14 - Efficacy against eggs of Tribolium confusum and Tribolium castaneum after fumigations with sulfuryl fluoride (ProFume®) in flour mills

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Abstract

After the phase out of methyl bromide and dichlorvos (DDVP) the disinfestation of flour mills is in a difficult position in the European Union. Sulfuryl fluoride (ProFume®) is registered in France for the disinfestation of empty premises since 2006. The cost of a fumigation is very high, that's why the aim of this study is to assess the effectiveness of fumigations at low concentrations of sulfuryl fluoride on eggs (the most tolerant stage) of the two mains flour mills pests: *Tribolium confusum* Jacquelin du Val and *Tribolium castaneum* (Herbst). Four mills were fumigated with different concentrations, for an exposure time of 21 to 39 hours with, in five levels of each mill, two 20 litres plastic drums containing flour wheat infested by eggs of *T. castaneum* in the first drum and eggs of *T. confusum* in the second. The two controls, containing eggs of these two species of Tenebrionidae, were placed in the same conditions but without undergoing the fumigation.

After fumigation, the CT products were included between 310 g.h/m3 to 1350 g.h/m3, with temperatures included between 19.6 to 34.1°C. The CT products correspond to 25 to 250% of the CT products advised by the Fumiguide® for a total disinfestation (all stages of all insects species controlled). Low concentrations did not kill all eggs of *Tribolium* spp. in these fumigations. However a variable level of egg control was achieved, depending on the conditions (temperature and CT product). For the eggs of *T. confusum* between 25 to 100% were killed compared with controls. The temperature and above all the CT product were the mains factors which can affect the efficacy on eggs. On the other hand, between 0 to 99.9% of *T. castaneum* eggs were killed, compared with controls, with temperatures below 30°C. But when temperatures exceeded 30°C, the efficacy was enhanced because between 65 to 100% of eggs were killed. For the *T. castaneum* species, the increase of temperature is the most important factor, compared with the CT products reached, which enhances the efficacy of egg's control. Few CT products were higher than the CT products advised by the Fumiguide® but nevertheless they didn't reach the 100% of egg's mortality, at a temperature below 30°C.

As a result, it seems necessary to combine fumigations with heat at 30°C minimum inside the flour mill before and during the treatment in order to reach 100% mortality on the most tolerant stage of *Tribolium castaneum*. Moreover, this practice improves the results of fumigations with low concentrations of sulfuryl fluoride allowing to be close to a total disinfestation.

Introduction

Since the phase out of methyl bromide and the loss of dichlorvos (DDVP), it is very complicated to disinfest with effectiveness the flour mills in the European Union. Sulfuryl fluoride (ProFume®, the DowAgrosciences fumigant) is registered for structure treatments in France since 2006 and this gas began to be used at commercial scale in 2007. However, sulfuryl fluoride is not a very good ovicide with an application rate of 20 g/m3 (dosage generally used with methyl bromide before its withdrawal). It is difficult for the gas to cross the chorion of the insect's eggs. The most tolerant life stage of *Tribolium* spp. with sulfuryl fluoride is the egg stage (Bell et al, 1998), that's why sometimes it is necessary to make flour mill's fumigations with an application rate of about 70 g/m3. This kind of practice can be expensive for millers and, in some cases, they can't do fumigations in their mill. So, the cost of the treatment is quite often a barrier to the use of ProFume® for the disinfestations of flour mills.

However, there is a huge difference between the dosages which ensure to control all stages of all flour mill insect pests, and the dosages which are necessary to kill all stages of these insect species, without a part of eggs, and more precisely a part of eggs of *Tribolium* spp. Moreover, there is a huge difference between the sensibility of *Tribolium castaneum* eggs and *Tribolium confusum* eggs to sulfuryl fluoride fumigations. The eggs of the first species are more tolerant to sulfuryl fluoride than the eggs of the second (Bell et al, 1998).

Sulfuryl fluoride dosages are expressed in Concentration Time Product (CTP or CT), in order to get a good estimation of biological efficacy. The CTs needed to obtain a good disinfestation depend of the temperatures recorded during the gas exposure time in mills, that's why this study tries to get a lot of cases where there were a large diversity of these three mains parameters: sulfuryl fluoride concentrations, exposure times and temperatures.

This study is set up to investigate the impact of flour mills fumigations with sulfuryl fluoride at different dosages on egg's populations of *Tribolium castaneum* and *Tribolium confusum* in full scale.

So, in the case where the results of low dosages of this study are beneficial to disinfestations programs, it leads to:

- open new opportunities to millers from an economic point of view,
- find a good alternative to dichlorvos treatments and to disinfestations by contact insecticides,
- decrease the risk of finding residues in the stored part of the mills close to fumigated areas.

Material and methods

The trials were carried out in four flour mills, with different conditions of temperature, injected gas amounts, speed of wind. The volumes of these premises were between 5000 to 7500 m3. These flour mills are located in France, two of them were selected for fumigation with low dosages in Peyrehorade (5000 m3) and Sallèles d'Aude (6900 m3). The two others were fumigated with the dosages recommended by the Dow Agrosciences Fumiguide® (a software used like a tool to advise and help the fumigators during the fumigation), to control all stages of the most tolerant stored product pest to sulfuryl fluoride: *Tribolium castaneum*, in Gond Pontouvre (7500 m3) and Gerzat (7500 m3). This investigation was undertaken between June 2008 and November 2008.

In laboratory, populations of the two species *Tribolium castaneum* and *Tribolium confusum* were reared in a chamber at 27 ± 1°C and 60% of relative humidity ± 5%. A week before each fumigation, for each species, 100 adult insects were put in a 20 litres plastic drums with one kilograms of wheat flour. After this week, the adults have laid eggs in the flour and there were in the drums a mixed aged eggs included between few hours to seven days. The development of the eggs to the larvae stage, in these conditions, is about 6.8 days for *T. castaneum* (Howe, 1956) and 7.7 days for *T. confusum* (Howe, 1960). The drums were closed but there was a gap in the lid closed with a Whatman® paper in order to have an air exchange but no insects circulation between the inside drum and the outside.

The drums containing the infested flour with adults and eggs were placed at different levels of the mills just before the injection of ProFume® inside the mill. All drums were equipped with a temperature/R.H. sensor/recorder Captsystèmes and a sampling gas pipe was placed on the top of the drum. For each trial, it had to take exact gas concentration and temperature measures for each level of the flour mill with an Automate (Captsystèmes). When the fumigation began, few hours later, the *Tribolium* spp. adults were removed from their drum in order to stop the laying in these control drums because in the fumigated drums, adults were killed by the gas.

The fumigations were carried out by a French professional pest control company: AgroTechmoHygiène (ATH). The dosage for sulfuryl fluoride was determined according to the temperature at the moment and in order to have overall several CTs with low and recommended dosages.

The fumigation results are expressed as Concentration - Time Products (CT) because it is easier to compare CT values (in g.h/m3) in the different mills. Then, the CTs reached in each level of each mill were compared with the registered CT recommended by the Dow AgroSciences Fumiguide®. After fumigation, the flour of each drum was sifted and the dead adults were counted and removed from the drum. Each drum was put in controlled conditions, in the rearing chamber, and after two months, the flour was sifted in order to count the adults resulting from the eggs at the moment of the treatment. These results were compared with the adult populations in the controls and then, a mortality rate of eggs was calculated for each modality.

Results and discussion

The fumigations with low dosages were carried out with an amount of injected gas included between 22.7 to 32.9 kg of ProFume® for 1000 m3 fumigated (Table 1). On the other hand, the two fumigations with recommended dosages have required between 68 to 90.7 kg of ProFume® for 1000 m3 fumigated. The dosages depend of the temperature inside the mill during the fumigation, but these amounts introduced show a trend of the reduction of dosages for sulfuryl fluoride fumigations. The low dosages fumigations needed, in these cases, twice to four time less gas than the fumigations with recommended dosages.

Tab. 1 Amount of injected gas for each fumigation of flour mill

	Injected gas amounts (kg/1000m3)	**Exposure time**
Gerzat	68	22h15
Gond-Pontouvre	90,7	39h
Peyrehorade	22,7	21h
Sallèles d'Aude	32,9	22h30

To enable a comparison of the efficacy of each fumigation on the egg stage of the two species of *Tribolium* spp., the two mains parameters (temperature and CT reached) involved in the efficacy of fumigations were collected in a 3D chart (Figure 1 and 2). These charts collect all the data obtained after the fumigation of all levels of each flour mill. The efficacy of fumigation is expressed as mortality rate of eggs compared with the control.

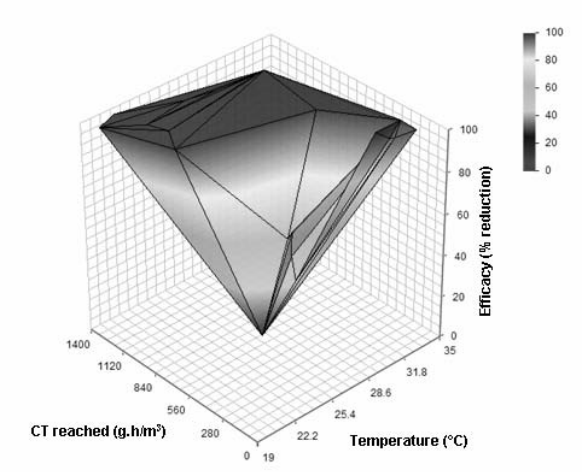

Fig. 1 Mortality rate of *T. confusum* eggs (compared with control) according to CT reached and temperature during the fumigation with sulfuryl fluoride

The results shown on this figure demonstrate that the CT products reached 310 to 1350 g.h/m3 and the temperatures recorded during the fumigations were between 19.6 to 34.1°C. The efficacy, related in percentage of *T. confusum* eggs killed (compared with the control), is more important when there was a high temperature (more than 30°C) in the mill during the fumigation or when the reached CT was important (more than 1000 g.h/m3) (Figure 1). However, in a situation where the reached CT and the recorded temperature were low, the percentage of mortality can decrease to an eggs mortality rate of about 20% compared with control.

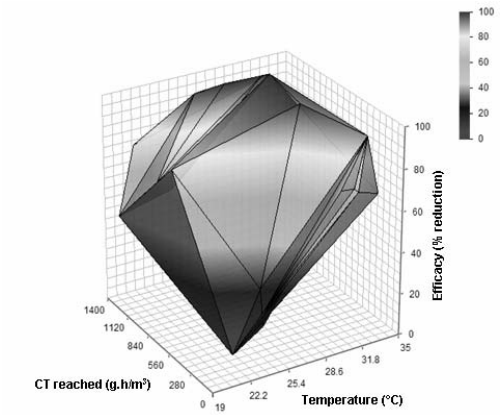

Fig. 2 Mortality rate of *T. castaneum* eggs (compared with control) according to CT reached and temperature during the fumigation with sulfuryl fluoride

First it is obvious on this chart that there is difference of sensibility between the two species of *Tribolium* spp. (Figure 2). The mortality rate of *T. castaneum* eggs is different from the previous figure. Comparing with the previous results, when the temperature during the fumigation is not very high (below 25°C), the efficacy of the treatment is not very good even if the CT reached is high. The temperature needs to be high to get a high effectiveness on eggs of *T. castaneum* when the CT is lower than the recommended CT. With a low temperature (about 23°C) and a low CT reached (about 330 g.h/m3), the efficacy resulting of this combination is bad because there are no differences between the control and this modality concerning the emergence of adults from eggs, but it is a good alternative to dichlorvos as no post embryonic stage survived. So, in this case, the temperature is the main factor which leads to a good ovicide efficacy. An increase of temperature with just few degrees shows direct effects

on the efficacy of fumigations (recommended or low dosages) on *Tribolium* spp. eggs. In the two cases, when the average temperature during the fumigation was 30°C or more, between 65 to 100% of eggs were killed depending on conditions.

Conclusion

The main factor of successful fumigations with low dosages is the temperature (particularly to control *T. castaneum* eggs). The fumigations (with recommended or low dosages) below 25°C seem to provide disappointing results, that's why the increase of temperature in order to reach 30°C at minimum allows to:

- reach for sure 100% of egg mortality (with recommended dosages) for *T. castaneum*,
- improve the egg's mortality with low dosages fumigations,
- reduce the gas exposure time,
- reduce the necessary amount of gas.

To conclude, this study confirms other studies (Reichmuth et al., 2003), the dosage can be reduced "intelligently" with good results in disinfestations of stored products pests. The fumigations carried out without controlling all the eggs of the populations of *Tribolium* spp. have allowed to kill all the others stages of these pests (larvae, pupae and adults). Moreover, with low dosages, even if the fumigations don't kill all the eggs of *Tribolium castaneum*, the most tolerant species to sulfuryl fluoride (Bell et al., 2002), the treatment may control all or almost all the stages of others species of insect pests. It is therefore a good alternative to the ban of dichlorvos.

May be the best way consists to combine the fumigations, with low dosages of sulfuryl fluoride, with heat in order to reach 30°C inside the mills before and during the treatment but the economic impact of that combination needs to be assessed.

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15 - Post harvest protection against insects in the bulk grain supply chain the views of economic operators

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Abstract

European (EU-27) grain & oilseeds storers are regularly facing insect management issues. Under worldwide trading standards, the grain industry is committed to maintaining the "zero tolerance" for live insects (WTO-SPS agreements). The grain being harvested each year therefore has to be stored in a manner which ensures that these standards are met. The presence of living insects in stored grains would jeopardize the supply of the grain & oilseeds supply chain, both for food and feed as well as for exports. In this context, our survey covers a quantity of agri-product that is equivalent to 5% of the EU-27 production. Results show that storage operators need several modes of action in order to prevent and cure the build-up of insect infestations in grain while avoiding pest resistance. Ventilation, silo cleaning and fumigation are important aspects in the implementation of an integrated pest management. Because of legislative restrictions, we now rely on one fumigant and on only a limited number of residual storage insecticides. As a result, we show that European operators will face difficulties to combine the available management technique. Therefore we stress the need for legislative development together with an