

Maximizing Toxicity of Certain Insecticides Against *Tribolium castaneum* (Herbst)

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رفع السمية الأبادية لبعض المبيدات الحشرية ضد خنفساء الدقيق الحمراء

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خلاصة: تم دراسة تأثير اختلاف درجات الحرارة و تأثير التعرض للإضاءة على سمية كل من الدلتاميثرين والكلوربيريفوس-ميثيل والملاثيون ضد حشرة خنفساء الدقيق الحمراء باستخدام طريقة الفيلم المتبقي. وقد أوضحت النتائج زيادة سمية المبيدات المختبرة بارتفاع درجة الحرارة وقد كانت درجة الحرارة المثلى للمبيدات المستخدمة في الدراسة هي 30 °م. وقد كان ترتيب المبيدات من حيث السمية كالتالي: الكلوربيريفوس-ميثيل الدلتاميثرين الملاثيون. علاوة على ذلك فإن التعرض للضوء قد أظهر زيادة واضحة في قيم السمية النسبية للمبيدات الثلاثة المختبرة مقارنة بسميتها تحت ظروف الإظلام. كما أن إضافة منشط البيرونييل بيوتوكسيد إلى كل من المبيدات المستخدمة قد أدى إلى زيادة السمية النسبية بمقدار حوالي أربع أضعاف وذلك تحت ظروف الإضاءة والإظلام. وقد أظهرت دراسة الفعل السام المشترك لمبيد الدلتاميثرين مع المبيدات الفوسفورية المختبرة أن خلط الكلوربيريفوس-ميثيل مع الدلتاميثرين قد أدى إلى زيادة السمية النسبية مقارنة بمبيد الدلتاميثرين بمفرده وذلك بمقدار 152.7 و 137.12 ضعف تحت ظروف الإظلام والإضاءة على التوالي. وأخيرا، فقد أوضحت الدراسة أن أفضل خلطة تم استخدامها أعطت أعلى تأثير ضد الحشرة المختبرة هي خلط الدلتاميثرين مع الكلوربيريفوس-ميثيل مع البيرونييل بيوتوكسيد تحت ظروف التعرض للضوء حيث كانت قيمة السمية النسبية هي 679.05 ضعف مقارنة بالدلتاميثرين بمفرده تحت نفس الظروف. لذلك يمكن تحسين الكفاءة الإبادية لمبيد الدلتاميثرين وذلك بزيادة درجة الحرارة وكذلك التعرض للضوء وأيضا باستخدام مثبطات إزالة السمية. يؤدي كل ذلك إلى رفع كفاءة المبيد ضد الحشرة المختبرة وبهذا يمكن تقليل المعدلات المستخدمة من المبيد وبالتالي خفض أخطار التلوث البيئي وكذلك خفض صفة المقاومة للحشرة للمبيدات.

ABSTRACT: Effects of temperature and light exposure on the toxicity of deltamethrin, chlorpyrifos-methyl, and malathion against *Tribolium castaneum* were extensively studied using the residual film method. Results revealed that mortality increased proportionally with an increase in temperature, where the optimum temperature for the three tested insecticides was 30°C. Toxicity of the tested insecticides could be arranged in the following descending order: chlorpyrifos-methyl > deltamethrin > malathion. Moreover, light exposure obviously enhanced toxicity of the three investigated insecticides compared to dark exposure. Piperonyl butoxide (PB) acted as an oxidase inhibitor, when mixed with each of the three insecticides, increased the toxicity ratio by about four fold in both dark and light. Joint toxic effects between deltamethrin and the two tested OP as esterase inhibitors, showed that mixing chlorpyrifos-methyl with deltamethrin increased deltamethrin toxicity by 152.7 and 137.12 fold in dark and light, respectively. Finally, deltamethrin + chlorpyrifos-methyl + PB blend was found to possess maximum efficiency, which increased deltamethrin toxicity by 679.05 fold under exposure to light conditions. Thus, modification of deltamethrin toxicity by increased temperature; light exposure and detoxification inhibitors maximized its toxicity to *Tribolium castaneum*, reduced insecticide rate, and thus reduces both the environmental stress, and the resistance pressure.

Keywords: Maximizing toxicity, deltamethrin, organophosphorus, *Tribolium castaneum*.

Chemical control of stored grain pests requires adequate and continuous attention to the storage rooms, during transportation, and to silo cells (Storey *et al.*, 1984). Annual losses of stored grains caused by insects are estimated to be over 15% of the total stored grains produced in Egypt (Essa, 1995), and up to 9% of the world's production (GIFAP, 1989).

The red flour beetle, *Tribolium castaneum* (Herbst) is one of the major insect pests of stored grain products in warm and tropical regions of the world (Semple, 1986). It is the most abundant and injurious pest in flour mills, bulks of grains, oilseeds and warehousing facilities (Zettler, 1991). Application of protectant insecticides is an integral part of the

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management of this pest (Bengston *et al.*, 1991). Malathion has been used extensively for nearly 30 years as a grain protectant to control this pest, but now, it is losing its effectiveness due to insect resistance (Horton, 1984). Among the OP pesticide, chlorpyrifos-methyl is a possible substitute for malathion as a stored grain protectant for the malathion-resistant species particularly the *T. castaneum* (Collins *et al.*, 1993). Since the grain insect pests are notorious for developing resistance to insecticides (Champ, 1986), and recently because there is a desire to reduce OP chemical residues on grains, alternatives to the OP have been sought by the grain protection industry. Most important of such alternatives are the α -cyanophenoxy benzyl cyclopropanecarboxylate pyrethroid derivatives, particularly deltamethrin synergised with PB (Arthur, 1994 a&b). However, high levels of resistance to pyrethroid insecticides have been reported in *T. castaneum* (Collins, 1990). Therefore, with two protectants being applied to grain, there is a potential for synergism between them (Daglish, 1998). Synergism between pyrethroids and organophosphorus insecticides has been demonstrated (Daglish, 1998 and Richter *et al.*, 1998). However, the use of chemical treatment to control stored insects has been limited by the risk of insecticide resistance, cost, and consumer obstruction to using toxic chemicals on food or food products. This has resulted in reducing the maximum residue limits (Armitage *et al.*, 1994). The aforementioned reasons have placed increasing reliance on the development of low-cost, low chemical input, and integrated pest management storage strategies that must be capable of guaranteeing the same degree of freedom from pests as chemical strategies. An integrated package of physical and chemical techniques had been recommended (Armitage *et al.*, 1994). The interaction between physical factors such as temperature and moisture may be used to minimize the required dose of protectant (Shawir and Mansee, 1997). The effect of photo-period has also been considered (Montasser, 1999). Thus, different pesticides or pesticide combinations could be selected depending on the ambient environmental conditions under which the grain is to be stored.

The present investigation estimated the effects of light exposure and temperature, on the toxicity of deltamethrin, chlorpyrifos-methyl and malathion against *T. castaneum*. In addition, synergistic and joint toxic effects of tested insecticides after light exposure were evaluated against the tested insect pest. The final aim of this study was to investigate the management toxicity of tested insecticides against *T. castaneum* by using physical parameters. Specifically, it was observed whether mixtures and conditions could be exploited to increase the toxicity with a reduction in the application rates for the control of stored product insects.

Materials and Methods

INSECTS: Adults of red flour beetle, *T. castaneum* (Herbst) were laboratory cultured, and reared on sterilized whole meal flour (12 % moisture content) in glass jars. Beetles were cultured at 25 ± 2 °C and 70% ± 5 R.h. The adults tested were 3-4 weeks old.

CHEMICALS: Deltamethrin [(S)- α cyano- 3-phenoxybenzyl (1R,3R)-3-(2,2-dibromovinyl)-2,2 dimethylcyclopropane-carboxylate], technical grade ($\approx 98\%$ a.i.); Chlorpyrifos-methyl [O,O- dimethyl O-(3,5,6- trichloro-2-pyridinyl) phosphorothioate, 99.2% purchased from ChemService Inc. USA.; Malathion [O,O-dimethyl-5-(1,2-dicarbethoxymethyl) phosphorodithioate], technical grade (99.5% a.i.); and piperonyl butoxide [5-[[2-(2-butoxy ethoxy) ethoxy]methyl]-6-propyl-1,3-benzodioxole], as an oxidase inhibitor, was purchased from same source.

BIOASSAY OF TESTED INSECTICIDES:

Effects of Light on Insecticide Toxicity at Different Temperatures

Using a 1 ml pipette, a 0.5 ml sample of diluted insecticide solution (diluted with acetone), at the selected concentrations, was applied on a Whatman No. 1 filter paper (7cm i.d.), placed in a petri dish to ensure even chemical distribution (Shawir and Mansee, 1997). The filter paper was allowed to dry for approximately half hour. Twenty normally active adult beetles were transferred to each petri dish, confined by plastic rings, and incubated at 15, 20, 22, 25, and 30°C. Dishes were kept in continuous light (14 W light source) in an incubator (Okiewelu *et al.*, 1998). Another group of petri dishes was kept under continuous dark conditions for comparison. Beetles were examined after 5 days of exposure and the mortality counts were recorded. Each group included seven concentrations and a control, each in three replicates. The LC_{50} values expressed as $\mu\text{g}/\text{cm}^2$ were calculated according to Finney (1971).

Synergism and Joint Toxic Effect of Tested Insecticides

Synergism of tested insecticides: Piperonyl butoxide (PB) was mixed, as an oxidase inhibitor, with each tested insecticides at the ratio of 1:5. Blends were tested against *T. castaneum* using the residual film method as previously mentioned, and were incubated at 30°C for tested insecticides, under continuous darkness or light. Toxicity and synergistic effect were computed according to the method of Metcalf (1967).

Joint toxic effects of synthetic pyrethroid, deltamethrin: Series of deltamethrin concentrations were mixed with malathion or chlorpyrifos-methyl at the ratio of 1:5 to evaluate the joint toxic effects between insecticides according to Bengston *et al.* (1987). The residual film application method as previously described was followed and treated insects were kept at the optimum

temperature degree, 30°C (Shawir and Mansee, 1997). The joint toxic effect was studied by mixing deltamethrin with the OP insecticide, chlorpyrifos-methyl, as an esterase inhibitor, and piperonyl butoxide, as an oxidase inhibitor. Deltamethrin was mixed with chlorpyrifos-methyl and piperonyl butoxide at the ratio of 1:4:8 respectively according to Bengston *et al.* (1983). The residual film application, as previously described, was used against *T. castaneum* at 30°C under continuous darkness or light for 5 days to evaluate the joint toxicity action. The 95% fiducial limits of the LC₅₀ values were used to test for the statistical significant differences in toxicity between different treatments (Koziol and Witkowski, 1982).

Results and Discussion

ROLE OF TEMPERATURE AND LIGHT EXPOSURE ON INSECTICIDE TOXICITY: Influences of temperature as well as exposure to source of light, on the toxicity of tested insecticides, deltamethrin, chlorpyrifos-methyl and malathion, against adults of *T. castaneum*, were extensively investigated. Results are presented in Figure 1 a, b, and c, as toxicity ratios of tested insecticide, under continuous darkness or light conditions at different temperatures. Toxicity ratio was calculated by dividing the lowest toxicity value (LC₅₀ of malathion treatment in darkness at 30°C, as 5.717 µg/cm²), with LC₅₀ values of each treatment. The Duncan test was used to test for the statistically significant differences in toxicity ratio among different temperature levels (Herzberg, 1983). Present results show that the toxicity of tested insecticides against *T. castaneum* after exposure to the light is higher than those of the corresponding toxicity in dark at each examined temperature. In addition, the data showed that the toxicity of tested insecticides to *T. castaneum* increased with a temperature increase, either in light or in dark, except in the case of deltamethrin. The toxicity ratio of deltamethrin treatments at 20, 22, and 25°C under continuous light or dark against *T. castaneum* seems to be negatively correlated with temperature. The present study also revealed a margin of temperature range at which deltamethrin exerts a negative temperature-toxicity correlation.

The optimum temperature was found to be 30°C for insecticides against *T. castaneum* under light or dark exposure. Moreover, chlorpyrifos-methyl was more toxic than deltamethrin or malathion at all temperatures under light or dark exposure. The toxicity ratios of chlorpyrifos-methyl values were calculated to be 6.381 and 12.138 folds at 30°C under darkness and light treatments, respectively against *T. castaneum*.

The current investigation revealed that synthetic pyrethroid, deltamethrin toxicity ratios at 20, 22, and 25°C, were negatively correlated with temperature. This is in agreement with the findings of Longstaff and Desmarchlier (1983) who reported that the toxicity of

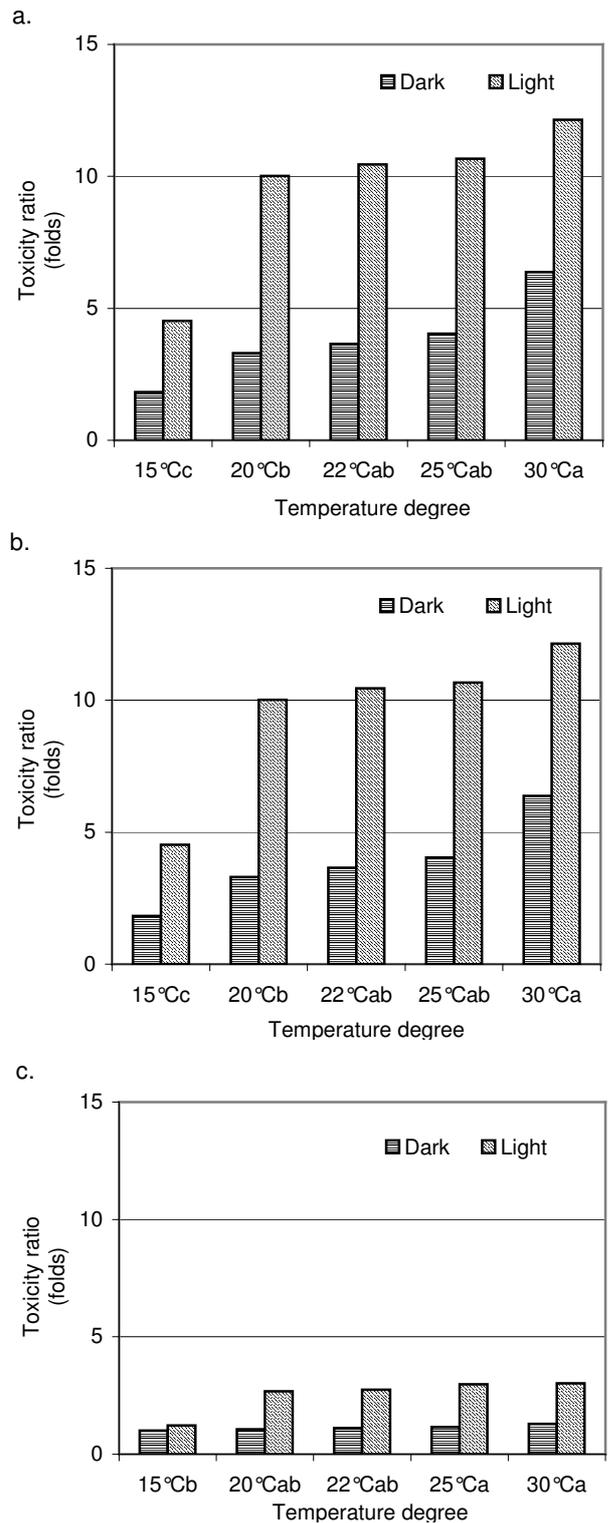


Figure 1. a. Effect of temperature on toxicity of deltamethrin against *T. castaneum*. b. Effect of temperature on toxicity of chlorpyrifos-methyl against *T. castaneum*. c. Effect of temperature on toxicity of malathion against *T. castaneum*. Toxicity ratio values for a given temperature followed by a common letter are not significantly different as Duncan test.

deltamethrin to *S. oryzae* decreased with increasing temperature. However, Watters *et al.*, (1983) reported that the toxicity of the pyrethroid insecticides cypermethrin and fenvalerate to *T. castaneum* was significantly higher at 20°C than at 10°C or 30°C.

Moreover, Shawir and Mansee (1997) reported that toxicity of the tetrahalo-pyrethroid tralomethrin to *S. oryzae* and *T. castaneum* using residual application was higher at 25°C than at 35°C or 15°C. They also reported that deltamethrin was more toxic at the higher temperature (35°C) for residual exposure against *S. oryzae* and *T. castaneum*. In other words, very low or very high temperature might have a severe effect on the biological and physiological activities of the insect that in turn may affect insect susceptibility to pyrethroids. The same trend of temperature-toxicity interaction was observed by Montasser (1999). Also, it was cited that the pyrethroid insecticide permethrin expressed a higher effect at 20°C than at 30, or 15°C to both tested insects.

The present investigation showed that the toxicity of two tested OP's, malathion and chlorpyrifos-methyl, increased by increasing temperature. Toxicity also increased as a result of light exposure rather than dark conditions. Desmarchelier (1977) indicated the effect of lower temperature and supported these findings in reducing toxicity of organophosphorus, dichlorvos, malathion, fentriothion and pirimiphos-methyl against *Tribolium* and *Sitophilus* species. In addition, Tyler and Binns (1982) mentioned that the effectiveness of malathion and pirimiphos-methyl against the examined susceptible stored product insects was greater at 25°C than at 17.5°C and was markedly lower at 10°C. Montasser (1999) added that tested organophosphorus insecticides, pirimiphos-methyl and malathion were more toxic at higher temperature against *S. oryzae* and *T. castaneum*. In contrast, Longstaff and Desmarchelier (1983) showed that the pirimiphos-methyl was shown to have opposite relationships with temperature to *S. oryzae*.

The present results show that the three tested insecticides could be arranged in a descending order according to their toxicity to *T. castaneum* at all examined temperatures as chlorpyrifos-methyl, deltamethrin and malathion. The present investigation also showed that light exposure plays an important role in the toxicity of each of the tested insecticides against *T. castaneum*. However, the toxicity of these insecticides was increased when exposed to light at the same temperature. It can also be concluded that light exposure increases the toxicity ratio compared to darkness by 280, 190.2, and 235.03% for deltamethrin, chlorpyrifos-methyl and malathion treatments respectively, at optimum temperature (30°C).

Previous work emphasized that the effects of exposure to light on the toxicity of pesticides especially for stored product insects are few. Fernandez and Randolph (1966) mentioned that the photoperiodic rearing conditions affect the susceptibility of houseflies to a given dosage of insecticides. It could be explained according to the assumption of Pittendrigh (1961), who found that the photoperiod could exert effects on other fundamental aspects of insect physiology. El-Sebae and

Moustafa (1970) studied the effect of three photoperiodic treatments such as continuous illuminating, 12 hours periodic light and dark and continuous darkness on the life cycle and susceptibility of *M. domestica* to DDT. They concluded that continuous illumination increased the activity of the insects. This might render the insects more vulnerable to DDT poisoning. Okiwelu *et al.* (1998) added that the photoperiod affects some aspects of the biology of the merchant grain beetle, *Oryzaephilus mercator*. Montasser (1999) supported the present findings and concluded that the toxicity of permethrin, pirimiphos-methyl and malathion after exposure to light, was higher than the corresponding toxicity in absence of light against both *S. oryzae* and *T. castaneum*.

INFLUENCE OF PB ON SYNERGISM OF TESTED INSECTICIDES: Synergistic effects of the oxidase inhibitor, piperonyl butoxide (PB) on the toxicity of insecticides at their optimum temperature (30°C) against *T. castaneum*, under continuous darkness or continuous light, are presented in Table 1. The LC₅₀ values for given treatments were compared. The significant differences between LC₅₀ values were detected by using the 95% fiducial limits (Koziol and Witkowski, 1982). The results show that addition of the oxidase inhibitor (PB) to deltamethrin, chlorpyrifos-methyl and malathion resulted in a remarkable synergism against *T. castaneum* under both exposure operations. In addition, synergistic ratios in the continuous light treatment were higher than those under darkness treatment for all tested insecticides. The toxicity of chlorpyrifos-methyl +PB blends against *T. castaneum* after exposure to light was the most toxic than all other tested insecticide blends, showed 0.115 µg/cm² and 4.09 folds as LC₅₀ and synergistic ratio, respectively. Furthermore, mixing PB with malathion resulted in the highest synergism, against *T. castaneum*. The values were calculated as 4.84 and 4.49 folds for darkness and light treatments conditions, respectively.

Mixed function oxidase (MFO) plays a significant role in degradation of pyrethroid insecticides (Yamamoto, 1973) or organophosphorus insecticides (Attia and Frecker, 1984). However, using piperonyl butoxide, well known as an MFO inhibitor, could be classified as an active synergist with all tested insecticides (Wilkinson, 1971). Thus, inhibition of these types of enzymes by PB is a possible explanation for the high level of synergism (Lloyd, 1973).

Adding PB to the three tested insecticides, in the present investigation, resulted in a remarkable synergism against *T. castaneum*. This result can be supported by the report of Bengston *et al.* (1983), who indicated that deltamethrin + pirimiphos-methyl + PB blend completely controlled *S. oryzae* (L.), *T. castaneum*, *T. confusum* and *R. dominica*. Marei *et al.* (1994) added that PB synergized the toxicity of deltamethrin against *S. oryzae* (L.). On the other hand, Wanas *et al.* (1982)

TABLE 1

Effects of oxidase inhibitor, piperonyl butoxide (PB), on insecticides toxicity to T. castaneum using residual film method at 30°C.

Insecticides		Treatments			
		In Dark		In Light	
		LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio** (Fold)	LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio** (Fold)
Deltamethrin	Without PB	2.00 (1.72-2.40)	-	0.713 (0.64-0.79)	-
	+ PB	0.625* (0.57-0.68)	3.2	0.166* (0.14-0.19)	4.3
Chlorpyrifos-methyl	Without PB	0.896 (0.82-0.97)	-	0.471 (0.40-0.54)	-
	+ PB	0.228* (0.20-0.26)	3.93	0.115* (0.10-0.13)	4.09
Malathion	Without PB	4.442 (4.1-4.82)	-	1.89 (1.76-2.03)	-
	+ PB	0.918* (0.84-0.99)	4.84	0.421* (0.39-0.45)	4.49

*LC₅₀ values followed by asterisks are significantly greater than without PB based on the 95% fiducial limits.

**Relative to the toxicity of insecticide without synergism (PB).

reported that PB could be used successfully as a synergist for malathion and other organophosphorus insecticides against *S. oryzae*. Moreover, Bengston *et al.* (1983) mentioned that pirimiphos-methyl + PB controlled common field strains of *S. oryzae* and *R. dominica*. The addition of PB to malathion was also attempted to increase the toxicity of this organophosphorus against *O. surinamensis* (Attia and Frecker, 1984). Montasser (1999) mentioned that mixing of PB with permethrin, pirimiphos-methyl and malathion resulted in a synergistic effect of toxicity against both *S. oryzae* and *T. castaneum*. The tested insecticide-synergist mixtures can be arranged in the following descending toxicity order: Pirimiphos-methyl + PB at 30°C > permethrin + PB at 20°C > malathion + PB at 30°C.

INFLUENCE OF ESTERASE INHIBITORS ON TOXICITY OF DELTAMETHRIN: Organophosphorus insecticides when mixed with pyrethroids used to play a role as an esterase inhibitor, which result in increasing the toxicity of pyrethroids (Marei *et al.*, 1982). Thus the joint toxic effects of chlorpyrifos-methyl and malathion, as an esterase inhibitors when mixed with deltamethrin, were extensively evaluated against *T. castaneum* at 30°C in continuous light or darkness (Table 2). The results show that inhibitors, when mixed with deltamethrin, significantly enhance its insecticidal toxicity against the tested insect in light and darkness conditions. However, when deltamethrin was mixed with chlorpyrifos-methyl, the blend was more toxic than the deltamethrin-malathion mixture under dark or light conditions. The LC₅₀ of the mixture (deltamethrin-chlorpyrifos-methyl) against *T. castaneum* under continuous dark treatment was 0.0131 µg/cm² with toxicity ratio of 152.7 folds, while in

continuous light treatment the values were 0.0052 µg/cm² and 137.12 folds, respectively. Meanwhile, the two tested deltamethrin-organophosphorus mixtures, showed more toxicity under light treatment than under dark treatment.

Organophosphorus compounds were classified as exceptionally potent pyrethroid esterase inhibitors (Marei *et al.*, 1982). The esterase enzymes play an important role in detoxification and degradation of pyrethroid insecticides. The inhibition of these enzymes by OP compounds enhanced pyrethroids persistence (Mansee, 1992).

The organophosphorus compounds, chlorpyrifos-methyl and malathion as esterase inhibitors, showed an effect on the insecticidal activity when used in mixtures with pyrethroid insecticide (deltamethrin) against the adults of *T. castaneum* (Herbst). Current findings may

TABLE 2

Effects of esterase inhibitors on Deltamethrin toxicity against T. castaneum using residual film method at 30°C.

Insecticides	Treatments			
	In Dark		In Light	
	LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio* (Fold)	LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio* (Fold)
Deltamethrin	2.00 ^a (1.72 – 2.40)	0	0.713 ^b (0.64 – 0.79)	0
Deltamethrin + Malathion	0.16 ^c (0.14 – 0.18)	12.5	0.0174 ^d (0.013 – 0.023)	41
Deltamethrin +Chlorpyrifos-methyl	0.0131 ^d (0.0081-0.013)	152.7	0.0052 ^e (0.0042-0.0063)	137.12

*Relative to the toxicity of deltamethrin alone.

LC₅₀ values for a given treatment followed by a common letter are not significantly different at the 5% level of probability based on the 95% fiducial limits.

TABLE 3

Joint toxic effects of Deltamethrin toxicity against *T. castaneum* using residual film method at 30°C.

Insecticides	Treatments			
	In Dark		In Light	
	LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio* (Fold)	LC ₅₀ (µg/cm ²) (95% Fiducial Limits)	Toxicity Ratio* (Fold)
Deltamethrin	2.00 ^a (1.72 – 2.40)	-	0.713 ^b (0.64 – 0.79)	-
Deltamethrin + PB	0.625 ^b (0.57-0.68)	3.2	0.166 ^c (0.14-0.19)	4.3
Deltamethrin + Chlorpyrifos-methyl	0.013 ^d (0.0081-0.013)	152.7	0.0052 ^e (0.0042-0.0063)	137.12
Deltamethrin + Chlorpyrifos-methyl + PB	0.0056 ^e (0.0046-0.0069)	357.14	0.00106 ^f (7.9E4-1.41E3)	679.05

*Relative to the toxicity of deltamethrin alone. LC₅₀ values for a given treatment followed by a common letter are not significantly different at the 5% level of probability based on the 95% fiducial limits.

also be supported by Carter *et al.* (1980) who found that chlorpyrifos-methyl, pirimiphos-methyl or fenitrothion in combination with permethrin resulted in potentiation for control of stored product insect pests. Bengston *et al.* (1983) added that pirimiphos-methyl + permethrin controlled *S. oryzae* (L.) and *R. dominica*, and completely prevented progeny production in *T. castaneum*, *T. confusum* and in *E. cautella*. Conversely, a mixture of permethrin and pirimiphos-methyl was less effective against *P. truncatus* and *S. zeamidis* (Richter *et al.*, 1998). Marei *et al.* (1994) found that mixing profenfos with deltamethrin resulted in enhancement of permethrin toxicity against the rice weevil, *S. oryzae* (L.). Also, the toxicity of pyrethroids to stored product insects was increased when mixed with other organophosphorus insecticides such as Chlorpyrifos-methyl (Daglish, 1998). Montasser (1999) concluded that the addition of the organophosphorus, TOCP, malathion and pirimiphos-methyl resulted in potentiation of the insecticidal toxicity of permethrin against the adults of *S. oryzae* (L.) and *T. castaneum* (Herbst). This is in agreement with our investigation. The toxicity of the mixtures against insects can be arranged in the following descending order: permethrin+ pirimiphos-methyl > permethrin + malathion > permethrin + TOCP > permethrin alone.

EFFECTS OF ESTERASE AND OXIDASE INHIBITOR COMBINATION ON DELTAMETHRIN TOXICITY: To study the joint toxic effect against *T. castaneum*, deltamethrin was mixed with chlorpyrifos-methyl and PB, at the ratio of 1:4:8 and kept at 30°C under continuous darkness and light conditions. The mixture gave LC₅₀ and toxicity ratio values of 5.6 x 10⁻³ µg/cm² and 357.14 folds under continuous darkness and 1.06 x 10⁻³ µg/cm² and 679.05 folds in continuous light, respectively (Table 3). This

mixture exhibited the most significant synergistic effect among all tested mixtures or deltamethrin alone.

The activity of deltamethrin, chlorpyrifos –methyl, and PB mixture showed an obvious effect over the activity of deltamethrin alone against *T. castaneum*. Generally, the relative toxicity of this mixture proved the highest ratio in the present study either in darkness or light conditions against tested insects.

The toxicity of the different mixtures with deltamethrin against stored-product insects could be arranged in the following descending order: deltamethrin plus chlorpyrifos-methyl plus PB > deltamethrin plus chlorpyrifos-methyl > deltamethrin plus PB > deltamethrin. In addition, all tested treatments showed a better effect to *T. castaneum* under light than under darkness condition.

COMPARING INSECTICIDE TOXICITY UNDER DIFFERENT CONDITIONS WITH RECOMMENDED APPLICATION RATE: The results showed that the used unit of malathion in dark at 25°C was 100 µg/cm², while at 30°C, the same value was 88.84 µg/cm² (Table 4). Both chlorpyrifos-methyl and deltamethrin, when tested in darkness at 30°C, showed increased toxicity against *T. castaneum* compared with malathion (used units was 17.36 and 40 µg/cm², respectively). The suggested blend of deltamethrin + chlorpyrifos-methyl + PB in dark at 30°C, increased the toxicity value by decreasing the units used (0.112 µg/cm²).

The toxicity values were expressed as 20 times of each LC₅₀ (µg/cm²). The LC₅₀ multiplied by 20 times, to simulate the dose of malathion recommended to control empty silos in Egypt (suggested by the Egyptian Ministry of Agriculture, 1997) as 100 µg/cm² of malathion at 25°C, which equal to 20 times of its LC₅₀ at the same conditions in the present study.

All the previous treatments when tested under light condition, increased the toxicity value of the treatment compared to the recommended application. The same table showed how much the treatments and blends save or decrease the amounts of insecticides used as compared to the recommended application by the Ministry.

TABLE 4

Comparative toxicity of tested insecticides under different conditions with special reference to the recommended application.

Treatments	Units Used (µg/cm ²)		Units Saved (%)	
	In Dark	In Light	In Dark	In Light
Malathion (25°C)	100.00*	38.30	-	61.70
Malathion (30°C)	88.84	37.80	11.16	62.20
Chlorpyrifos-methyl (30°C)	17.36	9.42	82.64	90.58
Deltamethrin (30°C)	40.00	14.26	60.00	85.74
Deltamethrin+Chlorpyrifos-Methyl + PB (30°C)	0.11	0.02	99.88	99.98

*Recommended dose of malathion in empty silos in Egypt at 25°C according to the Egyptian Ministry of Agriculture (1997), which is equal to 20 times of LC₅₀'s malathion at 25°C in dark.

MAXIMIZING TOXICITY OF CERTAIN INSECTICIDES AGAINST *TRIBOLIUM CASTANEUM* (HERBST)

It can be concluded that exposure to light saves more than 60% of the malathion dose, while in the case of chlorpyrifos-methyl and deltamethrin, savings reached 90% and 85%, respectively. The suggested blend in the present study might be used as an alternative to malathion. This will help to save about 99% of malathion units used in the regular recommendation.

Conclusions

Light exposure increases the toxicity of the tested insecticides against *T. castaneum*, compared to darkness exposure at all examined temperatures. The toxicity value increased proportionally with an increase in temperature. The optimum temperature level for the three examined insecticides was 30°C. Both oxidase and esterase inhibitors, when mixed with deltamethrin, increased the toxicity values in darkness and light. Moreover, modification of deltamethrin toxicity by temperature, light exposure and inhibitors resulted in an increase in the toxicity, thus reducing insecticide quantities required and minimizing environment pressures. Finally, to obtain the optimum efficacy it is suggested that the blend deltamethrin + chlorpyrifos-methyl + PB should be used at 30°C under light condition to protect stored products warehouses from *T. castaneum* infestation.

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