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Impact of Sulfuryl Fluoride Fumigation and Heat Treatment on Stored – Product Insect Populations in German Flour Mills

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Abstract: Comparative treatments of sulfuryl fluoride (SF) and heat were evaluated in Germany as replacements for methyl bromide (MB), an ozone – depleting fumigant which has now been banned in developed countries for most of its uses. A study was carried out in two flour mills in Germany to determine the impact of SF fumigation (ProFume™ Dow AgroSciences LLC) and heat treatment on populations of flour beetles: *Tribolium castaneum* (Herbst) and *T. confusum* Jacquelin du Val and stored product moths: *Plodia interpunctella* (Hübner) and *Ephestia elutella* (Hübner). One mill was selected for fumigation with ProFume? the other for the heat treatment. Traps baited with an aggregation pheromone lure and an oil – based food attractant were used to monitor populations of flour beetles. For the monitoring of flour moths, sticky traps baited with a pheromone lure were applied. Traps were placed inside the mill buildings within the areas selected for treatment. In the mill that was fumigated with SF, populations of stored product insects were monitored for 6 weeks prior to, and 16 weeks following, the treatment. In the mill that underwent a heat treatment, the monitoring started 15.5 weeks prior to, and ended 6.5 weeks following, the treatment. Both SF fumigation and heat treatment provided successful control of the target pests during the monitoring period. After the SF fumigation only 3 *Tribolium* individuals could be detected and no moths. After heat treatment 20 *Tribolium* beetles and 2 moths were detected. Thirteen beetles were found in the basement which is the most difficult place to heat while the remaining ones were scattered throughout the building. We conclude that both SF and heat are both suitable replacements for MB for controlling stored product pests in German flour mills.

Introduction

In Germany, MB use for fumigation of flour mills was phased out completely by the end of the year 2004 following the stipulations of the Montreal Protocol (Reichmuth, C., *pers. comm.* 2004). Among the alternatives studied in order to replace MB in flour mills, only fumigation with sulfuryl fluoride (SF) and heat treatments have shown sufficient action on stored product pests and suitability to be used in practice. Insecticide treatments are limited to special purposes such as pirimiphos-methyl application on surfaces or fogging with pyrethroids against flying moths. Such treatments should preferably be included in individually designed Integrated Pest Management (IPM) concepts which are based on components such as pest prevention by means of structural design, sanitation and monitoring of stored product pests using traps and lures. Additional features of IPM schemes for mills are proper documentation of pest occurrence and control measures, training and motivation of staff [1].

SF was developed in the 1950s by the Dow Chemical Company in the USA as a fumigant to control drywood termites and wood-boring beetles. Under its trade name Vikane (Dow Agrosciences LLC) it has been in use for this purpose until this day. In 2003, its proven efficacy against stored product insects[2] led to registrations as a fumigant for post-harvest applications under the trade name ProFume (Dow Agrosciences LLC) in the USA, followed by registrations for different post-harvest applications in the European Union from 2004 onwards[3].

Heat treatment has been previously described for controlling stored-product insects in the early 1900s[4]. It has been included in the first textbook on stored product protection ever published in Germany[5] and continued to play a substantial role for treating empty rooms to date[6].

The work described here was completed between August and December 2007. Its objective was to assess the impact of a SF fumigation and a heat treatment (both applied separately) on the post-treatment development of stored-product insect populations in German flour mills and to provide a comparison of both types of treatment. The design of the study was chosen in a way which allows easy comparison with a simi-

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lar study undertaken in the United Kingdom (Small, G. unpublished, pers. comm. 2006).

Materials and Methods

Both flour mills which were selected for this trial are situated in the North of Germany. The mill which was fumigated with SF (Mill A) consists of two parts for milling oats and maize, respectively. The buildings are not fully separated. The volume of this mill was 23,000 m^3 plus a loading hall with a volume of 9,000 m^3 and silos with a total volume of 1.850 m^3. The mill was built in 1848 and has been extended on three occasions. It is constructed of bricks and ferro-concrete, with mainly wooden floors and some parts in concrete.

The mill which was treated with heat (Mill B) is a flour mill for wheat and rye. The facility has two main buildings: the mill itself has a volume of about 40,000 m^3 and the flour silo 60,000 m^3. The mill-building was constructed 70 to 80 years ago with bricks for the outside frame and concrete plus wood inside. The inner building consists of steel-girder, ferro-concrete, pitch-pine floors and a wooden roof construction. Windows are made of plastic material. The flour silo is approximately 25 years old. Construction material is concrete plus a metal-sheet frame outside.

The SF fumigation at Mill A was carried out by a commercial fumigator using the Pro-Fume Fumiguide computer program from Dow AgroSciences LLC. Fumigation started on 31 August 2007 and concluded on 2 September 2007. The period of exposure was 50 h with a CT (product of concentration and time) of 1 013 $g \cdot h/m^3$.

The heat treatment was carried out by milling staff with 12 years of experience using this technology. It was completed using heaters located outside the building. The heat was conducted into the interior via tubes. The treatment started on 2 November 2007 and was concluded on 4 November 2007. The total duration of the treatment was 48 h. Exposure to lethal temperatures around 50℃ in all treated areas lasted 24 h.

In both mills, the presence of stored product insect pests was monitored using commercially available traps and pheromone lures which were distributed in all treated areas of the buildings. In order to detect the rust – red flour beetle *Tribolium castaneum* (Herbst) and the confused flour beetle *T. confusum* Jacquelin du Val, Dome Traps loaded with specific pheromones for detecting *Tribolium* spp. were used (20 traps in Mill A and 25 traps in Mill B). *Plodia interpunctella* (H bner) and *Ephestia elutella* (H bner) were detected with Delta Traps and a pheromone designed to attract *P. interpunctella* and different species of *Ephestia* (10 traps in Mill A and 12 traps in Mill B). These materials were obtained from Trece, Inc. (USA).

Trap catches were recorded immediately before the treatments and at monthly intervals after the treatment. All traps and pheromone lures were replaced during all inspections. Insect samples collected were sent to a Government laboratory for identification (LAVES, Mr. Stelling, Stade, Germany).

Results and Discussion

In order to provide an overview of infestation before and after the treatment, trap catches were pooled for the different floors or areas of both mills. For Mill A the respective *Tribolium* spp. numbers are shown in Table 1:

Table 1. Total numbers of *Tribolium confusum* and *T. castaneum* trapped before and after fumigation at mill A.

	Numbers of *Tribolium* spp. counted					
	07/07	08/07		09/07	10/07	12/07
Basement	2	8	Fumigation with sulfuryl fluoride	0	0	0
1st floor	12	4		0	0	0
2nd floor	13	2		0	0	0
3rd floor	51	4		0	0	0
4th floor	42	5		1	0	1
5th floor	31	7		0	0	0
Maize mill	4	5		1	0	0

Except for the three *Tribolium* spp. specimens that were detected after treatment, the percentage reduction of flour beetles was 100% in all areas of the fumigated Mill A throughout the three post-fumigation monitoring periods. Percentage reduction was calculated using the formula:

$$(C-T)\times 100/C$$

In this formula C = number of insects trapped during the pre-treatment monitoring period (09/07), and T = number of insects trapped during the single post-treatment monitoring periods.

The number of moths in the traps is shown in Table 2.

Table 2. Total numbers of *Plodia interpunctella* and *Ephestia elutella* trapped before and after fumigation at mill A

	Numbers of moths counted					
	07/07	08/07		09/07	10/07	12/07
Basement	2	4	Fumigation with sulfuryl fluoride	0	0	0
2nd floor	0	0		0	0	0
3rd floor	0	0		0	0	0
4th floor	4	3		0	0	0
Maize mill	28	9		0	0	0

No moths were detected throughout the three post-fumigation monitoring periods. Therefore, the percentage reduction of stored product moth species was 100% in all areas of Mill A, which were infested before the fumigation.

Table 3 shows the number of *Tribolium spp* trapped in Mill B which underwent a heat treatment.

Table 3. Total numbers of *Tribolium confusum* trapped before and after heat the treatment in Mill B

	Numbers of *Tribolium* spp. counted						
	07 - 08/07	08 - 09/07	09 - 10/07	10 - 11/07		11/07	12/07
Basement	13	20	25	12	Heat treatment	0	13
1st floor	2	6	6	1		0	1
2nd floor	8	12	6	5		0	0
3rd floor	3	13	17	2		1	0
4th floor	2	2	1	2		1	2
5th floor	0	5	4	0		0	2

Out of the two flour beetle species, only *T. confusum* was found in Mill B. At the time of the first post-treatment monitoring, only one confused flour beetle was detected on each of floors 3 and 4. During the second post-treatment monitoring period, a small beetle population had started to build up again. Out of the 18 individuals caught by that time, 13 were detected in the basement. As this cool area was the most difficult place to heat, there is a probability that some eggs survived the heat treatment in hidden places of the basement. They may have given rise to the small population discovered 6.5 weeks after treatment.

Moth catches in Mill B are shown in Table 4.

Table 4. Total numbers of *Ephestia elutella* trapped before and after heat treatment in Mill B

	Numbers of *Ephestia elutella* counted						
	07 - 08/07	08 - 09/07	09 - 10/07	10 - 11/07		11/07	12/07
Basement	6	20	4	7	Heat treatment	0	0
1st floor	2	3	0	5		0	0
2nd floor	8	14	19	26		1	0
3rd floor	2	3	2	2		0	0
4th floor	0	1	5	6		0	0
5th floor	0	4	3	0		0	0

In Mill B, only *E. elutella* could be detected but no *P. interpunctella*. Apart from one individual detected in the 2nd floor immediately after treatment, percentage reduction of *E. elute-*

lla was 100 % in all infested areas throughout the two post-fumigation monitoring periods.

The results of the trap catches indicate that both treatments, SF fumigation (Mill A) and heat treatment (Mill B), successfully controlled the target pests during the monitoring period. Compared with the SF fumigation, heat treatment appears to be slightly inferior for controlling flour beetles as 20 *Tribolium* beetles were detected after the treatment. All but two of them appeared 6.5 weeks after treatment. Thirteen of these were found in the basement which is the most difficult area to heat while the remaining ones were distributed all over the building. It is possible that eggs survived heat treatment in hidden cool places of the basement which gave rise to the small population discovered 6.5 weeks later. Apart from the basement, however, very few single insect specimens appeared elsewhere in the mill treated with heat.

These results confirm the findings of previous studies which reported excellent control of stored product pests under field conditions using SF[7]. In that research, infestation remained below pre-fumigation levels three months after fumigation in all parts of the mill. The reduction of infestation levels of *T. confusum* achieved by heat treatment varied between 95% and less than 70%, depending on the treated area/floor. The research concluded that the initial impact of SF fumigation on *T. confusum* populations was much higher than with heat treatment.

Our excellent pest control results using both types of treatments in Germany were certainly due to the fact that all of them were conducted by professionals that were experienced in using their respective technologies. In addition, our work was carried out in mill buildings which were constructed 25 to 150 years ago. The older parts of these mills provide a more rigorous test of heat and SF than relatively modern and well-sealed mills which have been constructed more recently.

We conclude that application of heat as well as SF fumigation can be considered as valid replacements for MB for controlling stored product pests in German flour mills.

It must be emphasized that freedom from pests is not permanent. Therefore, the heat and SF applications work best within a framework of elaborated IPM schemes, with emphasis on thorough inspection of incoming grain, pest exclusion and sanitation.

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