	
	0.3% DE	0.6% DE	0.3% DE	0.6% DE	0.3% DE	0.6% DE	0.3% DE	0.6% DE	0.3% DE	0.6% DE
2	3.0	4.0	18.0	24.0	1.0	4.0	-	-	-	-
3	6.0	10.0	55.0	68.0	5.0	13.0	-	-	-	-
5	38.0	57.0	75.0	84.0	45.0	54.0	21.0	24.0	7.0	15.0
7	68.0	88.0	86.0	90.0	63.0	83.0	23.0	30.0	17.0	24.0
10	-	-	-	-	-	-	28.0	39.0	20.0	25.0
14	-	-	-	-	-	-	33.0	45.0	23.0	28.0

Table (2): Combined action of Diatomaceous earth (DE) dust under MA of 30 ± 5 % CO_2 on some stored grain insects at grain

Exposure periods (days)	Mortalities (%) of insects after treatments of DE + MA of 30±5% CO_2						
	MA of 30±5% CO_2	Mixtures of DE+ MA		Values of Co-Toxicity factor		Type of obtained Joint action	
		0.3%DE	0.6%DE	0.3%DE	0.6%DE	0.3%DE	0.6%DE
S. oryzae (Adults)							
2	30.0	100.0	100.0	203.0	194.1	S	S
3	90.0	100.0	100.0	4.0	0.0	D	D
5	94.0	100.0	100.0	0.0	0.0	D	D
7	97.0	100.0	100.0	0.0	0.0	D	D
R. dominica (adults)							
2	6.0	93.0	100.0	288.0	233.0	S	S
3	50.0	96.0	100.0	-4.0	0.0	D	D
5	68.0	100.0	100.0	0.0	0.0	D	D
7	79.0	100.0	100.0	0.0	0.0	D	D
T. castaneum (adults							
2	3.0	70.0	77.0	1650.0	1000.0	S	S
3	17.0	95.0	98.0	332.0	227.0	S	S
5	34.0	100.0	100.0	27.0	14.0	S	D
7	78.0	100.0	100.0	0.0	0.0	D	D
T. granarium (active larvae)							
5	25.0	34.0	44.0	-26.0	-10.2	A	D
7	31.0	50.0	52.0	-7.4	-15.0	D	D
10	54.0	58.0	74.0	-29.3	-20.4	A	A
14	77.0	67.0	87.0	-33.0	-13.0	A	D
T. granarium (Diapaused larvae)							
5	16.0	22.0	32.0	-4.3	3.2	D	D
7	26.0	36.0	49.0	-16.3	-2.0	D	D
10	46.0	39.0	67.0	-41.0	-5.6	A	D
14	66.0	42.0	85.0	-52.8	-9.6	A	D

temperatureof 26+2 C and 55± 5% RH

A= antagonistic effect. D= additive effect and S= synergistic effect

MA of 60% CO_2 induced adult mortality of 98, 93, 84, 51 and 30 % after one week of exposure, respectively for the above mentioned species. While it was 100% for adults of *S.oryzae*, *R.dominica* and *T.castaneum* under DE and MA of CO_2. Results of efficacy and combined action of DE (at 0.3 and 0.6%w/w) under MA of 60±5%CO_2 to the tested insects at 26±C and 55 ±5%R.RH. was given in Table 3. The results showed improved mortalities with the various insect species at all periods of exposure. Co-toxicity values resulted from these mixtures indicated potentiation/ or additive effects for the different insect species with the exception of the mixture of DE (0.3%) for 10 and 14 days with the diapause larvae of *T.granarium*, whereas an antagonistic effect was recorded.

Table (3): Combined action of Diatomaceous earth (DE) dust under MA of 60±5% CO_2 to some stored grain insects at grain temperature of 26± 2 C and 55±5 % RH.

Exposure periods (days)	Mortalities (%) of insects after treatments of DE + MAs of 60±5% CO_2						
	MA of 60±5% CO_2	Mixtures of DE+MA		Values of Co-Toxicity factor		Type of obtained Joint action	
		0.3%DE	0.6%DE	0.3%DE	0.6%DE	0.3%DE	0.6%DE
S. oryzae (adults)							
2	44.0	97.0	95.0	106.4	98.0	S	S
3	92.0	100.0	99.0	2.0	-1.0	D	D
5	96.0	100.0	100.0	0.0	0.0	D	D
7	98.0	100.0	100.0	0.0	0.0	D	D
R. dominica (adults)							
2	28.0	96.0	98.0	109.0	88.5	S	S
3	72.0	98.0	100.0	-2.0	0.0	D	D
5	90.0	100.0	100.0	0.0	0.0	D	D
7	93.0	100.0	100.0	0.0	0.0	D	D
T. castaneum (adults							
2	38.0	94.0	98.0	141	133.3	S	S
3	53.0	97.0	99.0	67.2	50.0	S	S
5	64.0	100.0	100.0	0.0	0.0	D	D
7	84.0	100.0	100.0	0.0	0.0	D	D
T. granarium (active larvae)							
5	34.0	45.0	61.0	-18.2	5.2	D	D
7	51.0	75.0	74.0	1.4	-8.6	D	D
10	58.0	80.0	84.0	-7.0	-13.4	D	D
14	86.0	83.0	93.0	-17.0	-7.0	D	D
T. granarium (diapaused larvae)							
5	17.0	28.0	35.0	17.0	9.4	D	D
7	30.0	43.0	62.0	-8.5	14.8	D	D
10	48.0	54.0	82.0	-20.6	12.3	A	D
14	68.0	63.0	91.0	-30.7	-5.2	A	D

A= antagonistic effect, D= additive effect and S= synergistic effect

MA of 80% CO_2 induced adult mortality of 99, 97, 97, 54 and 34 % after one week of exposure, respectively for the above mentioned species. With The combined effect of MA of 80±5 CO_2%, with DE dust (at both 0.3 and 0.6%w/w) was shown in Table 4. Results showed also a synergistic effect (or potentiation) with both ratios of DE after shorter periods of exposure with adults of *S.oryzae*, *R.dominica* and *T.castaneum*. With increasing the exposure periods, the resultant effect changed to additive.

Table (4): Combined action of Diatomaceous earth (DE) dust under MA of 80± 5% CO_2 to some stored grain insects at grain temperature of 26± 2 C and 55±5 % RH

Exposure periods (Days)	Mortalities (%) of insects after treatments of DE + MAs of 80±5% CO_2						
	MA of 80±5% CO_2	Mixtures of DE+MA		Values of Co-Toxicity factor		Type of obtained Joint action	
		0.3%DE	0.6%DE	0.3%DE	0.6%DE	0.3%DE	0.6%DE
***S. oryzae* (adults)**							
2	62.0	94.0	91.0	44.6	37.9	S	S
3	97.0	100.0	98.0	0.0	-2.0	D	D
5	98.0	100.0	100.0	0.0	0.0	D	D
7	99.0	100.0	100.0	0.0	0.0	D	D
***R. dominica* (adults)**							
2	51.0	100.0	100.0	44.9	33.3	S	S
3	84.0	100.0	97.0	0.0	-3.0	D	D
5	93.0	100.0	100.0	0.0	0.0	D	D
7	97.0	100.0	100.0	0.0	0.0	D	D
***T. castaneum* (adults)**							
2	77.0	98.0	100.0	25.4	23.5	S	S
3	88.0	100.0	100.0	7.5	0.0	D	D
5	95.0	100.0	100.0	0.0	0.0	D	D
7	97.0	100.0	100.0	0.0	0.0	D	D
***T.granarium* (active larvae)**							
5	43.0	57.0	78.0	-10.9	16.5	D	D
7	54.0	100.0	96.0	29.9	14.3	S	D
10	62.0	100.0	100.0	11.1	0.0	D	D
14	94.0	92.0	100.0	-8.0	0.0	D	D
***T. granarium* (diapaused larvae)**							
5	18.0	48	68	92.0	106.1	S	S
7	34.0	51.0	75.0	0.0	29.3	D	S
10	51.0	68.0	97.0	-4.2	27.6	D	S
14	70.0	84.0	97.0	-9.7	-1.0	D	D

D= additive effect and S= synergistic effect

MA of 99% N_2, showed complete mortality of *S. oryzae* after 1 week and it was 48, 24, 8 and 6% for *R. dominica*, *T.castaneum* active and diapaused larvae of *T.granarium*, respectively. The data of the efficacy and combined action of DE dust at both 0.3 and 0.6%w/w under MA of 99% N_2 to the tested insects are summarized in Table (5). Combinations of DE and MA of 99% N_2 produced generally enhanced mortalities than each material separately, with all the tested insects. Co-toxicity values of the mixtures indicated in all cases potentiation/ or additive effect at various exposure periods. Synergistic effects were observed after shorter exposure periods with all tested insects, while additive action was noticed with longer exposure periods.

Table (5): Combined action of Diatomaceous earth (DE) dust under MA of 99 % N_2 on some stored grain insects at grain temperature of 26± 2 C and 55± 5% RH.

Exposure periods (Days)	Mortalities (%) of insects after treatments of DE + MAs of 99% N_2						
	MAs of 99% N_2	Mixtures of DE+ MA		Values of Co-Toxicity factor		Type of obtained Joint action	
		0.3%DE	0.6%DE	0.3%DE	0.6%DE	0.3%DE	0.6%DE
S. oryzae (adults)							
2	25.0	100.0	100.0	257.1	245.0	S	S
3	58.0	100.0	100.0	56.3	47.1	S	S
5	94.0	100.0	100.0	0.0	0.0	D	D
7	100.0	100.0	100.0	0.0	0.0	D	D
R. dominica (adults)							
2	8.0	96.0	96.0	269.2	200.0	S	S
3	11.0	98.0	100.0	48.5	27.0	S	S
5	15.0	100.0	100.0	11.1	1.0	D	D
7	48.0	100.0	100.0	0.0	0.0	D	D
T. castaneum (adults)							
2	2.0	95.0	96.0	3067.0	1500.0	S	S
3	3.0	96.0	98.0	1100	513.0	S	S
5	6.0	98.0	100.0	92.2	67.0	S	S
7	24.0	100.0	100.0	14.9	0.0	D	D
T. granarium (active larvae)							
5	3.0	91.0	93.0	279.0	244.4	S	S
7	8.0	95.0	96.0	206.5	152.6	S	S
10	45.0	96.0	98.0	31.5	16.6	S	D
14	94.0	100.0	100.0	0.0	0.0	D	D
T. granarium (diapaused larvae)							
5	5.0	63.0	68.0	425.0	240.0	S	S
7	6.0	76.0	80.0	230.4	166.7	S	S
10	15.0	83.0	85.0	137.1	112.5	S	D
14	66.0	85.0	88.0	-4.5	-6.4	D	D

D= additive effect and S= synergistic effect

The action of MA of CO_2 on the insect pests of stored grains is not fully understood. However, it could be explained due to increased solubility of CO_2 in the insect body fluids (Stahl *et al*.. 1985) or due to lesions in the cell membrane of both adult and larvae, which the exposed integument of the tested insects was severely damaged (Nakakita and Kawashima, 1994; Ulrich, 1994). Thus the extinction of insect pests of stored products achieved by this technique depends on insect stage, exposure period, and entry method of CO_2 inside the target tissue and the speed of applied pressure (Shazali *et al.*, 2004).

The previous results showed that insect susceptibility to MAs of CO_2 or N_2 is varied depending on insect type, insect stage (*T.granarium*), type and concentration of MA as well as concentration of DE. Carbon dioxide was found more effective at higher concentration against the tested insects with higher DE (0.6%). MA of either carbon dioxide or nitrogen with the DE enhanced the toxicity of tested insects especially with the higher DE concentrations. Thus, the obtained results showed the importance of these combined treatments as safe, non-chemical method and accepted by people as alternative method to control insect pest populations (Banks and Fields, 1995). Our results agree with those mentioned by Ofuya and Reichmuth (2002) which MA was demonstrated to increase insect mortalities by prolonging the opening of the insect spiracles. Thus, this method could be considered as a potential and effective alternative for methyl bromide fumigation of stored grain insects.

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فاعلية مسحوق التربة الدياتومايه تحت ظروف جوية معدله ضد بعض حشرات الحبوب المخزونة

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تم فى هذه الدراسة التطبيقية معرفة تأثير فاعلية مسحوق التربة الدياتومايه منفردا وتحت ظروف جوية معدلة ، وهى ٣٠% و٦٠% و٨٠%ثاني أكسيد الكربون و٩٩ % نيتروجين في صوامع من الصلب محكمة الغلق حجمها ١/٢ م³ تحتوى الواحدة على ٤٥٠ كجم من صوب القمح. وهذه الصوامع موجودة بأرضية مزرعة كلية الزراعة بمشتهر جامعة الزقازيق. وأجريت التجارب خلال الصيف حيث كان متوسط درجة حرارة الحبوب ٢٦ ± ١م والرطوبة النسبية ٥٥ ± ٥% على الحشرات الكاملة لسوسة الأرز وثاقبة الحبوب الصغرى وخنفساء الدقيق الكستنائية وكلك اليرقات النشطة والساكنة لخنفساء الصعيد. وقد أظهرت النتائج أن تأثير المسحوق منفردا يتوقف على التركيز ومدة التعريض ونوع الحشرة. وتبين أن اليرقات النشطة والساكنة لخنفساء الصعيد كانت أقل تأثرا بالمسحوق مقارنة بالحشرات الكاملة للأنواع الأخرى، حيث وصلت نسبة الموت فيها٣٠% ، ٢٤% بعد أسبوع على التوالي. وعند استخدام الأجواء المعدلة من ثاني أكسيد الكربون وبتركيزات ٣٠% و٦٠% و٨٠%ثاني أكسيد الكربون منفردة ، تبين أن الفعالية تتوقف علي تركيز الغاز وزمن التعريض ونوع الحشرة، حيث أزداد التأثير الناتج بزيادة تركيز الغاز ومدة التعريض وتبين كذلك أن اليرقات النشطة والساكنة لخنفساء الصعيد كانت أكثر تحملا للجوالمعدل من الحشرات الكاملة الأخرى. وعند استخدام الجوالمعدل الذي يحتوي على تركيز ٩٩% نيتروجين تبين أن نسبة الموت وصلت ١٠٠% لسوسة الأرز و٤٨% و٢٤ % للحشرات الكاملة لثاقبة الحبوب الصغرى وخنفساء الدقيق الكستنائية ، بينما كانت ٨% ،٦% لليرقات النشطة والساكنة لخنفساء الصعيد وذلك بعد أسبوع من المعاملة على التوالي. وعند أستخدم التربة الداياتومايه وبتركيزات ٠,٣ ، ٠,٦ % تحت الأجواء المعدلة من ٣٠% و٦٠% ثاني أكسيد الكربون وجد أن التأثير المشترك الناتج كان تنشيطيا أوإضافيا مع الحشرات الكاملة لكل من سوسة الأرز وثاقبة الحبوب الصغرى وخنفساء الدقيق الكستنائية، بينما مع الجوالمعدل الذي يحتوى الذي يحتوى على ٨٠% من ثاني أكسيد الكربون كان التأثير الناتج منشطا بعد الفترات القصيرة من التعريض للحشرات الكاملة المختبرة، ومع زيادة فترات التعريض تغير التأثير الى إضافيا. وبالنسبة للتأثير

المشترك لمسحوق التربة الدياتومايه تحت هذه الظروف الجوية المعدلة فكـــان منشــطا بعد الفترات القصيرة من التعريض مع كل الحشرات الكاملة المختبرة(ماعــدا سوســة الارز) وعند كل تركيزات المسحوق، ومع زيادة فترات التعريض كان التأثير النــاتج اضافيا.

تبين هذه الدراسة أن حساسية الحشرات المختبرة للجوالمعدل تتوقــف علــى نوع الحشرة والطور الحشري وتركيز الجوالمعدل من الغاز وكذلك تركيــز مســحوق الغلط (التربة الداياتومايه) ، كما وجد أن التأثير المشترك للجوالمعدل والمسحوق (في كل الحالات) يفوق بوجه عام تأثير مكوناته منفردا، وهذه الطريقة تعتبر تطبيقيه لأنهــا آمنة وغير كيماوية ويمكن أن تدخل كطريقة بديلة للتبخير بغاز بروموور الميثيل ضــد حشرات الحبوب المخزونة ومنتجاتها.