Flingelli G, Schöller M, Klementz DW, Reichmuth C (2012) Susceptibility of stored product moth eggs of different age towards fumigation with sulfuryl fluoride – a review. In: Navarro S, Banks HJ, Jayas DS, Bell CH, Noyes RT, Ferizli AG, Emekci M, Isikber AA, Alagusundaram K, [Eds.] Proc 9th. Int. Conf. on Controlled Atmosphere and Fumigation in Stored Products, Antalya, Turkey. 15 – 19 October 2012, ARBER Professional Congress Services, Turkey pp: 32-37

SUSCEPTIBILITY OF STORED PRODUCT MOTH EGGS OF DIFFERENT AGE TOWARDS FUMIGATION WITH SULFURYL FLUORIDE – A REVIEW

Gabriele Flingelli*, Matthias Schöller, Dagmar W. Klementz, Christoph Reichmuth

Julius Kühn-Institut, Federal Research Centre for Cultivated Plants,
Institute for Ecological Chemistry, Plant Analysis and Stored Product Protection,
Königin-Luise-Straße 19, D 14195 Berlin, Germany
*Corresponding author's e-mail: *Gabriele.Flingelli@jki.bund.de*

ABSTRACT

Eggs of insects require much higher dosages for pest control with sulfuryl fluoride (SF) than any other developmental stage. On the other hand, this fumigant is the most important gas replacing the phased out methyl bromide for control of insect pests in food processing premises. The pyralid moths *Ephestia kuehniella*, *E. elutella*, *Cadra (Ephestia) cautella*, *Corcyra cephalonica* and *Plodia interpunctella* are among the economically most significant pests in storage. In large mills, the shut down time for fumigation has to be short due to cost reasons. Additional heating instead of increasing the SF concentration is an alternative to ensure control while minimising the treatment time. Surviving individuals, especially eggs, are not acceptable for the food and feed industry. Eggs of *C. cautella* were found to be most tolerant. The available literature data concerning the control of eggs of different pest moths with SF is reviewed. A comparison of efficacies towards eggs of different age is carried out. Following the results as presented, will ensure effective fumigation with SF and complete kill of the moths.

Key words: sulfuryl fluoride, pyralid moths, control, eggs

INTRODUCTION

Pest moths cause significant damage in food and feed factories and the following chain of packaged products (Reichmuth et al., 2007; Rees, 2004). Layers of webbings on the top of stored grain in silo bins and granaries reduce the ventilation of the bulk with fresh air and favour mould growth. The webbings of the larvae, often mixed with frass and faeces, lead to blockage of the product flow in the factories, contamination of the processed raw materials and later claims by customers. Eggs surviving a control measure will lead again to the problems described above within a few weeks, and must therefore be fully controlled with the other stages.

Sulfuryl fluoride (SF) has been established as one of the main fumigants for pest control when methyl bromide (MeBr) was phased out in industrialized countries in 2005 due to its

ozone depleting potential (Anonymous, 2011a). Apart from other advantages compared to other fumigants (quick release, good penetration, not being corrosive to electronic equipment), SF has been suggested as a means of managing phosphine-resistant strains of pest insects (Williamson et al., 2011). A disadvantage of SF, the comparatively low susceptibility of egg stages of pest insects, has been discussed in comparison with other developmental stages (Bell et al., 1999, 2003; Reichmuth and Klementz, 2008; Anonymous, 2011b). This contribution summarizes the available mortality data for application of SF against eggs of moth pests and provides graphs and tables that allow the choice of an appropriate dosage for complete control for the given species.

LITERATURE SURVEY

For *Ephestia kuehniella* (Zeller), Bell and Savvidou (1999) observed the 1-2 day old eggs to be the most tolerant age group followed by 2-3, 0-1 and 3-4 day old eggs. According to the authors, a ct-product of about 800 g h m^{-3} at 25°C and about 3000 g h m^{-3} at 15°C were necessary for complete control of eggs. Efficacy was assessed by recording adult emergence reduction. As an additional result, no hatch occurred after treatment with 1000 g h m^{-3} at 25°C. About 4000 g h m^{-3} were necessary at 15°C. Reichmuth et al. (1999) found for *E. kuehniella* the 1 day old eggs to be more susceptible than 2, 3 and 4 day old eggs. In their study, complete control of all eggs was achieved with 1440 g h m^{-3} at 20°C. Ct-products for 24-h exposures achieving a high degree of control are summarized in the Table 1. The temperature dependency of the concentration is described in Fig. 1.

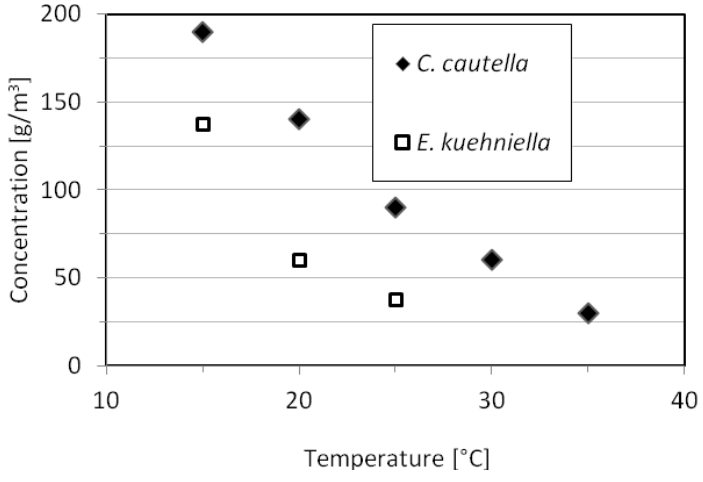

Fig. 1- Sulfuryl fluoride concentrations for complete control within one day at different temperatures data from Bell and Savvidou (1999) and Reichmuth et al. (1999) for *E. kuehniella* and data from Akan and Ferizli (2010) for *C. cautella*.

Akan and Ferizli (2010) found evidence for 0-1 day old eggs of *Cadra* (*Ephestia*) *cautella* (Walker) to be generally more susceptible than the older eggs of 1-2 or 2-3 days. According to the authors, this difference disappeared at temperatures above 30°C. Complete kill within 24 h fumigation with SF of eggs of all ages was achieved at 15°C, 20°C, 25°C,

30°C and 35°C with 190, 140, 90, 60 and 30 g m^{-3}, respectively (see Table 1 for the ct-product at 25°C). The eggs of this species were more tolerant than eggs of all other described pest moths. Fig. 1 offers information on the temperature dependence of the efficacy.

Table 1. Concentration time products for control with sulfuryl fluoride of different moth eggs of different ages; most data for 24 h fumigation at 25°C

Species	Tempe-rature [°C]	SF ct-product [gh/m^3]; (egg age in days)		Reference
Ephestia kuehniella	25	347	(0-1)	Bell and Savvidou (1999)
	25	667	(2-3)	
	25	912	(1-2)	
	25	240	(0-1)[a]	
	25	611	(2-3)[a]	
	25	764	(1-2)[a]	
	20	480	(1)(2)	Reichmuth et al. (1999)
	20	720	(3)[b](4)[c]	
Plodia interpunctella	27	175	(4)	Barakat et al. (2011)
	27	191	(2)	
	27	207	(1)	
	27	236	(3)	
Ephestia elutella	25	278	(0-1)[a]	Baltaci et al. (2006)
	25	511	(0-4)[a]	
Cadra cautella	25	1440	(0-1)	Akan and Ferizli (2010)
	25	1920	(2-3)	
	25	2160	(1-2)	

[a]data based on assessment of adult emergence, [b]95% kill, [c]89% kill

Baltaci et al. (2006) reported for eggs of ages between 1 to 4 days of *Ephestia elutella* (Hübner) that one day old eggs were most susceptible. A concentration of 21 g m^{-3} with at least 24 h exposure at 25°C led to complete kill of all stages.

Barakat et al. (2011) found with *Plodia interpunctella* (Hübner) a strong variation of egg susceptibility towards SF in tests at 27°C. With few exceptions, the 1-day-old eggs were most tolerant. This tendency was confirmed by Reichmuth et al. (1999) in tests at 20°C. In their study, 1-day-old eggs were slightly more tolerant than the 2-4 day-old eggs in a mixed age group. Contrary to these results, Schneider and Hartsell (1999) found at various concentrations 3-day-old eggs to be less susceptible than the other tested age groups. Walse (cited in Anonymous, 2011b) determined a LD_{99} of 559 g h m^{-3} (concentration = 23.3 g m^{-3}) for a 24-h treatment with SF of a mixture of 1-3 day-old eggs at 26.7°C.

One to 4 day-old eggs of *Corcyra cephalonica* (Stainton) were tested by Barakat and Reichmuth (2009) at 27°C. The youngest eggs were slightly more tolerant. A 72-h fumigation led to 100% mortality of all exposed eggs with a ct-product of 450 g h m^{-3}. A 48-h fumigation of eggs of all ages resulted in similar mortalities. Comparing all moths investigated, the eggs of *C. cephalonica* proved to be the most susceptible.

Table 1 summarizes the data of SF time concentration products for high mortality of moth eggs according to the cited references for about 25°C. Fig. 2 compares the efficacy of

SF against eggs of different age and moth species at almost comparable conditions of treatment and the corresponding lethal concentrations.

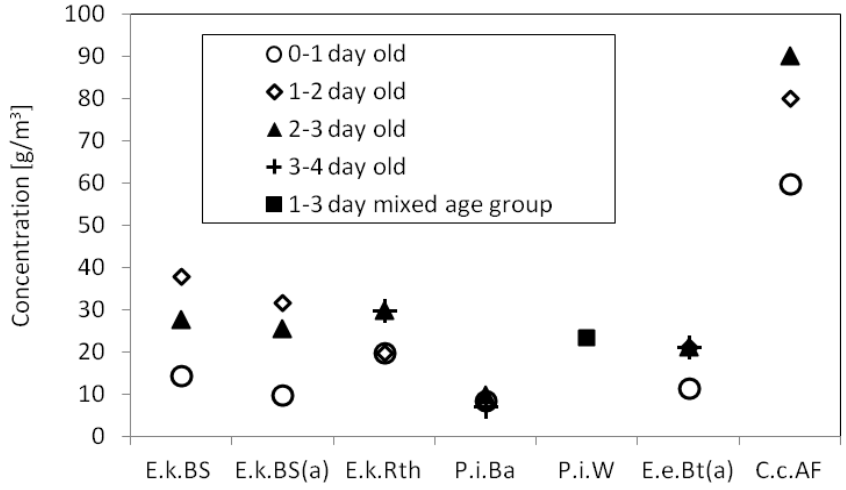

Fig. 2- Concentration of sulfuryl fluoride leading to control of eggs of different age and moth species within 24h fumigation at about 25°C. Data from table according to references: E.k.- *E. kuehniella*, P.i.- *P. interpunctella*, E.e.- *E. elutella*, C.c.- *C. cautella*, BS - Bell and Savvidou, (1999), Rth – Reichmuth et al. (1999), Ba -Barakat et al. (2011), Bt - Baltaci et al. (2009), AF - Akan and Ferizli (2010), W – Anonymus (2011b), (a)- data based on assessment of adult emergence.

DISCUSSION

According to data from the literature, there is contradicting information as to which age group of moth eggs is most tolerant towards SF. The results presented here were obtained from different laboratories with different experimental set ups for fumigation. Fig. 2 indicates the tendency of youngest eggs to be most susceptible when fumigated with SF at 25°C for 24 h.

Tests at higher temperatures (above 25°C) caused higher mortality at otherwise similar fumigation conditions. Presumably, increased speed of development during fumigation into more susceptible age stages of eggs or into susceptible young larvae may be the reason for this effect at higher temperature. According to Weidner (1983), hatch of eggs of *P. interpunctella* occurs within about 1.5 d, 2.5 d and 6 d at 30°C, 26°C and 23°C, respectively. In the case of *E. elutella*, the eggs require 5 days at 25°C to hatch. Since there is a minimum time required to allow for the developmental processes in the egg until hatch, a minimum exposure time at a given concentration should be ensured for efficacious fumigation (Barakat et al., 2011). With the exception of the data for *C. cautella,* a concentration of ca. 35 g m^{-3} seems to be adequate for 24 h fumigation at 25°C leading to high level of control of eggs of all moth species – if *C. cautella* occurs, 90 g m^{-3}. On the other hand, the determination of the moth species prior to fumigation offers the chance to determine the amount of SF really necessary for control following the principle of good fumigation practice: as little as possible but as much as necessary. Also longer exposure times could offer the opportunity to achieve control using less gas.

REFERENCES

Akan K, Ferizli AG (2010) Does sulfuryl fluoride and heat combination overcome the egg-weakness of almond moth? In: Obenauf GL (ed) Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Nov 2-5, 2010, Orlando, USA, pp 56-1 - 56-4.

Anonymous (2011a) United Nations Environment Programme (UNEP) 2010 Report of the Methyl Bromide Technical Options Committee (MBTOC) – 2010 Assessment. Nairobi, Kenya, Ozone Secretariat, Montreal Protocol on Substances that Deplete the Ozone Layer, http://ozone.unep.org/Assessment_Panels/TEAP/Reports/MBTOC/index.shtml, ISBN 978-9966-20-000-6.

Anonymous (2011b) In: United Nations Environment Programme (UNEP), Technology and Economic Assessment Panel (TEAP) Progress Report 2011, Vol. 1, Montreal Protocol on Substances that Deplete the Ozone Layer, Ozone Secretariat, P.O. Box 30552, Nairobi, Kenya, http://www.unep.org/ozone/teap/Reports/TEAP_Reports, ISBN: 978-9966-20-004-4.

Baltaci D, Klementz D, Gerowitt B, Drinkall M, Reichmuth Ch (2006) Lethal effects of sulfuryl fluoride on eggs of different ages and other life stages of the warehouse moth *Ephestia elutella* (Hübner). J Stored Prod Res 45: 19-23.

Barakat DA, Flingelli G, Reichmuth Ch (2011) Lethal effects of sulfuryl fluoride on eggs of different age of the Indian meal moth *Plodia interpunctella*. J Cultivated Plants 63:323-332.

Barakat DA, Reichmuth Ch (2009) Response of *Corcyra cephalonica* towards sulfuryl fluoride. In: Obenauf GL (ed) Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, USA, pp 61-1–61-4.

Bell CH, Savvidou, N (1999) The toxicity of vikane (sulfuryl fluoride) to age groups of eggs of the Mediterranean Flour Moth *Ephestia kuehniella.* J Stored Prod Res 53: 233-247.

Bell CH, Savvidou N, Wontner-Smith TJ (1999) The toxicity of sulfuryl fluoride (Vikane) to eggs of insects pests of flour mills. In: Zuxun J, Quan L, Yongsheng L, Xianchang T, Lianhua G (ed) Stored Product Protection, Proceedings of the 7th International Working Conference on Stored-Product Protection, 14-19 October 1998, Beijing, China, Sichuan Publishing House of Science and Technology, Chengdu, China, pp 345-350.

Bell CH, Wontner-Smith TJ, Savvidou N (2003) Some properties of sulphuryl fluoride in relation to its use as a fumigant in the cereals industry. In: Credland PF, Armitage DM, Bell CH, Cogan PM, Highley E (ed) Advances in Stored Product Protection, Proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July 2002, York UK, CAB International, Wallingford UK, pp 919-915.

Rees D (2004) Insects of Stored Products. Manson Publishing, London, UK, CSIRO Publishing, Collingwood, Australia.

Reichmuth Ch, Schneider B, Drinkall MJ (1999) Sulfuryl fluoride (Vikane) against eggs of different age of the Indian meal moth *Plodia interpunctella* (Hübner) and the Mediterranean flour moth *Ephestia kühniella* (Zeller). In: Zuxun J, Quan L, Yongsheng L, Xianchang T, Lianhua G (ed) Stored Product Protection, Proceedings of the 7th International Working Conference on Stored-Product Protection, 14-19 October 1998, Beijing, China, Sichuan Publishing House of Science and Technology, Chengdu, China, pp 416-422.

Reichmuth Ch, Schöller M, Ulrichs C (2007) Stored Product Pests in Grain. AgroConcept Verlagsgesellschaft, Bonn, Germany.

Reichmuth Ch, Klementz D (2008) How to overcome the egg-weakness of sulfuryl fluoride – combinations of control methods. In: Obenauf GL (ed) Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, USA, pp 88-1 - 88-4.

Schneider BM, Hartsell PM (1999) Control of stored product pests with Vikane gas fumigant (sulfuryl fluoride). In: Zuxun J, Quan L, Yongsheng L, Xianchang T, Lianhua G (eds) Stored Product Protection, Proceedings of the 7th International Working Conference on Stored-Product Protection, 14-19 October 1998, Beijing, China. Sichuan Publishing House of Science and Technology, Chengdu, China, pp 406-408.

Weidner H (1983) Vorratsschädlinge. In: Heinze K (ed) Leitfaden der Schädlingsbekämpfung, Band IV, Vorrats- und Materialschädlinge. Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart, Germany, pp 123-333.

Williamson P, Bridgeman B, Dewit B (2011) Profume moving forward in Australia. In: Obenauf, GL (ed) Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 31 Oct -2 Nov, San Diego, USA, pp 61-1 - 61-2.