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COMPARISON OF EFFICACY OF METHYL BROMIDE AND SULFURYL FLUORIDE FUMIGATIONS IN CANADIAN PASTA PLANTS

Paul G. Fields

Cereal Research Centre, Agriculture and Agri-Food Canada, 195 Dafoe Rd., Winnipeg, MB R3T 2M9, Canada
*Corresponding author's e-mail: *paul.fields@agr.gc.ca*

ABSTRACT

We conducted trials in three pasta manufacturing facilities in Canada: three trials with sulfuryl fluoride (SF, ProFume®) and five trials with methyl bromide (MB). The efficacy of treatments was estimated using bioassays and trapping. For the bioassays, just before the treatments, vials containing adults and eggs of the red flour beetle (*Tribolium castaneum*) were placed throughout the plants. For trapping, pheromone traps were placed throughout the plant before and after treatments. Both MB and SF treatments were effective in killing 100% of adult *T. castaneum* in bioassay vials. All eggs were killed in the MB fumigations. In the SF treatments, egg mortality ranged from 69 to 81%. Some of the egg survival could be due to doing partial fumigations and leaky sections of the plant. Insects caught in the traps rose after the MB fumigations in Plants #1 and 3. In Plant #1, insects were trapped immediately after MB fumigation, but insects trapped did not rise to pre-treatment levels within the 20 weeks of sampling. After the SF fumigation, insects trapped rose to 100% of pre-treatment levels in 12 weeks in Plants #1 and 3. Comparing the SF with the MB fumigations is difficult, because pest pressures change from year to year, weather conditions change from year to year, two of the three SF fumigations did not fumigate the entire plant, pheromone trapping did not start before MB fumigations in Plant #3, and Plant #2 had insect counts too low to estimate efficacy. Plants #1 and 3 replaced a MB fumigation with the SF, and did not have to redo the fumigation with MB. Plant #2 did not conduct a full plant SF treatment. In Plant #3, additional pest control measures, fogging with dichlorvos and extra sanitation, were needed after the SF fumigation, that were not needed after the MB fumigation.

Key words: SF, MB, pasta, red flour beetle, *Tribolium castaneum*

INTRODUCTION

Methyl bromide (MB) (Banks, 2002; Fields and White, 2002) is a very effective broad spectrum fumigant. It is used around the world to control a wide variety of pests (pathogens, nematodes, weeds and insects) in diverse substrates (soil, food, museum artefacts, buildings, equipment and aircraft). It is the major tool to control insects in food processing facilities, such as flour mills, pasta production plants and breakfast cereal plants.

In 1992, methyl bromide was recognized as a significant ozone depletor and was to be phased out in 2005 for developed countries and 2015 for developing countries. Given that methyl bromide is such a widely used fumigant, critical use exemptions (CUE; MBTOC,

2007) for very specific uses of methyl bromide was allowed after these dates. CUE have been granted for some pasta plants in Canada from 2005-2011.

Sulfuryl fluoride (SF or SO_2F_2) has been proposed as a replacement for methyl bromide in the fumigation of flour mills and other structures (Bell et al., 1996; Banks, 2002). Sulfuryl fluoride was originally registered for termite control in 1961, under the trade name Vikane®. Since 1995, Dow AgroSciences has been expanding the use pattern of sulfuryl fluoride for use in flour mills, under the trade name ProFume® (Schneider and Hartsell, 1999). Currently it is registered in USA, Canada, across Europe, Mexico and Australia.

MATERIALS AND METHODS

Treatments

Plant #1 had a MB treatment in May 2007, May 2008 and September 2008 and a partial SF treatment in October 2007. As SF can not come into contact with food or food ingredients, not all of the plant was treated. The regrind area, which takes pasta and grinds it into semolina, is separate from the production area in the middle of one of the warehouses. It was sealed and treated with SF. Plant #2 had a MB treatment in June 2007 that treated the processing, warehouse, packing and semolina receiving areas. October 2007, they had a SF treatment of just the semolina receiving area. This area is adjacent to the processing area, doors and vents leading to the processing area and the outside were sealed before the fumigation. Plant #3 did a MB treatment June 2007. They did an SF fumigation of their entire facility in June 2008. We obtained the *ct*-product (CTP) and the Half Loss Time (HLT) for both SF and MB the using Fumiguide™. It is a computer program created by Dow AgroSciences to guide fumigators in ProFume fumigations.

Dome traps

Dome traps (Trece Inc) that are specific for trapping flour beetles were placed throughout the facilities, and the insects removed and counted each week. The traps were in the facilities 6-20 weeks before the SF fumigations. The traps were baited with a pheromone for the confused and red flour beetles (*Tribolium confusum* Jacquelin du Val and *Tribolium castaneum* (Herbst)) and a vegetable oil attractant. The vast majority of insects caught in the traps were flour beetles, and those data are reported here. The insect numbers are expressed as a percentage of the pre-treatment populations. The mean number of insects/trap/day in the pre-treatment periods was calculated and the means divided by pre-treatment mean and multiplied by 100 to give a standardized measure of efficacy.

Plant #1 started trapping (eighteen traps) in July 2007, several weeks after a MB fumigation, but well before the SF fumigation. They have made the trapping part of their pest management program and made available the data from 2008 and 2009. Plant #2 started trapping (twelve traps) well before the MB and the SF fumigation, but no flour beetles were ever found in pheromone traps, despite flour beetles being present in the plant. Plant #3 started trapping (fourteen traps) after the MB fumigation. As there is no pre-treatment trapping, no trap data for Plant #3 is reported. Plant #3 started trapping 6 weeks prior to SF fumigation and continued 20 weeks after fumigation.

Bioassays

The red flour beetle, *T. castaneum* (Steinbach strain), was used as a test insect. They were reared on white wheat flour with 5% brewer's yeast at 30°C, 60% r.h. Twenty unaged adults of unknown sex were placed in 16 g of culture medium in plastic vials, 4-8 d before the treatment, and held at 20-30°C, 60% r.h. So at the time of the treatment there were twenty adults per vial and an unknown number of immatures, of which most would be in the egg stage. Eggs are the stage most resistant to SF. Eight vials were used as untreated controls. They were treated as the insects exposed to the treatment, but they were not held in the plant during the treatment. Twenty-five vials were placed throughout the facility a few hours before the treatment and retrieved a few hours after the treatment. About half of the vials were placed in the middle of the facility and half of them near windows or doors. Data loggers (Hobo Dataloggers, Onset Computers Inc.) were placed with each vial, and the temperature recorded every 15 minutes.

RESULTS and DISCUSSION

Fumigant

Full results are reported in Harrison (2009). Plants took 8-23 h to prepare for the fumigation, the gas was held for 22-26 h, and the plant employees were allowed back into the buildings 5-17 h after the end of the fumigation, total shutdown was 48-138 h. MB and SF fumigations had similar durations.

Less MB (26 g/m^3) was added than SF (58-62 g/m^3) (Table 1). The HLT for MB fumigations were longer than SF fumigations for Plant #1 and 2. The resultant CTP varied considerably between treatments (Table 1). For the SF fumigation in Plant #1, regrind and bin rooms were especially leaky with HLT of 2-5 h, resulting in CTP (412-492 gh/m^3, Table 2) below the target of 658 gh/m^3. In Plant #2, the CTP for SF (461 gh/m^3) was below the target of 600 gh/m^3, due to a leaky structure (HLT of 4 h). The regrind room of Plant #1 and the semolina room of Plant #2 had interior walls common to other areas of the plant that were not being fumigated. Normally, these adjacent areas would also be under fumigation, so leakage is not normally a problem. Even with that taken into consideration, the remaining areas of Plant #1 had a much lower HLT with SF (8.8 h) compared with the previous fumigation with MB (13.3 h). Higher winds, fluctuations in temperature or changes in sealing may account for these differences.

Methyl bromide CTP values were much higher (298-573 gh/m^3, Table 1) than that seen in the fumigations with flour mills (108-443 gh/m^3 average 286 gh/m^3, Harrison 2007). HLT in the pasta plants were much longer (9.9-17 h, Table 1) than in flour mills (1.2-12 h, average 5.4 h, Harrison 2007). This could be due to the pasta plants being newer structures and do not require explosion panels compared to flour mills.

Bioassays

Both MB and SF treatments were effective in killing 100% of adult *T. castaneum* in the bioassays. In the sulfuryl fluoride treatments, average egg mortality ranged from 69 to 81%. All eggs were killed in the MB fumigation (Table 1). Note, that the estimation of egg mortality is approximate, as the number of eggs varied from vial to vial. In the control vials, the number of adults that emerged from vials varied from 192-309 adults (247 $\pm$ 16, 8; mean $\pm$ SEM, n) for SF fumigation of Plant #1. Therefore, egg mortalities from individual vials, only give a rough estimate of survival at a given location, but all the vials taken together should give a good estimate of overall survival.

The lower than target CTP due to leakage was probably the cause of the egg survival in SF fumigations. There were 25 bioassays, located throughout the building. Whereas, the gas was sampled at ten locations in Plant #1 and Plant #3 and at two locations in Plant #2. This is sufficient sampling to estimate if more gas is needed in a particular area of the plant.

Table 1. Summary of efficacy of MB or SF fumigations in Canadian pasta plants.

Gas	Plant #	Start Date (month/yr)	Temp. Inside (°C)	Temp. Outside (°C)	Total Gas Added (g/m^3)[1]	Gas CTP (gh/m^3)	Gas Half Loss Time (h)	Bioassay Adult Mortality (%)	Bioassay Immature Mortality (%)	Trap catches Rebound Time (wks) Regularly Found[2]	Trap catches Rebound Time (wks) 100%[3]
MB	1	05/07	27.3	16.3	26	447	13.3	100	100	5	-
MB	1	05/08	-	-	26	494	12.3	-	-	1	never
MB	1	10/08	-	-	26	488	12.3	-	-	3	+ 20
MB[4]	2	06/07	29.0	20.0	-	573	17.1	100	100	-	-
MB[4]	3	06/07	30.9	17.4	22	298	9.9	100	100	12	-
SF	1	10/07	29.2	11.0	62	863	7.7	100	81	3	12
SF	2	10/07	27.6	12.1	59	461	4.0	100	69	-	-
SF	3	06/08	30.5	21.8	58	712	16.5	100	94	5	12

[1] g/m^3 is very close to $oz/1000\ ft^3$
[2] 3 consecutive weeks of insects trapped some where in plant, Plant #1 MB 05/07 trapping only started 5 weeks post fumigation
[3] Weeks for populations to return to 100 % pre-treatment levels
[4] No pre-trapping before fumigation, therefore unable to calculate time to rebound to 100%

Table 2. Concentrations of SF in different areas of Plant #1 and survival of bioassay insects

Fumigant	Plant #	Start Date (month/yr)	Location	Gas CTP (gh/m^3)	Gas Half Loss Time (h)	Bioassay Adult Mortality (%)	Bioassay Immature Mortality (%)
SF	1	10/07	New Bin Room	492	1.9	100	53
SF	1	10/07	Regrind	412	5.1	100	33
SF	1	10/07	Rest of Plant	965	8.8	100	89

Howver, there can be significant differences in gas at different locations in the building. For example, a vial was located beside a door and had 61% immature mortality, but the CTP for this area is 1005 gh/m^3, which should be sufficient to kill all eggs, but the CTP at the vial is probably lower due to leakage of gas out the door.

Traps

Only trap data from the SF fumigations in Plants #1 and 3 are presented. Flour beetles were found in Plant #2, however, Plant #2 never caught any insects in the traps, despite traps being deployed well before the MB and SF fumigations.

After MB fumigation in Plant #1, there were adults present right after the fumigation. Insects caught in traps rose after the MB fumigation in Plant #1. Insects were consistently caught in traps 1-5 weeks after MB fumigation. However, insects never returned to the pre-treatment levels after the MB fumigation in Plant #1 within in the 19-20 weeks post fumigation. The Plant #3 MB fumigation placed traps 3 weeks after fumigation, so there is no estimation of populations before the MB treatment. Insects were consistently caught in traps 12 weeks after MB fumigation in Plant #3.

After the SF fumigation, insects caught in traps in Plants #1 and 3 rose to 100% of pre-treatment levels 11 and 12 weeks respectively, after the SF fumigation. Insects were consistently caught in traps 3-5 weeks after SF fumigations (Table 1, Fig. 1).

Alternatives to MB

There are several alternatives to MB fumigation to control stored-product insects, the main ones being SF, heat, IPM and phosphine combination treatment (Banks, 2002; Fields and White, 2002; Harrison, 2007; MBTOC, 2007). These alternatives have mainly been used in flour mills, with only a few studies being done in pasta manufacturing facilities (Subramanyam, 2006; Trematerra and Süss, 2006).

This study followed three SF fumigations in pasta plants. Two of the fumigations were partial fumigations, with sections of the facility sealed off from SF. This caused excessive gas loss through leaking into other sections of the facilities. In 2007 and 2008, the label for ProFume only allowed fumigation of empty structures. Dow AgroSciences has applied for food tolerances for sulfuryl fluoride in cereals. This is under review by Health Canada. Being able to fumigate the entire structure, as done with Plant #3, will simplify the fumigation, and allow for better retention of the gas and hence more effective fumigations.

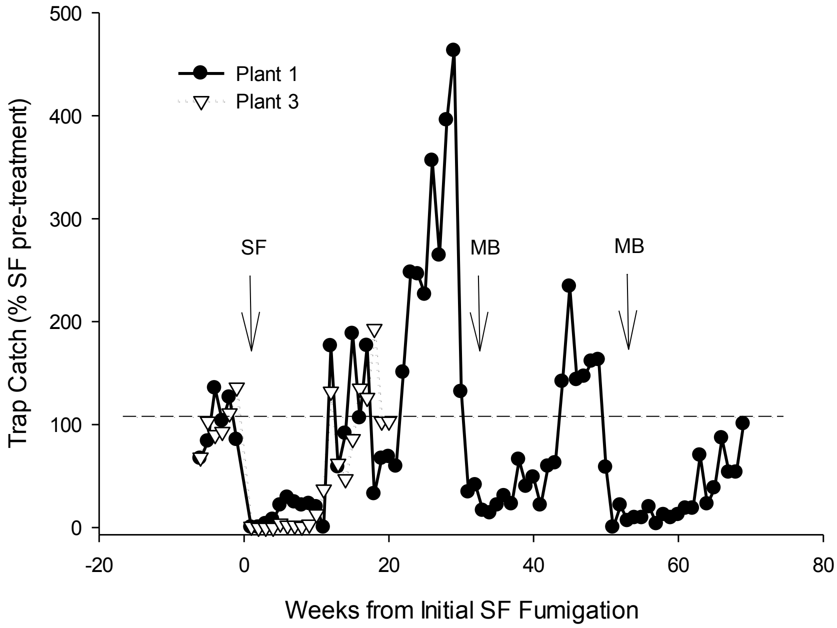

Fig. 1- The pheromone trap catch of flour beetles in Plants #1 and 3 before and after a fumigation with sulfuryl fluoride. Plant #1 continued trapping 60 weeks after SF fumigation (10/07) with a spring and fall MB fumigation in 2008. All numbers as % of SF pre-treatment.

Comparing fumigations is difficult, because pest pressures change from year to year, weather conditions change from year to year, two of the three SF fumigations were partial fumigations, pheromone trapping did not start before MB fumigations in Plant #3, Plant #2 had populations too low to measure the effect of fumigation and there are only three tests of SF. Immature mortality tended to be less with SF than with MB, although additional replication would be needed to verify this. Some of the immature survival could be due to doing partial fumigations, leaky sections of the plant and not achieving the target CTP values.

Plants #1 and 3 replaced a MB fumigation with the SF, and did not have to redo the fumigation with MB. Plant #2 did not conduct a full plant SF treatment. In Plant #3, after the SF fumigation in June 2008, nine additional foggings with dichlorvos were needed starting 2 months after the fumigation. Also, an additional cleaner was hired to increase sanitation to prevent an increase in insect populations. These measures had not been required in the past after MB fumigations.

All pasta facilities have extensive capacity for heating, so unlike flour mills, there would be no capital investment needed for boilers. Several issues would need to be addressed before heat could be used to control insects (Fields and White, 2002). However, there is one facility in the USA that has been using heat for insect control for several years (Subramanyam, 2006). The phosphine combination treatment (phosphine at 100 ppm, carbon dioxide at 5% and temperature at 30°C) has been used extensively in the USA and tested three times in Canada (Harrison, 2007). The European Community phased out MB in flour mills and pasta plants since 2008 (MBTOC, 2007). The alternatives have been mainly, increased sanitation, increased contact insecticides, SF or heat treatments (Trematerra and Süss, 2006).

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