Using liquid ethyl formate for disinfestation of insect pest in farm bin

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Field trials were carried out in Australia with ethyl formate for insect control in wheat (Harden, NSW), and split faba beans (*Vicia faba*) (Two Wells, SA) and sorghum (milo) (Warwick, Qld) in unsealed metal bins used to store grain on farms. Three adjacent unsealed metal bins (two for treatment and one for control) located on each farm site were used for the trials. Liquid ethyl formate was applied as a split dose (a first dose of 85 g t^{-1} and after 4 hours another dose of 85 g t^{-1}) to the top of the grain through a PVC probe (4 cm i.d. × 1.2 m) (Figure 1). This method of application was chosen to maintain ethyl formate concentrations below the flammability level, reduce vaporisation, maintain an effective concentration of ethyl formate for >10 hours, and to avoid liquid ethyl formate accumulating at the bottom of the bin. Table 1 provide details of trial's materials, dosage and bins.

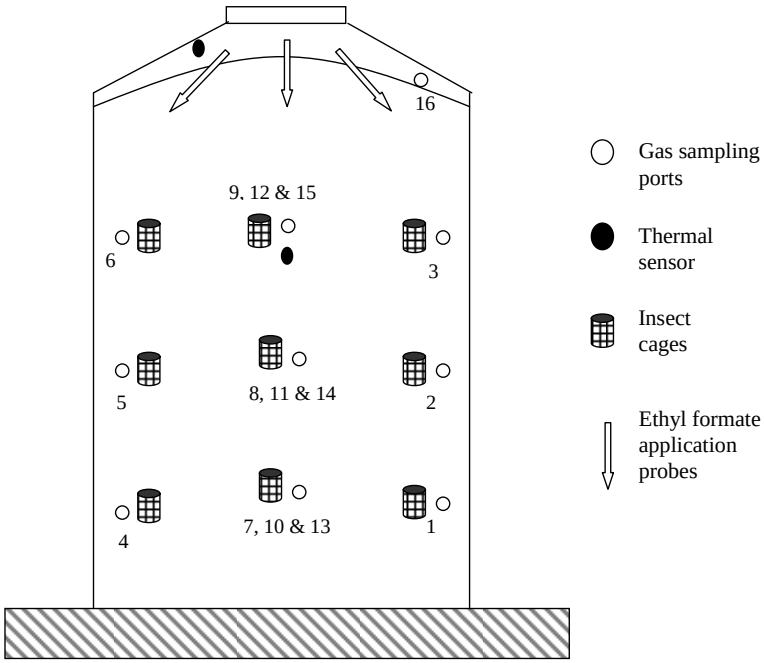

Fig. 1. Schematic representation of an unsealed farm bin showing gas sampling ports (1-16) and ethyl formate application system (5 application points).

- Gas sample ports 3, 6, 9 and 12 located at 1m below the grain surface and 0.4 - 0.5 m from bin wall.
- Gas sample ports 2, 5, 8 and 11 located at 2.5 m below the grain surface and 0.4 - 0.5 m from bin wall.
- Gas sample ports 1, 4, 7 and 10 located at 4m below the grain surface and 0.4 - 0.5 m from bin wall.
- Gas sample ports 13, 14 and 15 located at 1, 2.5 and 4 m and below the grain surface and in middle of the bin.
- Gas sample port 16 located at 0.5 m above the grain surface and in the central headspace.

Table 1 Details of unsealed metal bins on farms fumigated with ethyl formate on wheat, split faba beans and sorghum

Bin No.	Conditions	Wheat (Harden, NSW)	Split faba beans (Two Wells, SA)	Sorghum (Warwick, Qld)
1	Capacity	125t	75t	145t
	Quantity of grain	125t	75t	140t
2	Capacity	125t	75t	140t
	Quantity of grain	125t	75t	135t
1	Moisture content	11.1%	11.8%	15.2%
2		11.3%	11.8%	15.6%
1	Grain	34°C	27°C	10°C (later
2	temperature	34°C	27°C	harvested) 20°C
	Dose of ethyl formate	First dose: 85 g t^{-1} Second dose: 85 g t^{-1}	First dose: 85 g t^{-1} Second dose: 85 g t^{-1}	First dose: 85 g t^{-1} Second dose: 85 g t^{-1}

In-bin ethyl formate concentration during fumigation and airing. The average concentrations of ethyl formate in the bins after 1, 24 and 48 hours from application are shown in Table 2. The in-bin concentrations declined rapidly within the first day for sorghum and split faba beans. The distribution of ethyl formate became relatively even 4 hours after the first dosing in all but the low temperature sorghum bin. With wheat and split faba beans, the concentrations of ethyl formate were maintained at effective levels for about 2 days. Split faba beans and sorghum sorbed ethyl formate more strongly than wheat. After two days, the concentrations of ethyl formate declined to 8.5-8.8 g m^{-3} in wheat bins, 3.4-3.6 g m^{-3} in split faba bean bins and 1.6-3.8 g m^{-3} in sorghum bins. From day 2 to 5, the average readings fell from 8.8 g m^{-3} to 0.1 g m^{-3} for wheat at 33.5°C, from 3.5 g m^{-3} to 0.05 g m^{-3} for split faba beans at 26.5°C, and from 3.8 g m^{-3} to 0.1 g m^{-3} for sorghum at 20°C and 10°C. Before opening the inloading hatches, concentrations were well below the safety workspace level of 100 ppm of ethyl formate v/v and further declined once the grain was aerated.

Bioassays. Complete mortality of adult test insects was obtained in all bins and the proportions of insects surviving are shown in Table 3. With wheat and split faba beans, the in-bin concentrations of ethyl formate were maintained at effective levels for about 2 days at grain temperatures above 25°C. The concentration × time (*Ct*) products of 1100-2100 mg h L^{-1} obtained were sufficient to kill all adult stages rapidly (Tables 2, 3). With sorghum, the temperature was just below 20°C in Bin 2 and the relatively low *Ct* product of 950 mg h L^{-1} obtained was sufficient to kill all insect stages rapidly, but not the internal stages of S. oryzae (Tables 2, 3). Sorghum temperature was below 10°C in Bin 1, a low Ct product of 840 mg h L^{-1} was obtained, and adult insects were completely killed. Internal stages of S. oryzae and R. dominica, however, were controlled to a high level but not with 100% mortality (Tables 2, 3). This was probably due to liquid ethyl formate vaporising more slowly to ethyl formate gas at these lower temperatures, and the grain strongly absorbing the ethyl formate at the higher grain moisture content.

During the Harden, NSW trials, we found the natural insect population was >20 insect kg^{-1} (grain) after a short period of storage of the newly-harvested wheat. The insects were *Tribolium* spp., *Sitophilus* spp., psocids and wasps. More than 2% of the wheat was damaged by the insects causing loss of dry mass and quality (commercial value) of wheat. It would appear that the newly-harvested grain was infested with insects probably from headers and harvest bins. During the Two Wells, SA and Warwick, Qld trials, we found similar damage on the sorghum and split faba beans. This indicates that the loss of dry mass and commercial value due to insect damage is a common issue in on-farm storage. Complete mortality of natural infected insects was obtained in all bins with ethyl formate treatment.

Table 2 Mean ± SD (n=16) in-bin ethyl formate concentrations in farm bins containing wheat, split faba beans and sorghum at 1, 24 and 48 hours after completion of the application and concentration × time (*Ct*) product

Commodities	Bin No.	Ethyl formate concentration (g m^{-3})			*Ct* product (mg h L^{-1})
		1 hour	24 hours	48 hours	
Wheat	1	82.3±10.2	48.4±3.1	8.8±1.4	2140
	2	80.2±9.8	43.6±3.2	8.5±1.2	2100
Split faba beans	1	76.0±7.6	9.9±1.5	3.6±0.5	1200
	2	67.1±7.1	10.7±1.7	3.4±0.5	1100
Sorghum	1	57.7±6.1	6.6±3.0	3.8±0.4	840
	2	62.9±6.7	8.8±3.3	4.6±0.7	950

Table 3 Insects emerging from mixed-age cultures after treatment with ethyl formate in farm bins containing wheat, split faba beans and sorghum. The data recorded in the table were from 6 weeks after treatment

Commodities	Bin No.	*Sitophilus oryzae*	*Rhyzoperth a dominica*	*Tribolium castaneum*	*Callosobruchu s phaseoli*
Wheat	1	0	0	0	-
	2	0	0	0	-
Split faba beans	1	0	0	0	0
	2	0	0	0	0
Sorghum	1	18(0-23)%	1(0-3)%	0	-
	2	4(0-16)%	0	0	-

Workspace and environmental levels of ethyl formate. During the three field applications, 60 samples were taken in the working environment at distances of 3 m, 6 m and 15 m from the bins. Ethyl formate was detected in 6 air samples and was always below 15 ppm which is well below the worker safety (TLV) level of 100 ppm. Ethyl formate was not detected in the other 54 air samples, with a limit of detection of 0.5 ppm v/v which is 0.5% of the TLV of 100 ppm v/v. During the 2-3 days exposure period, 58 air samples were taken in the working environment at distances of 3 m, 6 m and 15 m from the bins and the level of ethyl formate was below the limit of detection (0.5 ppm v/v) in all air samples. All readings taken to determine workspace and environmental levels of ethyl formate during application to the grain and during exposure were far below the TLV limit of 100 ppm v/v.

Residues and natural levels of ethyl formate in grains. At the end of the fumigation, the top hatch was opened and grain samples were taken with a probe at depths of 0.5 m, 2 m and 3.5 m below the grain surface. More than 120 samples (including 12 untreated samples) were analysed. After 7 days fumigation, the ethyl-formate residues were determined and the results are shown in Table 5. Residues were even and declined uniformly and rapidly without aeration. For wheat and sorghum, residues were reduced quicker than split faba beans, but still were higher than the natural levels (levels of ethyl formate in unfumigated samples). For wheat, split faba beans and sorghum, after 2, 4 and 3 weeks from fumigation respectively, the residues had declined to natural levels. The ethyl formate residue profiles for freshly-harvested sorghum and the older split faba beans were also examined in the laboratory. In freshly-harvested sorghum ethyl-formate residues were reduced to natural levels within 3 weeks from application but split faba beans took more than 4 weeks for residues to return to near background levels. The residues in split faba beans however, were slower to break down than expected. Residues in the sorghum at 10ºC also persisted significantly longer than at 20ºC.

Conclusions. Field trials have shown that ethyl formate has good potential as a fumigant in unsealed small metal bins on farms. Unlike phosphine, which takes days to kill insects, ethyl formate kills rapidly. At the split two dosage of 85 g t^{-1}, ethyl formate gave a high level of control of all stages of most of the test insects in the wheat, split faba beans and sorghum bins. With sorghum, it was difficult to achieve complete control of insects when the temperature was lower than 20°C. Therefore, it is suggested that 20°C is the marginal temperature for use of ethyl formate with sorghum as a grain fumigant. Ethyl formate, as shown in these and other trials, has advantages in terms of worker and environment safety. During application and fumigation, the levels of ethyl formate in the working environment did not exceed the worker safety level of 100 ppm (TLV). Ethyl formate residues can be reduced to natural levels without aeration.