Türk. entomol. derg., 2013, 37 (1): 57-64
ISSN 1010-6960

Orijinal araştırma (Original article)

Toxicity of carbon dioxide to different developmental stages of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) and *Trichogramma embryophagum* Hartig (Hymenoptera: Trichogrammatidae)

Ephestia kuehniella Zeller (Lepidoptera: Pyralidae) ve *Trichogramma embryophagum* Hartig (Hymenoptera: Trichogrammatidae)'un farklı gelişme evrelerine karşı karbon dioksitin toksik etkisi

Dilek PANDIR[1*] Fahriye SÜMER ERCAN[1] Hatice BAŞ[1]

Summary

The use of carbon dioxide (CO_2) is a very effective method for controlling insect pests. The effects of CO_2 on developmental stages of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) and *Trichogramma embryophagum* Hartig (Hymenoptera: Trichogrammatidae) were determined in this study. We aimed to establish a technique that can be used for controlling the stored-product pest, *E. kuehniella* with a natural enemy, *T. embryophagum*. Egg, larva, pupa and adult stages of *E. kuehniella* and *T. embryophagum* were exposed to 0, 10 and 20% CO_2 gases in a CO_2 incubator at 27 ^{o}C and atmospheric pressure for different exposure times. The adult stage of *E. kuehniella* was more sensitive than its egg, larva and pupa in either percentage of CO_2 or increasing exposure time. But the adult of *T. embryophagum* was the most sensitive stage at only highest dose of CO_2. On the other hand the larvae of *T. embryophagum* were the most resistant stage at 10% CO_2. Consequently, the developmental stages of two insect species had different susceptibility to increasing percentage of CO_2. These results suggest that a low percentage of CO_2 may be used with *T. embryophagum* for controlling the stored-product pest, *E. kuehniella*.

Key words: Carbon dioxide, *Ephestia kuehniella*, *Trichogramma embryophagum*, developmental stages

Özet

Zararlı böceklerin kontrolünde karbon dioksit (CO_2) kullanımı oldukça etkili bir yöntemdir. Bu çalışmada *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) ve *Trichogramma embryophagum* Hartig (Hymenoptera: Trichogrammatidae)'un gelişim evreleri üzerine CO_2'in etkisi belirlenmiştir. Depolanmış ürün zararlısı *E. kuehniella'nın* kontrolü için doğal düşman *T. embryophagum* ile birlikte kullanılacak bir yöntem geliştirilmesi amaçlanmıştır. *E. kuehniella* ve *T. embryophagum'un* yumurta, larva pupa ve ergin evreleri CO_2 inkübatörü içerisinde 27 ^{o}C ve atmosferik basınç altında değişik uygulama sürelerinde % 0, 10 ve 20'lik CO_2 gazına maruz bırakılmıştır. Artan uygulama süresinde ve her iki CO_2 konsantrasyonunda *E. kuehniella'nın* ergin evresi yumurta, larva ve pupadan daha duyarlıdır. Fakat *T. embryophagum* için sadece en yüksek CO_2 dozunda en duyarlı evre ergin evredir. Diğer taraftan %10 CO_2 uygulamasında *T. embryophagum'*un larva evresi en dirençli evredir. Sonuç olarak, artan CO_2 konsantrasyonuna karşı farklı iki böcek türünün gelişim evreleri farklı duyarlılığa sahiptir. Bu sonuçlar depolanmış ürün zararlısı *E. kuehniella'nın* kontrolü için düşük CO_2 dozunun *T. embryophagum*'la birlikte kullanılabileceğini göstermektedir.

Anahtar sözcükler: Karbon dioksit, *Ephestia kuehniella*, *Trichogramma embryophagum*, gelişim evreleri

[1] Bozok University, Faculty of Arts and Science, Department of Biology, 66100 Divanliyolu/Yozgat, Turkey
* Sorumlu yazar (Corresponding author) e-mail: durak77@gmail.com
Alınış (Received): 06.07.2012 Kabul ediliş (Accepted): 02.11.2012

Introduction

Food industries preserve stored dried and desiccated fruit, ingredients of many confectionery against foodstuff pests (Locatelli et al., 1999). *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) is the most ruinous pest in stored products. Control of serious pests by using chemical insecticides such as malathion, dichlorvos and methyl bromide have disadvanteges because of their destructive environmental effects, including depletion of atmospheric ozone, development of resistance in insects and disruption of the food chain (Tuncbilek et al., 2009, Azizoglu et al., 2011). Therefore, many studies on stored product pests have focused on improving biological control strategies (Hodges, 1999). The egg parasitoid, *Trichogramma* genus, is used worldwide in biological control against insect pests (Schöller & Fields, 2002). At the same time, environmentally friendly techniques such as aromatic plant extracts and carbon dioxide (CO_2) treatments that do not leave any pesticide residues in stored products have been used against pests as an alternative method (AliNiazee & Lindgren, 1970; Wang et al., 2009; Bachrouch et al., 2010; Razavi, 2012). For the successful control of insect pests, the usage of a combination of effective and safe methods is preferred in an integrated pest management program.

CO_2 has toxic effects on different developmental stages and age-groups of insects. Many researchers have determined the toxic effects of CO_2 according to exposure time to kill the insects (Adler, 1999; Gunasekaran & Rajendran, 2005). Furthermore, CO_2 was used as an anesthetic against insects in many studies although the precise control mechanism was not known (Valles & Koehler, 1994). CO_2 has been known as an environmentally friendly technique for control of stored-product insects with no residue in food for a long time (Jayas et al., 1991).

In *Tribolium casteneum* Herbst (Coleoptera: Tenebrionidae), *T. confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) and *Plodia interpunctella* Hubner (Lepidoptera: Phycitidae), a high CO_2 concentration caused the reduction of egg production and hatchability (AliNiazee & Lindgren, 1970; Lum & Flaherty, 1972). In another study, a complete kill of *P. interpunctella* eggs was obtained at 25 ^{o}C and 20 bar CO_2 (Reichmuth & Wohlgemuth, 1994). *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) adults were the most sensitive stage for CO_2 treatments at different high pressures (bar) and exposure times (Noomhorm et al., 2009). Prozell & Reichmuth (2001) reported 100% mortality for *S. granarius* (Linnaeus) (Coleoptera: Dryophthoridae) and *Stegobium paniceum* (Linnaeus) (Coleoptera: Anobiidae) at 15-20 bar CO_2 up to 15 ^{o}C. Furthermore, Wang et al. (2009) stated that the application of different levels of CO_2 is expensive in a long treatment period but 10-30% CO_2 combination with another potential fumigants has been researched in several laboratories in the world for disinfestation technology.

Some researchers have evaluated the combination of different high pressures and chemicals with CO_2 against all life stages of many insects (Prozell & Reichmuth, 1990; Nakakita & Kawashima, 1994; Prozell & Reichmuth, 2001). The objective of present study was to determine the efficiacy of CO_2 against *E. kuehniella*, a serious pest of many stored products, and its effects on the non-target egg parasitoid, *T. embryophagum.* For that purpose, different developmental stages of *E. kuehniella* and *T. embryophagum* were exposed to different concentrations of CO_2 in a CO_2 incubator at atmospheric pressure at different times.

Materials and Methods

Test insects

Tests were applied to different life stages of the flour moth, *E. kuehniella* and its egg parasitoid, *T. embryophagum,* which were obtained from the Biological Control Research Station, Adana. All stages of *E. kuehniella* were obtained from cultures reared at 27 ± 1 ºC and 70 ± 5 % r.h. under a light regime of

14 h light, followed by 10 h darkness (14 h L:10 h D), and a diet of one kg wheat flour and 5% yeast, using standard culture techniques (Donahaye,1990). Larvae [15-day-old young larval instars (third instar)], pupae (1-day-old) and adults (24-h-old) were collected from prepared cultures. Eggs were obtained daily from the plastic jars with a 250-µm mesh sieve. Eggs, larvae, pupae and adults of *E. kuehniella* were treated with 0, 10 and 20% CO_2 doses for 24, 48, 72 and 96 h at atmospheric pressure. Each replicate consisted of 10 adults, larvae or pupae, or 100 eggs, for each dose and exposure time of CO_2 and each treatment was replicated six times.

For tests with *T. embryophagum,* 50 eggs of *E. kuehniella* were used as hosts. Twenty hours old *T. embryophagum* adults were used for parasitization. Tests were carried out under laboratory conditions which were set at 24 ± 1 ºC and 70 ± 5% r.h. and under a light regime of 14 h L:10 h D. Eggs (1 day after parasitization), larvae (3 days after parasitization), pupae (6 days after parasitization) (Knutson, 1998) and adults (24 h old) were collected from prepared cultures. Immediately after they were obtained, the eggs, larvae, pupae and adult stages of *T. embryophagum* were exposed to doses of 0, 10 or 20% CO_2, according to their different life stages. Each replicate consisted of 10 adults, or 50 eggs, larvae or pupae for each dose and exposure time of CO_2 and each treatment was replicated six times.

Fumigation procedure

The CO_2 incubator (Hera Cell 150) was used for fumigation with different doses of CO_2. After fumigation, the exposed adults, larvae and pupae of *E. kuehniella* were immediately transferred into 50 mL glass jars, and maintained at 27 ± 1 ºC and 70 ± 5 % r.h. Wheat flour and yeast were added as food into the glass jar containing exposed larvae. Eggs of *E. kuehniella* were transferred to test tubes and incubated under the same conditions. In order to determine the mortalities for each dose and exposure time, each stage of *E. kuehniella* was evaluated for failure to progress to the following stage (larva to pupa, pupa to adult and egg hatchability). For *T. embryophagum,* ten adults exposed to 0, 10 or 20% CO_2 for each exposure time (24, 48, 72 or 96 h) were transferred to test tubes and *E. kuehniella* eggs were provided for parasitization. The control groups were under the same conditions but without CO_2 exposure. Moribund adults were recorded as dead. Eggs of *T. embryophagum* were exposed to 0, 10 and 20% CO_2 for 24 h and then adult emergence was recorded. Fifty larvae of *T. embryophagum* were treated with 0, 10 or 20% CO_2 for 24, 48 or 72 h. For pupae of *T. embryophagum,* the same concentrations of CO_2 were used for different exposure times (24, 48, 72 and 96 h).

Data analysis

One-way analysis of variance (ANOVA) ($p<0.05$) in the SPSS 10.0 software package was used to compare the mortality values for different life stages of insects, followed by Tukey's procedure for multiple comparisons (SPSS, 2001).

Results

The percentage mortality of different stages of *E. kuehniella* and *T. embryophagum* exposed to CO_2 at different doses and exposure times are shown in Figs 1-2 and Tables 1-2; 94% mortality of *E. kuehniella* adults was obtained at 20% CO_2 for 96 h, while 95.83% mortality of *T. embryophagum* adults was achieved at 20% CO_2 for 96 h. On the other hand, there are not significantly differences between 24-96 h exposure times at 10% CO_2 for adults of *T. embryophagum.*

Mortality significantly increased with increasing exposure time for the adult stage of *E. kuehniella* (for 10% CO_2; $F= 67.9$ $df= 4$ $p<0.05$; for 20% CO_2; $F= 100.3$ $df= 4$ $p<0.05$) and *T. embryophagum* (only for 20% CO_2; $F= 2805.9$ $df= 4$ $p<0.05$).

Table 1. Mean percentage mortality of different stages of *Trichogramma embryophagum* exposed to 10% CO_2. Different letters above numbers indicate significant differences between exposure times. Numbers with the same letter are not significantly different. The ages (hour and days) of different stages were as follows: eggs, 1 day after parasitization; larvae, 3 days after parasitization; pupae, 6 days after parasitization; adult 24 h old.

Exposure Time	Stage			
(h)	Egg	Larvae	Pupae	Adult
Control	3.5±1.52	4.67±1.21^{a}	4.83±0.98^{a}	3.83±1.33^{a}
24	15.67±2.58	5.33±1.51^{a}	5.33±1.21^{a}	7±0.89^{b}
48	-	5.83±1.17^{a}	15.17±2.48^{b}	7.67±0.82^{b}
72	-	6.17±1.60^{a}	49.33±3.56^{c}	8±1.41^{b}
96	-	-	80.17±3.71^{d}	8.5±2.07^{b}

Table 2. Mean percentage mortality of different stages of *Trichogramma embryophagum* exposed to 20% CO_2. Different letters above numbers indicate significant differences between exposure times. Numbers with the same letter are not significantly different. The ages (hour and days) of different stages were as follows: eggs, 1 day after parasitization; larvae, 3 days after parasitization; pupae, 6 days after parasitization; adult 24h old.

Exposure Time	Stage			
(h)	Egg	Larvae	Pupae	Adult
Control	1.83±0.75	2.,67±0.82^{a}	4.67±1.21^{a}	4.17±0.75^{a}
24	28.33±3.88	3.5±1.049^{a}	25.33±2.50^{b}	4.5±1.05^{a}
48	-	4.16±1.17^{a}	30.33±4.50^{b}	79.17±3.06^{b}
72	-	37.5±2.95^{b}	69.5±3.78^{c}	93±2.37^{c}
96	-	-	95±3.22^{d}	95.83±2.64^{c}

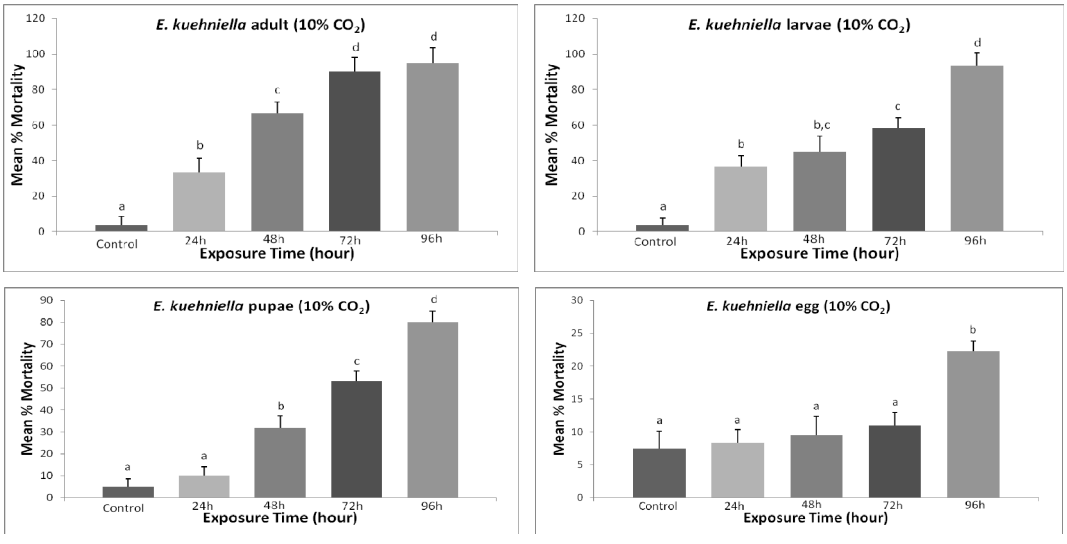

Figure 1. Mean percentage mortality of different stages of *Ephestia kuehniella* exposed to 10% CO_2. Different letters above bars indicate significant differences between exposure times; bars with the same letter are not significantly different. Error bars indicate SD of means.

The toxicity of CO_2 to the egg stage of *E. kuehniella* is shown in Figs 1-2. Twenty three percent and 59% mortality were obtained at 10 and 20% CO_2 for 96 h, respectively. Compared with the control, *E. kuehniella* eggs treated with 10% CO_2 only for 96 h had significantly reduced egg hatching. There were also significant differences between exposure times for 10% and 20% CO_2 (for 10% CO_2; F= 25.6 df= 4

p<0.05; for 20% CO_2; F= 352.8 df= 4 p<0.05). The egg of *E. kuehniella* was the most tolerant stage for each dose of CO_2 but *T. embryophagum* eggs reached the larval stage after 24 h exposed each dose of CO_2 (Tables 1-2).

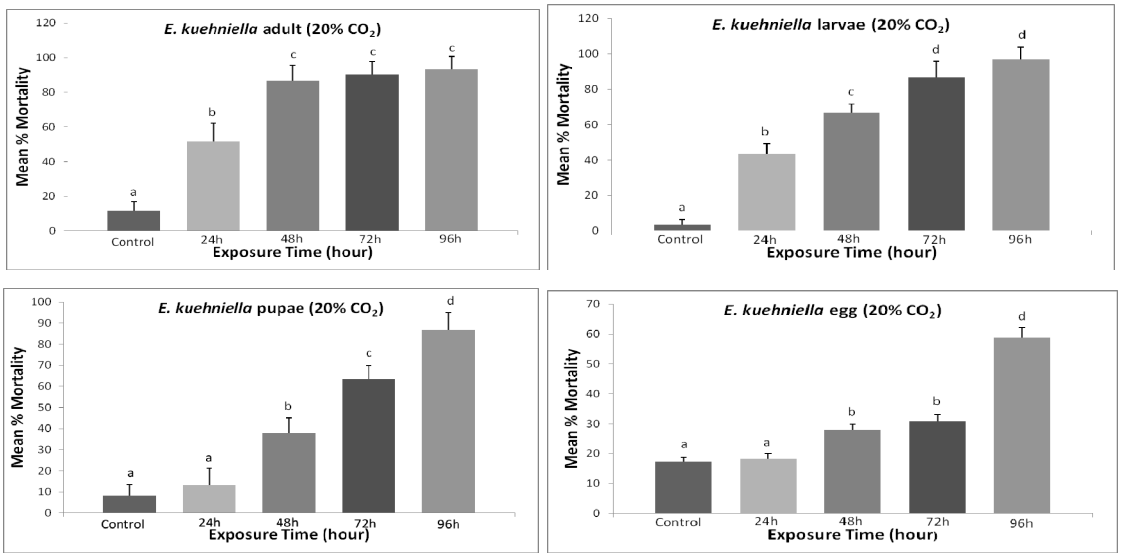

Figure 2. Mean percentage mortality of different stages of *Ephestia kuehniella* exposed to 20% CO_2. Letters above bars indicate significant differences between exposure times; bars with the same letter are not significantly different. Error bars indicate SD of means.

Ephestia kuehniella larvae were killed at 10% and 20% CO_2 for 96 h but in *T. embryophagum* larvae, there were no significant differences between exposure times at 10% CO_2 treatment (F=1.333 df= 3 p≤0.292). The larvae of *T. embryophagum* were the most resistant stage at this concentration.

Pupae of *E. kuehniella* were more tolerant than larvae and adults at 10 and 20% CO_2. At 10% and 20% CO_2, there was a significant difference between 24-96 h exposure, and the contol group was not significantly different from the 24 h application groups at 10 and 20% CO_2 (for 10% CO_2; F= 52.7 df= 4 p<0.05; for 20% CO_2; F= 39.8 df= 4 p<0.05). *T. embryophagum* pupae did not reach the adult stage at 20% CO_2 for 96 h.

Discussion

Carbon dioxide is one of the gases in the atmosphere, being uniformly distributed over the earth's surface at a concentration of about 0.033% or 330 ppm. It plays an important role in plant and animal metabolic processes, such as photosynthesis and respiration. Also, this gas was used as an alternative control method for disinfestation of stored-products because of its toxic effect on insects and environmentally safety properties (Nicolas & Sillans, 1989). Bailey (1965) found that most stored-product insects were killed by <3% O_2 or >40% CO_2 and that CO_2 required several days exposure for different species of insects at different growth stages. In another study, development of most tested insect eggs was prevented by using high pressure (20 bar) CO_2. In the same study, adults of *Rhyzopertha dominica* Fabricius (Coleoptera: Bostrichidae) and *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae) were all killed at 20 bar pressure CO_2 treatment (Riudavets et al., 2010). Sabio et al. (2001) applied metyhl bromide in combination with 0, 10 and 20% CO_2 to control *E. cautella* Walker (Lepidoptera: Pyralidae) and they revealed that this application technique decreases the methyl bromide amount and also decreases its emission that is harmful to the environment. In the present study, the same concentrations of CO_2 were used to treat developmental stages of stored-product pest *E. kuehniella* and its egg parasitoid, *T. embryophagum.*

The response of different stored-grain pests to CO_2 differs. The most tolerant stored-product insect to a CO_2 rich atmosphere (>40% CO_2) was *Sitophilus oryzae* Linnaeus (Coleoptera: Curculionidae) (Annis, 1986). In another study, 100% mortality was obtained for *S. zeamais* in a shorter time than that for *S. oryzae* (Annis & Morton, 1997). Variations in CO_2 tolerance of different insects may result from usage of different techniques (Noomhorm et al., 2009). Also, the time required to kill insect pests is varies for the species and its life stages. In the present study, different CO_2 concentrations (0, 10 and 20% CO_2) and exposure times (24, 48, 72 and 96 h at atmospheric pressure) were applied to all developmental stages of *E. kuehniella* and *T. embryophagum.* Lum & Flaherly (1972) reported that high CO_2 concentration reduced the egg production and hatchability of *Plodia interpunctella* (Lepidoptera: Phycitidae). In the present study, egg hatchability of *E. kuehniella* was started reducing at 10% CO_2 for 96 h exposure and 20% CO_2 for 48 h exposure. For 24 h exposure, egg hatchability was slightly reduced when compared with the control for each CO_2 concentration.

Carbon dioxide has efficacy against ethological, biological, physiological and metabolic properities of insects (Nicolas & Sillans, 1989) and all living creatures showed different resistance to high CO_2 (Annis, 1986). However, there are many unknown mechanisms of the action of CO_2 against insects. CO_2 causes a lethal decrease in the pH of hemolymph (Stahl et al., 1985; Gerard et al., 1988; Reichmuth, 1991) and destruction of cell membranes and organs due to its expansion in gas bubbles (Ulrichs & Reichmuth, 1997). This physiological action of CO_2 may vary according to the different developmental stages of the insects. *E. kuehniella* was reported to be more sensitive than most of other pest species tested at 20 bar high pressure CO_2 for 15 min (Riudavets et al., 2010). This study showed that adults of both *E. kuehniella* and *T. embryophagum* were more sensitive than their immature stages at 20% CO_2.

Bell (1976) showed that the egg was the most tolerant developmental stage of 4 species, *E. elutella* Hübner (Lepidoptera: Pyralidae), *E. kuehniella*, *E. cautella* Walker (Lepidoptera: Pyralidae) and *P. interpunctella* tested against phosphine. Similarly, in the present study, the egg stage of *E. kuehniella* was the most resistant stage against CO_2 for all exposure times. For *T. embryophagum* adults, 8.5% mortality was observed at 10% CO_2 for 96 h exposure in present study. But after 10% CO_2 treatment we look at the parasitization capacity of survivor *T. embryophagum* adults, parasitization was not observed for them. The highest mortality of *T. embryophagum* adults was obtained at 20% CO_2 for 72 and 96 h.

Use of chemical insecticides effectively reduces pest populations but leaves environmental residues. Many studies showed that CO_2 gas is a potentially efficacious insecticide in stored products and with no pesticides residues (Jayas et al., 1991; White & Jayas, 1991; Wang et al., 2009). At the same time, different insect species and developmental stages have different susceptibilities to increasing CO_2 concentration. Determination of the required exposure time and concentration of CO_2 and its effects on natural enemies is very important for any control program.

In conclusion, it may be possible to effectively use CO_2 as a part of an integrated pest management (IPM) program after the release of *Trichogramma* or alternatively a low percentage of CO_2 may be used with the egg parasitoid for controlling *E. kuehniella*. Therefore, it may also be worthwhile to investigate the use of CO_2 gas with the egg parasitoid for the control of other stored-product pests. This study showed that fumigant toxicity of CO_2 varied with different developmental stages of tested insects.

Acknowledgements

The authors would like to thank Ms. Sevcan Oztemiz (Biological Control Research Station, Adana, Turkey) for supplying the *Trichogramma embryophagum* and *Ephestia kuehniella* used in the experiments.

References

Adler, C., 1999. ‘‘Efficacy of modified atmospheres against diapausing larvae of the Indian Meal moth Plodia interpunctella (Hübner) (Lepidoptera: Pyralidae), 685-691’’. Proceedings of the 7th International Working Conference on Stored-Product Protection (14-19 October 1998, Beijing, China), 1998 pp.

AliNiazee, M. T. & D. L. Lindgren, 1970. Egg hatch of *Tribolium confusum* and *T. castaneum* (Coleoptera: Tenebrionidae) in different carbon dioxide and nitrogen atmospheres. Annals of the Entomological Society of America, 63 (4): 1010–1012.

Annis, P. C., 1986. ‘‘Towards rational controlled atmosphere dosage schedules: a review of current knowledge, 128-148’’. Proceedings of the Fourth International Working Conference on Stored-product Protection (21–26 September 1986, Tel Aviv, Israel), 668 pp.

Annis, P. C. & R. Morton, 1997. The acute mortality effects of carbon dioxide atmosphere on staling and water relations in bread. Journal of Food Science, 55:413-416.

Azizoglu, U., S. Yılmaz, S. Karaborklu & A. Ayvaz, 2011. Ovicidal activity of microwave and UV radiations on Mediterranean flour moth *Ephestia kuehniella* Zeller, 1879 (Lepidoptera: Pyralidae). Turkish Journal of Entomology, 35 (3): 437-446.

Bachrouch, O., J. M. B. Jemaa, I. Chaieb, T. Talou & B. Marzouk, 2010. Insecticidal activity of *Pistacia lentiscus* essential oil on *Tribolium castaneum* (Coleoptera: Tenebrionidae) as alternative to chemical control in storage. Tunisian Journal of Plant Protect, 5: 63-70.

Bailey, S. W., 1965. Air-tight storage of grain; its effect on insect pest-IV *Rhyzoperta dominica* (F.) and some other Coleoptera that infested stored grain. Journal of Stored Products Research, 1: 25-33.

Bell, C. H., 1976. The tolerance of developmental stages of four stored product moths to phosphine. Journal of Stored Products Research, 12: 77-86.

Donahaye, E., 1990. Laboratory selection for resistance by the red flour beetle *Tribolium castaneum* (Herbst) to an atmosphere of low oxygen concentration. Phytoparasitica, 18: 189-202.

Gerard, D., J. Kraus, K.V. Qumn & R. Wohlgemuth, 1988. Anwendung von Kohlendioxid (CCh) unter Druck zur Bekampfung vorratsschadlicher Insekten und Milben. Pharrnazeutische Industne, 50:1298-1300.

Gunasekaran, N. & S. Rajendran, 2005. Toxicity of carbondioxide to drugstore beetle *Stegobium paniceum* and cigarette beetle, *Lasioderma serricorne*. Journal of Stored Products Research, 41(3): 283-294.

Hodges, R. J., 1999. ‘‘Biological control methods for insect pests of stored grain in the tropics-constraints and prospects for developing countries, 1193-1204’’. Proceedings of the 7th International Working Conference of Stored-Product Protection (14-19 October 1998, Beijing, China), 1998 pp.

Jayas, D. S., B. Khangura & N. D. G. White, 1991. Controlled atmosphere storage of grains. Postharvest News and Information, 2: 423–427.

Knutson, A., 1998. The *Trichogramma* manual, Agricultural communication, The Texas A&M University System, Texas. 42 pp.

Locatelli D. P., L. Suss & M. Frati, 1999. ‘‘The use of high pressure carbon dioxide (20 bar) to control some insects of foodstuff, 671-675’’. Proceedings of the 7th International Working Conference of Stored-Product Protection (14-19 October 1998, Beijing, China), 1998 pp.

Lum, P. T. M. & B. R. Flaherty, 1972. Effect of carbon dioxide on production and hatchability of eggs of *Plodia interpunctella* (Lepidoptera: Phycitidae). Annals of the Entomological Society of America, 65: 976-977.

Nakakita, H. & Kawashima, K., 1994. ‘‘A new method to control stored product insects using carbon dioxide with high pressure followed by sudden pressure loss, 126-129’’. Proceedings 6th International Working Conference on Stored-Product Protection (17-23 April 1994, Canberra, Australia), 1274 pp.

Nicolas, G. & D. Sillans, 1989. Immmediate and latent effects of carbon dioxide on insects. Annual Review of Entomology, 34: 97-116.

Noomhorm, A., P. Sirisoontaralak, J. Uraichuen & I. Ahmad, 2009. Effects of pressurized carbon dioxide on controlling *Sitophilus zeamais* (Coleoptera: Curculionidae) and the quality of milled rice. Journal of Stored Products Research, 45 (3): 201-205.

Prozell, S., & C., Reichmuth, 1990. Wirkung von Kohlendioxid unter Hochdruck auf den Kornkäfer *Sitophilus granarius* (L.) [Effect of carbon dioxide under high pressure on the granary weevil *Sitophilus granarius* (L.). *Mitteilungen der Deutschen Phytomedizinischen Gesellschaft,* 20, 14.

Prozell, S. & C. Reichmuth, 2001. ''Carbon dioxide under high pressure for stored-product protection in temperate climates, 719-725''. Proceedings International Conference Controlled Atmosphere and Fumigation in Stored Products (29 October - 3 November 2000, Fresno, USA) 841 pp.

Razavi, S. M., 2012. Chemical composition and some allelopathic aspects of essential oils of (*Prangos ferulacea* L.) Lindl at different stages of growth. Journal of Agricultural Science and Technology, 14: 349-356.

Reichmuth, C., 1991. ''New techniques in fumigation research today, 709-724''. Proceedings 5th International Working Conference on Stored-Product Protection (9-14 September 1990, Bordeaux, France), 2064 pp.

Reichmuth, C. & R. Wohlgemuth, 1994. ''Carbon dioxide under high pressure of 15 bar and 20 bar to control the eggs of the Indianmeal moth *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) as the most tolerant stage at 25°C, 63-172''. Proceedings of the 6th International Working Conference on Stored Product Protection (17-23 April 1994, Canberra, Australia) 1274 pp.

Riudavets, J., C. Castañé, O. Alomar, M. J. Pons & R. Gabarra, 2010. The use of carbon dioxide at high pressure to control nine stored-product pests. Journal of Stored Products Research, 46: 228-233.

Sabio, G., S. Navarro, J.E. Donahaye, M. Rindner, A. Azrieli & R. Dias, 2001. ''Control of *Ephestia cautella* with low levels of methyl bromide and carbon dioxide gas mixtures, 113-117''. Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products (29 October-3 November 2000, Fresno, USA) 841 pp.

Schöller, M. & P. Fields, 2002. ''Screening of North American species of *Trichogramma* Westwood (Hymenoptera: Trichogrammatidae) for control of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), 1-10''. Proceedings of the Eighth International Working Conference of Stored-Product Protection (22-26 July 2002, York, United Kingdom). 1071 pp.

SPSS., 2001. SPSS version 10.0.SPSS Inc, 233 S.Wacker Drive, Chicago, Illinois.

Stahl, E., G. Rau & H. Adolphi, 1985. Entwesung von Drogen durch Kohlendioxide-druchbehandlung. Pharmazeutische Industne, 47:528-530.

Tuncbilek, A. S., U. Canpolat & F. Sumer, 2009. Suitability of irradiated and cold-stored eggs of *Ephestia kuehniella* (Pyralidae: Lepidoptera) and *Sitotroga cerealella* (Gelechidae: Lepidoptera) for stockpiling the egg-parasitoid *Trichogramma evanescens* (Trichogrammatidae: Hymenoptera) in diapause. Biocontrol Science and Technology, 19 (1):127-138.

Ulrichs, C. & C. Reichmuth, 1997. Emfluss physikalischere Parameter auf die Bekampfung des Tabakkafers *Lasioderma serricorne* Fab. (Col.: Anobudae) mit Kohlenstoffdioxid unter Hochdruck. Anzeiger fur Schadlmgskunde, 70:81–86.

Valles, S. M. & P.G. Koehler, 1994. Influence of Carbon Dioxide Anesthesia on Chlorpyrifos Toxicity in the German Cockroach (Dictyoptera: Blattellidae). Journal of Economic Entomology, 87(3): 709-713.

Wang, F., D. S. Jayas, N. D. G. White & P. Fields, 2009. Combined effect of carbon monoxide mixed with carbon dioxide in air on the mortality of stored-grain insects. Journal of Stored Products Research, 45:247-253.

White, N. D. G. & D. S. Jayas, 1991. Controll of insects and mites with carbon dioxide in wheat stored at cool temperatures in non-airtight bins. Journal of Economic Entomology, 84: 1933-1942.