

DIATOMACEOUS EARTH - AN INERT DUST FOR THE MANAGEMENT OF STORED GRAIN PESTS : A REVIEW

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ABSTRACT

Management of stored grain pests depends mostly on insecticides and fumigants. Alternative control methods of stored grain pests are being emphasized to reduce the application of insecticides and to decrease the development of insecticide resistant pests. The use of inert dust for management of stored grain pests is a technique with a long history. With the advent of synthetic chemicals, this method was neglected. However, the problems that chemical insecticides present today, such as control failures, residues in food, pest resistance, etc., are proportioning the return of this efficient method of control of stored grain pests. "Diatomaceous earth" - based inert dust derives from diatomaceous algae fossils, which naturally possesses a thin silica layer. Dust particles adhere to the insect's body by contact. Inert dust acts by removing the epicuticular wax, causing loss of water. Diatomaceous earth is persistent in its action, poses few or no pest resistance problems and it leaves no residue. The efficacy of Diatomaceous earth is affected by factors like its provenance, temperature, humidity and characteristics of target pests and substrate.

KEY WORDS: *Diatomaceous Earth, Management, Stored Grain Pests*

INTRODUCTION

Diatomaceous earth (DE) is a natural product mined from deposit of fossilized diatoms (Golob, 1997). Diatoms – a type of single-celled algae with microscopic, beautiful geometric shells made of silicon dioxide. Over millennia, diatoms accumulate in aquatic sediments as fossils that can be harvested and dried into a fine white dust. It is an inert dust harvested from sediments at the bottom of oceans, lakes and rivers around the globe.

According to Korunic (1998) there are two types of commercial deposits:

1. Marine DE found on the continental margins, and
2. Freshwater DE from diatoms from lakes or marshes

Storage of agricultural produce is a part of the post-harvest system through which agricultural products pass on its way from field to consumer. It is generally accepted that 5-15 per cent of the total weight of all cereals, oilseeds and pulses is lost after harvest. There is a continuous need to protect the stored products against deterioration, especially loss of quality and weight during storage (Mohale *et al.*, 2010). Synthetic insecticides have been used since

1950s to control stored-products insects (Subramanyam and Hagstrum, 1995). However, because of increasing concern over...

- Worker exposure to insecticide,
- Development of resistant populations,
- Pesticide residues in human and animal food and
- Environmental consequences

Alternative methods are needed to be developed to control stored-products pests. As an alternative to chemical control, inert dust has been increasingly used and recognized as an essential component of IPM in stored-products (Korunic, 1999).

Mode of action of DE

- ✓ Purely physical.
- ✓ DE particles adhere to the insect cuticle and absorb epicuticular lipids, causing death by desiccation (Korunic, 1998).
- ✓ According to Subramanyam and Roesli (2000), the action of DE attributed to the desiccation caused by adsorption and abrasive properties that breaks the epicuticular wax layer, causing loss of body water and death within hours or days.
- ✓ The dust interferes with water transpiration by absorption of cuticular lipid and causes desiccation (Korunic, 1998).
- ✓ It has been postulated that insects will not be selected genetically by the action of these dust for genetic resistance as DE is not come in to the metabolic pathway (Mohale *et al.*, 2010).

Other theories proposed are....

- ✓ Surface enlargement of the integument following dehydration
- ✓ Impairment of the digestive tract
- ✓ Blockage of stigmata and trachea
- ✓ Absorption of cuticle lipids, and/or
- ✓ Damage to the protective wax layer

Advantages

- ✓ Since only a physical method is involved, genetic resistance is unlikely

- ✓ Low mammalian toxicity
- ✓ Stable on grain
- ✓ Provide long term protection
- ✓ Do not leave residue

Limitations

- ✓ Reduction in the bulk density and flowability of grains
- ✓ Dusty to apply
- ✓ Reduction in efficacy at high moisture content
- ✓ Unlike a fumigant, it will not control the immature stages that remain within the grain kernel

Insecticidal qualities of DE

Insecticidal DE should be...

- ✓ Highly pure amorphous silica
- ✓ Having particles of equal diameter (< 10 µm)
- ✓ pH < 8.5, containing the least possible number of clay particles
- ✓ Less than 1% crystalline silica

Factors affecting efficacy of DE

Temperature

The insects have higher respiration rates at higher temperatures (Cotton, 1932) and consequently the greater water loss via spiracles promoting desiccation (Zachariassen, 1991). Several studies indicated that DE is more effective at higher temperature (Fields and Korunic, 2000). Aldryhim (1990) observed that *Sitophilus oryzae* Linnaeus and *Rhizopertha dominica* Fabricius are more susceptible to DE at 30°C than at 20°C. For lesser grain borer, Aldryhim (1993) reported that mortality on different wheat classes treated with DE product Dryacide increased as temperature increased. Red flour beetle, *Tribolium castaneum* Herbst and confused flour beetle, *Tribolium confusum* DuVal exposed to Protect-It (DE) (5 g/m²), mortality of both species increased from 22 to 27 and then 32°C (Arthur, 2000).

Humidity

Generally at high relative humidity, insects can moderate the water loss, which

increases survival even after exposure to a DE treated substrate (Korunic, 1998). Aldryhim (1990) observed a decrease in activity of silica dust toward *T. confusum* adults with an increase in relative humidity from 40 to 60 per cent. Arthur (2000) reported a decrease in the efficacy of DE against red flour beetle adult as relative humidity increased from 40 to 75 per cent. Efficacy of DE against adult *S. granaries* (Mewis and Ulrich, 2001) and *Oryzaephilus surinamensis* Linnaeus (Arthur, 2001) and larval *Ephestia kuehniella* Zeller (Nielsen, 1998) decreased with increased relative humidity. Stathers *et al.* (2004) found that an increase in relative humidity level from 50 to 60 per cent significantly decreased the effectiveness of Protect-It (DE) and Dryacide (DE) against *Pericoptus truncates* Fabricius.

Grain type

Chanbang *et al.* (2007) determined effectiveness of two DE formulations against lesser grain borer (*R. dominica*). The results showed that although these two DE formulations had given good control of lesser grain borer in stored wheat, they were not as effective in paddy. Athanassiou *et al.* (2008) evaluated the efficacy of three DE formulations, PyriSec (DE), Protect-It (DE) and DEBBM against *S. oryzae* reared on wheat, barley and maize and found maize reared insects to be most susceptible.

Target species

Moth larvae are considered less susceptible to DE than beetle larvae (Desmarchelier and Dines, 1987). When comparing the efficacy of DE Protect-It and Dryacide (DE) against *P. truncates* and *S. zeamais*, Stathers (2003) reported that these DE were very effective against *S. zeamais*, but for *P. truncatus*, parental survival and progeny production were high. *T. confusum* adults could also survive exposure to SilicoSec (DE) at dose rates that caused 100

per cent mortality to *S. oryzae* adults at the same condition (Athanassiou *et al.*, 2005).

Life stage

Difference in the epicuticular morphology and composition among instars may be responsible for differences in the rate of water loss (Hadley, 1994). Mewis and Ulrichs (2001) found that first instars of *Plodia interpunctella* Hubner were very sensitive to the DE than older ones. Vayias and Athanassiou (2004) exposed young larvae (1-3 instars) and old larvae (4-7 instars) of *T. castaneum* to SilicoSec® and stated that after 24 h of exposure to DE, approximately 61 per cent of young larvae were dead, while the respective mortality for old larvae was only 26 per cent. The adults of *Tyrophagus putrescentiae* Schrank (Storage mite) were more tolerant to DE than the immature stages (Iatrou *et al.*, 2010).

Exposure interval

Studies show that short exposure interval of 1 to 2 day may not give satisfactory mortality, longer exposure period is required for complete mortality (Athanassiou *et al.*, 2005). Vrba *et al.* (1983) exposed *T. confusum* for 1, 2, 3 and 5 h to DE and demonstrated increase in mortality with increased exposure interval. Lorini and Beckel (2006) recorded 100 per cent mortality of *T. castaneum* following 20 days exposure to wheat treated with Keepdry® (DE). Mortality of *T. castaneum* on wheat treated with SilicoSec® increases with exposure time (Shayesteh and Ziaee, 2007).

Depth of DE treatment

Varedman *et al.* (2006) studied effect of depth of DE treated wheat on the per cent survival of lesser grain borer. The result showed that there is a positive relationship between depth and mortality. As the depth of DE increased, the percentage mortality also increased.

Insect strain

Rigaux *et al.* (2001) reported that different strains of *T. castaneum* collected from different parts of the world had different level of susceptibility to DE formulation Protect-It. The DENMARK, UK and GERMANY strains of *T. castaneum* were significantly more susceptible than ITALY and PORTUGAL. PORTUGAL proved to be significantly more tolerant than rest of treatments (Vayias *et al.*, 2006).

Particle size

Ideally, active DE should have high amorphous silicon dioxide content with a uniform particle size (less than 10 µm in diameter) (Quarles, 1992). Protect-It and INSECTO were the most efficient formulations for managing *T. castaneum*. The high efficiency of Protect-It could be explained by the size of its particle, almost equal to INSECTO and smaller than the other two (PermaGuard and Dryacide) tested. It was observed that the biological activity of the DE increased significantly with reduced particle size (Arnaud *et al.*, 2003).

Dose rate

Cristina *et al.* (2008) studied mean mortality (%) of *S. zeamais* in stored corn at different doses of DE and revealed that as the dose increased the percentage mortality also increased.

DE for management of stored grain pests

Tests on Drayacide® for stored-product protection found that population of the rice weevil, lesser grain borer and red flour beetle showed 100 per cent mortality with use of 1000 ppm at 65 per cent RH and 20°C (Desmarchelier and Dines, 1987). Subramanyam *et al.* (1998) reported 96 per cent mortality of first instar of *T. castaneum* after 21 days when INSECTO was applied to shelled maize at the rate of 125 and 250 mg/kg. Varedman *et al.* (2007) reported the highest mortality of *R. dominica* in wheat with Dryacide® followed by Protect-It® and

Insecto®. Survival and progeny production of *R. dominica* was lower in Dryacide. Protect-It was more effective than SilicoSec against *C. maculatus*, while the reverse was true for *S. oryzae*. Further, the efficacy of DE could be improved by adding certain monoterpenoids against certain insect pests (Islam *et al.*, 2010).

DE in combination with other grain protectants

DE with microbial

Bio agents such as *Beauveria bassiana* and *Metarhizium anisopliae* are well known entomo-pathogen with a broad host range and regarded as safe biopesticide (Anon., 2000). The entomopathogenic fungi must adhere to, germinate on and penetrate through the host integument. Ebeling (1971) hypothesized that its efficacy may be improved in presence of other surface active agents. Lord (2001) found that amorphous silicon dioxide (DE) had a synergistic interaction with *B. bassiana* against some stored product pests. Vassilakos *et al.* (2006) stated that combination of *B. bassiana* and DE had an additive effect on fungal efficacy against *R. dominica* and *S. oryzae*. Mortality on wheat treated with *Paecilomyces fumosoroseus* with SilicoSec was significantly higher than SilicoSec or *P. fumosoroseus* alone (Michalaki *et al.*, 2007). The addition of DE increased the attachment by fluorescent conidia of *B. bassiana* on *T. confusum* and *S. oryzae* (Stephou *et al.*, 2012).

DE with insecticide

The beta cyfluthrin and SilicoSec (DE) significantly reduced the progeny production of *S. oryzae* in wheat as compared with beta cyfluthrin alone (Athanasios, 2006). Survival of *T. confusum* individuals decreased as the rate of DE increased at each dose of spinosad (0.01, 0.1 and 0.5 ppm) in maize and wheat (Vayias *et al.*, 2009). The greatest mortality of *R. dominica* was observed in a

combination of DE with thiomethoxam compared to DE alone (Wakil *et al.*, 2012).

DE with botanicals

Concentration of essential oil of garlic alone required for an effective treatment and the application rate of DE can be reduced when combined with each other. The results showed that the combination of treatments was significantly more effective than either treatment alone against *T. castaneum* (Yang and Liang, 2010).

DE with IGR

The insect growth regulator (IGR) methoprene can affect larval development (Arthur, 2001). There was an unexpected increase in the adult mortality of *R. dominica* in stored rough rice seeds treated with DE (Protect-It®) and methoprene (Chanbang *et al.*, 2007).

CONCLUSION

Diatomaceous earth (DE) is a natural product and physical in action for the management of stored product insect-pests. Due to its abrasive and absorptive properties, wax layer of insect cuticle is broken down and cause mortality due to desiccation. The efficacy of DE is attributed by the several factors. DE alone and in combination with microbials, synthetic insecticides, botanicals and IGR is found effective against stored product insect-pests.

REFERENCES

Aldryhim, Y. N. (1990). Efficacy of the amorphous silica dust, Dryacidae, against *Tribolium confusum* Duv. and *Sitophilus granaries* (L.) (Coleoptera; Tenebrionidae and Curculionidae) *J. Stored Prod. Res.*, **26**: 207-210.

Aldryhim, Y. N. (1993). Combination of classes of wheat and environmental factors affecting the efficacy of amorphous silica dust, Dryacide®, against *Rhyzopertha dominica* (F). *J. Stored Prod. Res.*, **29**: 271-275.

Anonymous (2000). [http:// www. .gov/ pesticides/biopesticidesfactsheets/fs128924t.htm](http://www.gov/pesticides/biopesticidesfactsheets/fs128924t.htm)

Arnaud, L.; Huong, T. T.; Brostaux, Y. and Haunrue, E. (2003). Efficacy of diatomaceous earth formulations admixed with grain against populations of *Tribolium castaneum*. *J. Stored Prod. Res.*, **41**: 121-130.

Arthur, F. H. (2000). Toxicity of diatomaceous earth to red flour beetles and confused flour beetles (Coleoptera: Tenebrionidae): Effects of temperature and relative humidity. *J. Econ. Ento.*, **93**: 526- 532.

Arthur, F. H. (2001). Immediate and delayed mortality of *Oryzaephilus surinamensis* (L.) exposed on wheat treated with diatomaceous earth: effects of temperature, relative humidity, and exposure interval. *J. Stored Prod. Res.*, **37**: 13-21.

Athanassiou, C. G. (2006). Toxicity of beta cyfluthrin applied alone or in combination with diatomaceous earth against adults of *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Tribolium confusum* DuVal (Coleoptera: Tenebrionidae) on stored wheat. *Crop Prot.*, **25**(8): 788-794.

Athanassiou, C. G. ; Vayias, B. J.; Dimizas, C. B.; Kavalliratos, N. G.; Papagregoriou, A. S. and Buchelos, C. T. (2005). Insecticidal efficacy of diatomaceous earth against *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Tribolium confusum* DuVal (Coleoptera: Tenebrionidae) on stored wheat: Influence of dose rate, temperature and exposure interval. *J. Stored Prod. Res.*, **41**: 47-55.

Athanassiou, C. G.; Kavalliratos, N. G.; Vayias, B. J. and Panoussakis, E. C. (2008). Influence of grain type on

- the susceptibility of different *Sitophilus oryzae* (L.) populations, obtained from different rearing media, to three diatomaceous earth formulations. *J. Stored Prod. Res.*, **44**(3): 279-284.
- Chanbang, Y.; Arthur, F. H.; Wilde, G. E. and Throne, J. E. (2007). Efficacy of diatomaceous earth and methoprene, alone and in combination, against *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) in rough rice. *J. Stored Prod. Res.*, **43**(4): 396-401.
- Cotton, R. T. (1932). The relation of respiratory metabolism of insects to their susceptibility to fumigants. *J. Economic Ento.*, **25**: 1088-1103.
- Cristina F. C.; Lazzari, S. M.; Lazzari, F. A. and Pinto Junior, A. R. (2008). Eficacia de terra de diatomacea e temperatura para o controle do gorgulho em milho armazenado. *Scientia agrarian Curitiba*, **9**(1): 73-78.
- Desmarchelier, J. M. and Dines, J. C. (1987). Dryacide treatment of stored wheat: Its efficacy against insects, and after processing. *Aus. J. Exp. Agri.*, **27**: 309-312.
- Ebeling, E. (1971). Sportive dusts for pest control. *Ann. Rev. Ento.*, **16**: 123-158.
- Fields, P. and Korunic, Z. (2000). The effect of grain moisture content and temperature on the efficacy of diatomaceous earths from different geographical locations against stored product beetles. *J. Stored Prod. Res.*, **36**: 1-13.
- Golob, P. (1997). Current status and future perspectives for inert dusts for control of stored product insects. *J. Stored Prod. Res.*, **33**(1): 69-79.
- Hadley, N. F. (1994). *Water Relations of Terrestrial Arthropods*. Academic, New York.
- Iatrou, S. A.; Kavallieratos, N. G.; Palyvos, N. E. (2010). Acaricidal effect of different diatomaceous earth formulations against *Tyrophagus putrescentiae* (Astigmata: Acaridae) on stored wheat. *J. Econ. Ento.*, **103**(1): 190-196.
- Islam, Md. S.; Hasan, Md. M. Lei, C.; Mucha-pelzer, T.; Mewis, I. and Ulrichs, C. (2010). Direct and admixture toxicity of diatomaceous earth and monoterpenoids against the storage pests *Callosobruchus maculatus* (F.) and *Sitophilus oryzae* (L.). *J. Pest Sci.*, **88**(2): 105-112.
- Korunic, Z. (1998). Rapid assessment of the insecticidal value of diatomaceous earths without conducting bioassays. *J. Stored Prod. Res.*, **33**: 219-229.
- Korunic, Z. (1999). Enhanced diatomaceous earth: an alternative to methyl bromide. *Aus. J. Tech.*, **2**: 95-104.
- Lord, J. C. (2001). Desiccant dusts synergize the effect of *Beauveria bassiana* (Hyphomycetes: Moniliales) on stored-grain beetles. *J. Econ. Ento.*, **94**: 367-372.
- Lorini, I. and Beckel, H. (2006). Efficacy of "diatomaceous earth" to control the main stored grain pests. *Proceedings of 9th International Conference on Stored Product Protection*. p. 863-867.
- Mewis, I. and Ulrichs, C. (2001). Action of amorphous diatomaceous earth against different stages of the stored product pests *Tribolium confusum*, *Tenebrio molitor*, *Sitophilus granarius* and *Plodia interpunctella*. *J. Stored Prod. Res.*, **37**: 153-164.
- Michalaki, M. P.; Athanassiou, C. G.; Steenberg, T. and Buchelos, C. T.

- (2007). Effect of *Paecilomyces fumosoroseus* (Wise) Brown and Smith (Ascomycota: Hypocreales) alone or in combination with diatomaceous earth against *Tribolium confusum* Jacquelin DuVal (Coleoptera: Tenebrionidae) and *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). *Biological Control*, **40**(2): 280-286.
- Mohale, S; Allotey, J. and Siame, B. A. (2010). Control of *Tribolium confusum* J. Du Val by diatomaceous earth (protect-it™) on stored groundnut (*Arachis hypogaea*) and *Aspergillus flavus* link spore dispersal. *African J. Food Agric. Nutri. Dev.*, **10**(6): 2678-2694.
- Nielsen. P. S. (1998). The effect of a diatomaceous earth formulation on the larvae of *Ephestia kuehniella* Zeller. *J. Stored Prod. Res.*, **34**: 113-121.
- Quarles, W. (1992). Diatomaceous earth for pest control. *IPM Practitioner*, **14**: 1-11.
- Rigaux, M.; Haubruge, E and Fields, P. G. (2001). Mechanisms for tolerance to diatomaceous earth between strains of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Ento. Exp. Appl.*, **101**: 33-39.
- Shayesteh, N. and Ziaee, M. (2007). Insecticidal efficacy of diatomaceous earth against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Caspian J. Env. Sci.*, **5**(2): 119-123.
- Stathers, T. E. (2003). Combinations to enhance the efficacy of diatomaceous earths against the larger grain borer, *Prostephanus truncatus* (Horn). *Proceedings of the 8th International Working Conference on Stored-Product Protection*. CAB International, UK. p. 925-929.
- Stathers, T. E.; Dennif, M. and Golob, P. (2004). The efficacy and persistence of diatomaceous earth admixed with commodity against four tropical stored product beetle pests. *J. Stored Prod. Res.*, **40**: 113-123.
- Stephou, V. K.; Tjamos, S. E.; Paplomatas, E. J. and Athanassiou, C. G. (2012). Transformation and attachment of *Beauveria bassiana* conidia on the cuticle of *Tribolium confusum* and *Sitophilus oryzae* in conjunction with diatomaceous earth. *J. Pest Sci.*, **85**(3): 387-394.
- Subramanyam, B. H. and Hagstrum, D. W. (1995). Resistance measurement and management. In: Integrated Management of Insect in Stored Products. *Marcel Decker, New York*, **1** (42005- 361-2): 331-398.
- Subramanyam, B.; Madamanchi, N. and Norwood, S. (1998). Effectiveness of Insecto™ applied to shelled maize against stored-product insect larvae. *J. Econ. Ento.*, **91**: 280-286.
- Subramanyam, B. H. and Roesli, R. (2000). Inert dusts (Eds. B. H. Subramanyam and D. W. Hagstrum). Alternatives to pesticides in stored product IPM. Kluwer Academic Publishers, Dordrecht, the Netherlands, 321-380.
- Varedman, E. A.; Arthur, F. H. Nechols, J. R. and Cambell, J. F. (2006). Effect of temperature, exposure interval, and depth of diatomaceous earth treatment on distribution, mortality, and progeny production of lesser grain borer (Coleoptera: Bostrichidae) in stored wheat. *J. Econ. Ento.*, **3**(99): 1017-1024.

- Varedman, E. A.; Campbell, J. F.; Arthur, F. H. and Nechols, J. R. (2007). Behaviour of female *Rhyzopertha dominica* (Coleoptera: Bostrychidae) in a mono-layer of wheat treated with diatomaceous earth. *J. Stored Prod. Res.*, **43**(3): 297-301.
- Vassilakos, T. N.; Athanassiou, C. G.; Kavallieratos, N. G. and Vayias, B. J. (2006). Influence of temperature on the insecticidal effect of *Beauveria bassiana* in combination with diatomaceous earth against *Rhyzopertha dominica* and *Sitophilus oryzae* on stored wheat. *Biological Control*, **38**(2): 270-281.
- Vayias, B. J. and Athanassiou, C. G. (2004). Factors affecting the insecticidal efficacy of the diatomaceous earth formulation SilicoSec against adults and larvae of the confused flour beetle, *Tribolium confusum* DuVal (Coleoptera: Tenebrionidae). *Crop Prot.*, **23**: 565-573.
- Vayias, B. J.; Athanassiou, C. G. and Buchelos, C. T. (2009a). Effectiveness of spinosad combined with diatomaceous earth against different European strains of *Tribolium confusum* DuVal (Coleoptera: Tenebrionidae): Influence of commodity and temperature. *J. Stored Prod. Res.*, **45**(3): 165-176.
- Vayias, B. J.; Athanassiou, C. G.; Kavallieratos, N. G. and Buchelos, C. T. (2006). Susceptibility of different European Populations of *Tribolium confusum* (Coleoptera: Tenebrionidae) to five diatomaceous earth formulations. *J. Econ. Entom.*, **5**(99): 1899-1904.
- Vayias, B. J.; Athanassiou, C. G.; Korunic, Z. and Rozman, V. (2009b). Evaluation of natural diatomaceous earth deposits from south Eastern Europe for stored-grain protection: The effect of particle size. *Pest Mgt. Sci.*, **65**(10): 1118-1123.
- Vrba, C. H.; Arai, H. P. and Nosal, M. (1983). The effect of silica aerogel on the mortality of *Tribolium confusum* (DuVal) as a function of exposure interval and food deprivation. *Can. J. Zool.*, **61**: 1481-1486.
- Wakil, W.; Riasat, T. and Ashfaq, M. (2012). Residual efficacy of thiamethoxam, *Beauveria bassiana* (Balsamo) Vuillemin, and diatomaceous earth formulation against *Rhyzopertha dominica* F. (Coleoptera: Bostrychidae). *J. Pest Sci.*, **85**(3): 341-350.
- Yang, F. L. and Liang, G. W. (2010). Diatomaceous earth enhances toxicity of garlic, *Allium sativum*, essential oil against stored product pests. *J. Stored Prod. Res.*, **46**(2): 118-123.
- Zachariassen, K. E. (1991). Routes of transpiratory water loss in a dry habitat Tenebrionid beetle. *J. Exp. Biol.* **157**: 425-437.