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FUMIGATION OF OATEN HAY FOR EXPORT – ALTERNATIVES TO METHYL BROMIDE

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ABSTRACT

Oaten hay for animal feed, is shipped to Japan and other countries from Australia after methyl bromide or phosphine fumigation. However for environmental as well as health and safety reasons these techniques require alternatives. Trials were conducted to develop alternatives using 2% PH_3 in CO_2 (Phosphume) and CO_2 alone. Approximately 300 containers of 67 m^3 were used. In addition treatments were carried out in pallet sized units for break-bulk shipment. The pests fumigated were mainly stored-product insects. Quality control procedures were developed through moisture measurement in the field, before harvest and through the drying and baling stages. Techniques were developed to (a) increase the packing density without affecting product quality, (b) improve gastightness, and (c) reduce fumigant dosage. A quality assurance process was developed to reduce quarantine inspections while achieving the highest standards of shipped produce. Economic analysis showed a benefit / cost between 30 and 44 depending on the measures adopted. The techniques developed could be used for the treatment of other durable commodities in developing countries.

INTRODUCTION

Oaten hay is an important Australian export commodity. Approximately 225,000 tonnes worth more than AU$ 74 million are exported annually from Australia to Japan. Since live insect contamination is a major factor affecting profits and Japan has a nil tolerance for live insects, effective disinfestation is essential to increasing profitable trade.

In a previous paper on disinfestation of export hay in containers, (De Lima *et al.*, 1994), new fumigation protocols were developed for effective use of methyl bromide (MB) and phosphine (PH_3) that required the rapid and uniform dispersal of fumigant throughout the container. MB is widely used in hay disinfestation because of the short exposure period required. However, it is a potent ozone depleter due to be phased out by 2005, and alternative treatments must be considered. The work reported here was undertaken to test PH_3 and carbon dioxide (CO_2) as alternatives to MB fumigation.

MATERIALS AND METHODS

Insects tested

Hay is often contaminated during field drying by a number of minor insect pests, and during storage, by stored-product insects, often due to its proximity to grain stored on the farm. Since surviving insects in hay are stored-product pests, two major species, *Tribolium castaneum* (Herbst) and *Sitophilus granarius* (L.) were tested, the latter species being noted for its tolerance to phosphine. Cultures containing all stages (>10,000 insects) were placed in gauze covered vials at 1 m intervals in a 12 m PVC tube, introduced into the centre of the container filled with bales of export hay. After exposure to the specified treatment, vials were removed and placed in an incubator. They were sieved after 2 and 14 d to assess survival. Mortality in control samples was assessed at the first sieving.

Test containers and sampling methods

Trials were conducted in 12.2 m (40 ft), 67 m^3 ISO shipping containers loaded with compressed bales approximately 500 mm x 400 mm x 400 mm and weighing 50 - 56 kg depending on moisture differences and compression by the baler. Each container carries approximately 598 bales giving a load of 30-34 tonnes/container. The gross product volume is approximately 48 m^3, achieving a load factor of 71.4% and approximately 0.47 tonnes/ m^3.

The majority of the trials were conducted in containers packed with hay ready for export. These containers were fitted with 3 nylon gas sampling lines along the front, middle and rear end of each container. The required treatments were applied, and observations made every 24 h or more frequently if necessary. The containers were released for shipment on the request of the exporter.

For long term trials, containers were rented, that had a specific gas-tightness. Fifty gas sampling lines were introduced into each container to measure gas concentrations uniformly, in 15 positions in the airspace between bales and 35 positions in the center of bales. Each sampling point measured approximately 1.34 m^3 of surrounding space. All gas sampling lines were drawn to the top surface of the container directly above their position in order to minimise the dead volume in the line. Temperatures were measured by placing thermistor probes in bales uniformly at 7 locations throughout the container. One external probe measured the ambient temperature outside the container. The probes were connected to a digital data logger (TREND™) programmed to record data at hourly intervals throughout each trial.

Measurement of gas-tightness of containers

The gas-tightness of test containers was measured by introducing compressed air from a ‘G’ size cylinder into the sealed container through an air hose fitted with a shut-off valve. A modified "finger device" (Sharp and Cousins, 1982) of hard plastic tubing was fitted under the door-jamb of the sealed container to admit compressed air and to sense the pressure developed. The pressure was measured by a "Dwyer Magnahelic™ Differential Pressure Gauge series 2000, 250 PaC" that required the needle on the gauge to register a deflection of 250 Pa before the compressed air supply is turned off. As the pressure drops, the time taken (in seconds) for the pressure to drop from 250 to 125 Pa is measured on a stop-watch and is used as the pressure decay value. All containers used in the trials reported in this paper had a pressure decay value of 6 sec or greater. This enabled the trials to be conducted without the use of tarpaulins.

Application of fumigants

Commercial applications of ECO_2FUME® (2% PH_3 in CO_2 by weight in cylinders) were done without the need for a heat exchanger, by using a purpose-built PVC application pipe the same length as the container, and with 4 mm diameter holes drilled at 100 cm intervals starting 200 cm from the door end of the container. The pipe was introduced along the top of the bales through the center of the container and was left in place for the duration of the fumigation. A similar PVC application pipe was used for application of PH_3 in sachets. The pipe diffuses the gases uniformly and allows removal of sachets before export, thus eliminating residues.

Food grade CO_2 was applied as a gas using 2 x 'G' size cylinders to deliver 62 kg of CO_2 through the PVC application pipe. Alternatively, CO_2 was applied as 60 kg dry ice placed in one polystyrene box (replacing one bale of hay) in front of the container and 31 kg of CO_2 gas applied from the cylinder through the PVC application pipe. The third application method was to apply 120 kg dry ice placed in two polystyrene boxes (replacing 2 bales of hay) in front of the container. Fumigations were conducted throughout the year, under temperatures ranging from 15–35°C.

Measurement of fumigant concentrations

Gas concentrations were measured at regular intervals by using direct reading instruments (Riken™ interferometer for methyl bromide; an EC80 Phosphine Monitor™ for PH_3; and an ANRI Instruments BM2™ solid state infra red filtered monitor for CO_2); gas detector tubes (Auer™) and gas chromatographs (Varian™ 3400 Series with a Flame Ionisation Detector for methyl bromide; and a Thermionic Specific Detector for PH_3). Cumulative Ct products were calculated using the method described by Bond (1989).

RESULTS

Trials under warm spring, summer and autumn conditions (20–30°C) showed that PH_3 at the standard dose (approximately 1,000 ppm initial dose) applied as ECO_2FUME® was uniformly available as an effective dose (>100 ppm) within the first 2 h of application. It was well above 400 ppm in containers exceeding the 6 sec pressure decay value after 4 days (Table 1). The 4 d (96 hour) exposure was sufficient to control *T. castaneum*. Reduction of the initial PH_3 dose by 50% to give approximately 500 ppm was found to be effective against *S. granarius*. Thus the 4-day exposure period was sufficient for control of these stored-product pests, provided the end concentration in the container after 96 h was above 200 ppm. This finding has practical benefits in terms of cost, residual period for PH_3 and turn-round time for export shipments.

TABLE 1
Fumigation of export hay in shipping containers using phosphine under spring, summer and autumn conditions (diurnal range 20 – 30°C)

Pressure decay test (sec)	Phosphine conc. (ppm) mean ± s.d. following initial (nominal) dosage shown*				No. insects exposed	No. of survivors	Control mortality (%)
	24 (h)	48 (h)	96 (h)	144 (h)			
Insects treated : *Tribolium castaneum* (Herbst) Phosphine applied as: (ECO_2FUME® 1000 ppm initial dose*)							
6	945 ± 31	552 ± 28	427 ± 16	-	10,816	0	0.8
8	1013 ± 78	672 ± 20	453 ± 31	-	11,648	0	1.4
10	978 ± 28	682 ± 28	488 ± 19	-	11,246	0	0.6
Insects treated : *Sitophilus granarius* (L.) Phosphine applied as: (ECO_2FUME® 500 ppm initial dose*)							
7	435 ± 30	352 ± 20	225 ± 31	-	11,456	0	0.6
6	418 ± 26	375 ± 31	252 ± 18	-	10,304	0	0.8
8	470 ± 36	358 ± 40	272 ± 35	-	11,328	0	1.2

Trials under cold autumn, winter and spring conditions (15–20°C), showed that PH_3 applied as ECO_2FUME® at 500 ppm was effective against *T. castaneum* as a 6 d treatment provided the final dose remained above 100 ppm (Table 2). When PH_3 was applied as aluminium phosphide sachets at the nominal dose of 1,200 ppm, the concentration after 24 h was above 400 ppm and declined to approximately 200 ppm after 6 d. This treatment was effective against *S. granarius* in the shipping containers.

Control using CO_2 alone was found effective when temperatures exceeded 25°C during the summer months. Carbon dioxide was applied as dry ice or as a combination of CO_2 gas drawn from cylinders and dry ice (Table 3). The treatments were effective against both *S. granarius* and *T. castaneum* over an exposure period of 14 days. The advantage of using a gas + dry ice combination is that only one hay bale needs to be removed from the container. In addition a higher initial gas concentration is available over 48 h, although this does not affect the outcome for control over the 14-day exposure period. The disadvantage of treatments using CO_2

alone, is that containers are required to have a very high level of gas-tightness (>14 sec) to be able to retain the gas concentration above 25% over 14 d.

TABLE 2
Fumigation of export hay in shipping containers using phosphine under autumn, winter and spring conditions (diurnal range 15 – 20ºC)

Pressure decay test (sec)	Phosphine conc. (ppm) mean ± s.d. following initial (nominal) dosage shown* 24 (h)	48 (h)	96 (h)	144 (h)	No. insects exposed	No. of survivors	Control mortality (%)
Insects treated : *Tribolium castaneum* (Herbst) Phosphine applied as: (ECO_2FUME® 500 ppm initial dose*)							
7	409 ± 35	359 ± 31	208 ± 24	178 ± 18	10,496	0	0.7
9	455 ± 39	333 ± 35	198 ± 30	141 ± 18	11,200	0	0.4
12	424 ± 25	351 ± 51	206 ± 29	185 ± 20	10,720	0	2.1
Insects treated : *Sitophilus granarius* (L.) Phosphine applied as: aluminum phosphide sachets 1200 ppm initial dose*							
8	414 ± 32	628 ± 47	335 ± 45	225 ± 30	10,176	0	1.1
12	553 ± 39	779 ± 28	341 ± 31	220 ± 25	11,008	0	0.9
11	468 ± 28	729 ± 43	358 ± 32	231 ± 43	10,624	0	0.8

In Australia, exporters do readily have access to highly sealed containers. For this purpose a combination of PH_3 and CO_2 is a more practical alternative (Table 4). Trials carried out over autumn, winter and spring at temperatures ranging from 15–20°C showed effective control of both *S. granarius* and *T. castaneum* over a 14-day exposure, when phosphine levels remained above 50 ppm and CO_2 exceeded 15%.

DISCUSSION

Phosphine and CO_2 were found to be suitable alternatives to MB in the fumigation of export hay. The advantage of MB is that it can be used to achieve disinfestation within a few hours, whereas PH_3 and CO_2 require 4 d and 14 d respectively in summer. The disadvantage of MB is that it is highly adsorbed on hay and is a severe ozone depleter. MB will shortly be phased out in Australia.

The successful use of PH_3 as a gas requires an exposure period of 4 d at temperatures > 20°C and 6 days at 15–20°C. This method of treatment is a viable alternative to MB since application can be done shortly before shipping in suitable gas-tight containers and disinfestation is achieved in-transit. This method is economical and cost effective, and can achieve turn-round times similar to MB treatments.

Pressure testing of containers is essential for fumigation with PH_3 and CO_2. Phosphine should not be used in containers with a pressure decay value of less than 6 seconds. Effective CO_2 concentrations cannot be held in containers with a pressure decay value of less than 14 seconds.

TABLE 3
Fumigation of export hay in shipping containers using carbon dioxide. Summer conditions (diurnal range 25 – 35ºC)

Pressure decay test (sec)	Carbon dioxide (%) mean ± s.d. following initial (nominal) dosage shown* 2 (d)	6 (d)	10 (d)	14 (d)	No. insects exposed	No. of survivors	Control mortality (%)
Insects treated : *Tribolium castaneum* (Herbst) Carbon dioxide (%) applied as: dry ice 120 kg initial dose*							
16	42 ± 4	36 ± 5	37 ± 6	30 ± 8	10,304	0	1.3
14	46 ± 4	39 ± 7	36 ± 5	33 ± 3	10,912	0	0.9
14	51 ± 7	37 ± 8	36 ± 6	28 ± 3	11,392	0	0.4
Insects treated : *Sitophilus granarius* (L.) Carbon dioxide (%) applied as: dry ice 60 kg + gas 31kg initial dose*							
16	61 ± 5	51 ± 3	38 ± 6	30 ± 4	11,520	0	0.0
16	66 ± 4	56 ± 11	40 ± 7	34 ± 7	12,288	0	0.2
14	66 ± 3	51 ± 10	44 ± 7	29 ± 8	11,264	0	0.6

Carbon dioxide fumigations are not effective at temperatures below 25°C. Containers charged with CO_2 and supplemented with dry ice to give initial concentrations of 60% CO_2 showed that concentrations should be maintained at approximately 35% for 10 d and above 25% for 14 d for effective control to be achieved.

Combinations of CO_2 and PH_3 offer the best option for use in the export hay industry where containers of 6 seconds pressure decay value are more readily available. CO_2 may be applied as gas or dry ice, while PH_3 may be applied as solid (sachets) or as a 2% gas in CO_2. The advantage of using the PVC pipe with sachet application of PH_3 is that residues may be removed before shipment. Phosphine concentrations must be above 50 ppm and CO_2 above 15% for 14 days.

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TABLE 4
Fumigation of export hay in shipping containers using carbon dioxide + phosphine.
Autumn, winter, spring, conditions (diurnal range 15 – 20ºC)

Pressure test (sec)		Phosphine conc. (ppm) mean ± s.d. + Carbon dioxide (%) mean ± s.d. 2 (d)	6 (d)	10 (d)	14 (d)	No. insects exposed	No. of survivors	Control mortality (%)
Insects treated : *Sitophilus granarius* (L.) Phosphine applied as: aluminum phosphide sachets 1200 ppm initial dose* Carbon dioxide (%) applied as: dry ice 60 kg initial dose*								
8	PH_3	616±66	259 ± 49	129 ± 21	68 ± 15	12,672	0	1.1
	CO_2	41 ± 8	31 ± 3	25 ± 5	18 ± 2			
6	PH_3	679±56	203 ± 27	105 ± 22	54 ± 12	10,112	0	0.8
	CO_2	46 ± 3	34 ± 5	25 ± 4	18 ± 4			
8	PH_3	694±70	219 ± 27	118 ± 24	61 ± 19	12,480	0	0.3
	CO_2	42 ± 4	35 ± 4	26 ± 2	20 ± 3			
Insects treated : *Tribolium castaneum* (Herbst) Phosphine applied as: (ECO_2FUME[illegible] 500 ppm) initial dose* Carbon dioxide (%) applied as: dry ice 60 kg initial dose*								
8	PH_3	358±52	193 ± 43	139 ± 28	61 ± 18	10,624	0	0.2
	CO_2	41 ± 5	32 ± 6	26 ± 5	18 ± 3			
9	PH_3	398±62	163 ± 40	102 ± 21	76 ± 18	11,456	0	0.9
	CO_2	44 ± 5	37 ± 10	23 ± 3	16 ± 4			
6	PH_3	386±67	139 ± 38	84 ± 34	52 ± 19	12,032	0	0.5
	CO_2	45 ± 4	38 ± 4	23 ± 7	18 ± 4			

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