Navarro, S. and Donahaye, E. [Eds.](1993) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd., Jerusalem, pp. 477-481.

THE EFFECT OF DECREASING CONCENTRATIONS OF CARBON DIOXIDE ON THE SURVIVAL AND DEVELOPMENT OF INSECT PESTS OF STORED-PRODUCTS

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ABSTRACT

An experimental protocol was devised that permitted controlled leakage of carbon dioxide (CO_2) from a metal drum. The effects were studied at 27°C, on the survival and development of *Sitophilus oryzae, S. zeamais, Tribolium castaneum*, and *Rhyzopertha dominica*, using initial concentrations of CO_2 of 60 - 80% diminishing over various time periods. Control of all developmental stages of these insects was not found possible in the time period associated normally with conventional fumigants, but might be possible in fumigation periods of five to seven days.

INTRODUCTION

Increasing concern regarding the development of insect resistance to phosphine, and increasingly likely restrictions in the future on using methyl bromide, have heightened interest in the potential use of carbon dioxide (CO_2) as a grain fumigant. It is not particularly toxic to insects, and previous recommendations, derived mostly from toxicity data at constant concentrations, have recommended high initial gas concentrations with exposure periods exceeding ten days (Annis, 1987). An investigational programme was initiated to determine the effect of decreasing concentrations of CO_2 on selected insect pests, in order to establish if shorter exposure periods might be used to provide effective control.

MATERIALS AND METHODS

Adult and pre-adult stages of *Sitophilus oryzae* (L.), *S. zeamais* (Motsch.), *Tribolium castaneum* (Herbst), and *Rhyzopertha dominica* (F.), contained in metal cages, were exposed to CO_2 at 27°C and 70% relative humidity (r.h.), in a 200 l gas-tight metal drum. CO_2, (99% purity), was introduced into the drum, residual air being ventilated through an aperture, until the desired gas concentration was obtained. A stirrer and gas sampling port were provided, enabling measurement of CO_2 and oxygen (O_2) concentrations, using a Bedfont 425 Dual Gas Analyser. Initial CO_2 concentrations were of the order of 80%, diminishing by approximately 10% in successive periods of 24 hr. Observations of adult insect mortality were made 24 hr and seven days after removal of exposed samples from the drum. To determine the effect on pre-adult stages, samples were retained for a sufficient period for completion of the life-cycle.

RESULTS AND DISCUSSION

Effective control of three of the four species of adult insects tested was obtained within a two-day period under the CO_2 regime employed, but control of adult *S. zeamais* required three days (Fig. 1). Pupal and 4th instar larval stages of *T. castaneum* were not controlled in a two-day exposure, but were controlled in an exposure lasting five days, the concentration of CO_2 by this time having decreased to 40% (Fig. 2).

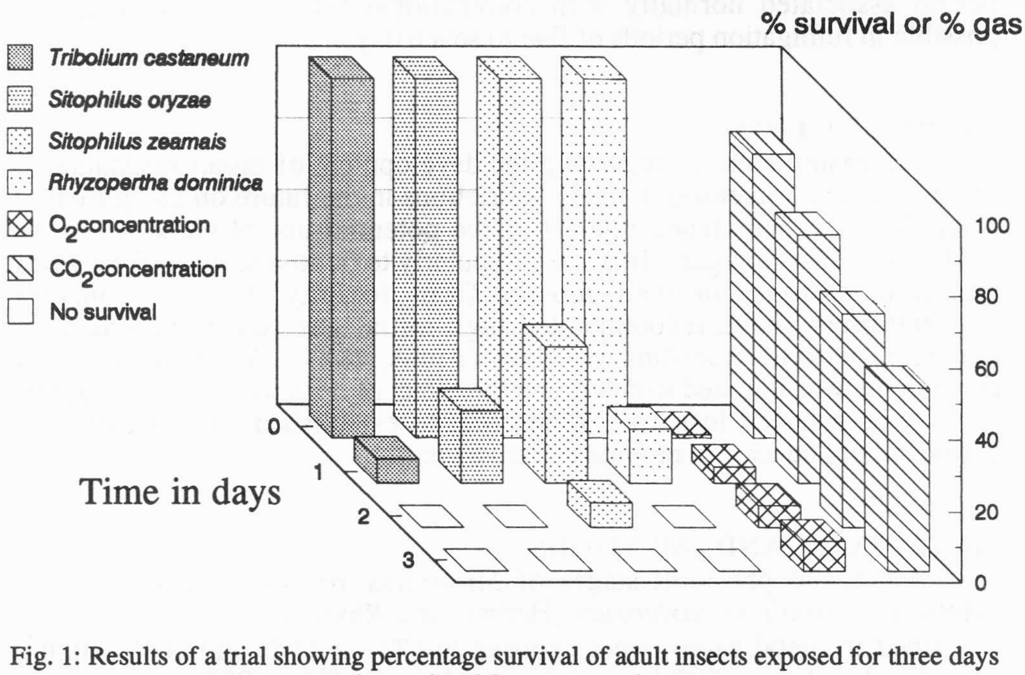


Fig. 1: Results of a trial showing percentage survival of adult insects exposed for three days to decreasing CO_2 concentrations.

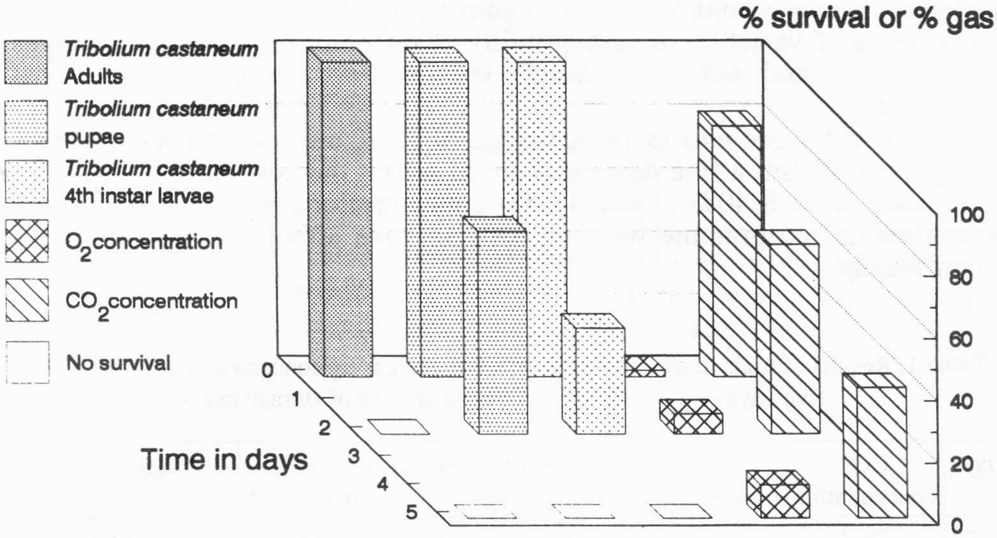
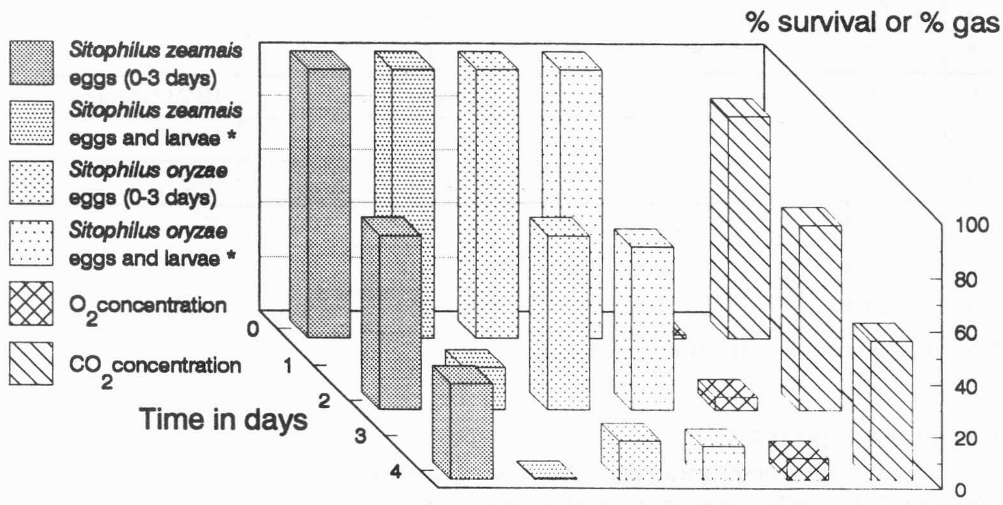


Fig. 2: Results of a trial showing percentage survival of different stages of *Tribolium castaneum* exposed for five days to decreasing CO_2 concentrations.



*** juvenile stages (eggs and young larvae) 0-16 days old**

Fig. 3: Results of a trial showing percentage adult emergence from immature stages of *Sitophilus* spp. exposed to decreasing concentrations of CO_2.

Exposure of egg and larval stages of *S. zeamais* and *S. oryzae* for a four-day period, in which the concentration of CO_2 decreased from 83-53%, failed to produce complete insect control (Fig. 3). There were, however, indications of variation in susceptibility of different developmental stages both within and between, insect species. For example, larval/pupal stages of *S. oryzae* and *S. zeamais* in the age-range of 23-30 days, were not controlled completely within a five day exposure in which the concentration of CO_2 decreased from 8-40% (Table 1), O_2 concentrations recorded during the experimental programme were unlikely to have affected insect mortality significantly.

Table 1: Results of trials to determine the effect of decreasing concentrations of CO_2 over five days on juvenile stages of three species of storage pest.

Days	CO_2 concentration	O_2 concentration	*S. zeamais**	*S. oryzae**	*R. dominica**	Age (days)
0	78.7	1.9	100	100	100	0-8 (eggs/larvae)
2	73.1	3.2	30	25	1	0-8 "
5	58.4	7.0	0	0	0	0-8 "
0	80.4	2.0	100	100	100	8-15 (larvae)
2	60.7	6.8	1.3	6	0	8-15 "
5	42.0	10.8	0	0	0	8-15 "
0	80.4		100	100		10-23 (larvae)
2	63.2		62	52		10-23 "
5	40.5		0	0		10-23 "
0	80.4		100	100	100	23-30 (larvae/pupae)
2	63.2		36	24.8	68	23-30 "
5	40.5		7	6.7	0	23-30 "

* Percentage survival with respect to control.

CONCLUSIONS

Data obtained under conditions of diminishing CO_2 concentration indicated that effective control of some of the more common insect pests of stored-products is not achieved using exposure periods of the duration employed commonly for conventional fumigants. However, it seems likely that effective control of these insects might be achieved in periods of five to seven days at temperatures of 25-30°C, indicating a possible use for CO_2 in some circumstances, as an alternative to fumigation with phosphine. Further investigational programmes are essential to determine if CO_2 plays any real role as an alternative to conventional fumigants, and to what extent sufficiently gas-tight conditions could be obtained under practical, cost effective, field situations.

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Navarro, S. and Donahaye, E. [Eds.](1993) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd., Jerusalem, p. 483.

SEALED STORAGE TECHNOLOGY ON AUSTRALIAN FARMS

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ABSTRACT

The technology of sealed storage has been commercially available to Australian grain growers since the early 1980s. Widespread application on farms has, however, only occurred in the state of Western Australia. Factors that affect adoption rates are detailed in the paper and include government policy, availability of information, grain quality standards and geographical location. Sealed storage has several advantages over conventional unsealed storage on farms: it allows rapid and complete disinfestation of stored grain; "non-chemical" control agents such as carbon dioxide can be used; lower dosages of fumigants are effective thus reducing costs; unacceptable residues from contact insecticides are avoided; and reinfestation of grain is less likely. The advantages are most apparent to silo operators who store "non-traditional" crops such as grain legumes. These commodities often have stricter market limits on quality and/or attract insects that are relatively tolerant of poor fumigation and controlled atmosphere (CA) practices. On-farm sealed storage is restricted almost exclusively to metal silos, including flat-bottomed and elevated designs. The evolution over the last 15 years of sealing methods used on these storages was discussed, and cost/performance compromises identified. The importance of effective transfer of information on the design, performance and operation of sealed silos to both manufacturers and operators was stressed. Inadequate maintenance of silos often results in a rapid decline in performance, and is a major barrier to wider adoption of sealed storage on farm

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QUALITY CHANGES IN PEANUTS SHIPPED BY RAIL UNDER CARBON DIOXIDE

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ABSTRACT

Forty-eight loads of shelled peanuts were shipped by rail from May 15 - October 5, 1991 from southern Alabama to Lexington, Kentucky. Rapid gaseous CO_2 filling stations were engineered to fill the rail cars to a concentration of 55-80% CO_2 (approximately 410 kg CO_2 per car) before sealing and shipment. Forty one loads were treated with CO_2 and seven companion loads were fumigated with PH_3. The maximum CO_2 concentration in the ambient atmosphere surrounding the cars was below 0.5% during filling and no elevated CO_2 was detected during unloading. The effectiveness of CO_2 fumigation depends on the retention of CO_2 for several days. There was complete insect control in all but two of the cars treated with CO_2, and these had to be refumigated with PH_3 in Lexington. After shipment, neither the moisture content (m.c.) nor the microflora of the peanuts shipped under CO_2 atmosphere differed from those found with the PH_3 fumigation.

EXPERIMENTAL

This field trial was designed to find out if CO_2 fumigation of rail cars to approximately 60%CO_2 could be used to control insects while not adversely affecting the peanuts during rail shipment. Forty-eight rail cars (86,000 kg/car) of US no.1 shelled peanuts (6-7% kernel m.c.) were shipped from two locations in Alabama to Lexington, Kentucky in 1991 (Table 1). The initial and final CO_2 percentages in the atmosphere and number of dead and live insects at Lexington are given in Table 2.

The incidence of fungi before and after transit is given in Tables 3 and 4. The numbers in Tables 3 and 4 represent % of 200 kernels from each location from which the fungus was isolated after incubation for 7 days at 30°C on malt salt agar containing 10% NaCl. Peanuts were sampled from the top and bottom of the rail car during loading and unloading. Fungi presence was tested before and after fumigation with CO_2 or PH_3. The m.c. was unaffected by the treatments.

Table 1: Treatments of US no.1 shelled peanuts shipped to Lexington, KY from May 15 - October 5 1991 by 48 rail cars.

Shipping point	Treatment	Tempered[a]	Non-Tempered	Total
Sunstates	CO_2[b]	11	6	17
Dothan, AL	PH_3[c]	2	3	5
DOMCO	CO_2	0	24	24
Headland, AL	PH_3	0	2	2
		13	35	48

[a] Tempered - peanuts were tempered after removal from cold storage before unloading rail cars.
[b] Gaseous CO_2 was added during bulk loading. The entire CO_2 fumigation added about 15 minutes to the loading process.
[c] Aluminium phosphide strips were used at the recommended dosage for peanuts.

SUMMARY OF FINDINGS

1. All Sunstates peanut shipments gave complete insect control, while two of 24 DOMCO shipments required refumigation with PH_3 in Lexington, KY.
2. Costs were as follows:
    a) CO_2 tank installation ranges from $3,000-$11,000.
    b) 410 kg CO_2 were required per car, amounting to $70/car.
    c) Tank rental was $425 per month, plus an annual rental fee.
3. CO_2 filling stations were efficient. No vacuum developed in bulk cars.
4. Peanut m.c. and microflora counts were similar after shipment for CO_2 and PH_3 treatments.
5. CO_2 levels outside rail cars were less than 0.5% during loading and did not elevate during unloading.

CONCLUSION

Rail cars were fumigated successfully with CO_2. The CO_2 treatment resulted in the death of insect adults and larvae when the CO_2 did not escape too rapidly. The CO_2 fumigation had a minimal effect on m.c. and fungal microflora during shipment in this field trial.

Table 2: Selected data on CO_2 concentrations and insect control[a,b].

Fill Date	Unload Date	Ship From	Initial CO_2	Final CO_2	Dead Insects	Live Insects
15 May	27 May	DOM	74	70	5	0
16 May	30 May	SSD	64	58	0	0
28 May	6 Jun	SSD	62	8	25	0
7 Jun	18 Jun	SSD	77	60	0	0
7 Jun	20 Jun	DOM	60	24	0	0
10 Jun	25 Jun	DOM	60	10	0	0
11 Jun	26 Jun	DOM	60	7	0	0
12 Jun	18 Jun	SSD	75	5	0	0
12 Jun	22 Jun	SSD	75	49	0	0
14 Jun	25 Jun	SSD	73	23	0	0
27 Jun	3 Jul	SSD	75	35	0	0
28 Jun	5 Jul	SSD	75	48	0	0
9 Jul	15 Jul	SSD	75	0	0	0
12 Jul	20 Jul	SSD	73	30	1	0
16 Jul	24 Jul	SSD	73	40	0	0
16 Jul	24 Jul	DOM	60	20	8	5*
18 Jul	24 Jul	SSD	73	20	0	0
24 Jul	5 Aug	DOM	58	4	1	0
25 Jul	5 Aug	DOM	63	60	1	0
31 Jul	17 Aug	DOM	58	4	0	0
3 Aug	16 Aug	DOM	58	3	0	0
8 Aug	19 Aug	DOM	58	5	0	20*
10 Aug	19 Aug	DOM	60	20	1	0
14 Aug	21 Aug	DOM	58	10	1	0
14 Aug	23 Aug	DOM	58	10	0	0
10 Sep	24 Sep	DOM	60	5	8	1
14 Sep	25 Sep	DOM	60	7	0	0
27 Sep	9 Oct	DOM	60	0	3	0
2 Oct	11 Oct	DOM	70	3	0	1

[a] Shipping point: DOM = DOMCO, SSD = Sunstates. No live insects were found in the 7 cars fumigated with PH_3.

[b] Loads marked with * were refumigated with PH_3 in Lexington.

Table 3: Mean incidence (average % from 41 cars) of fungi in peanuts before CO_2 treatment and after transit.

	Top		Bottom	
	Before	After	Before	After
Aspergillus flavus	45	39	39	39
Aspergillus niger	28	25	32	26
Other *Aspergilli*	69	68	61	41
Penicillium spp.	1	1	1	3
Fusarium spp.	1	1	1	1
Other fungi	13	19	19	26

Table 4: Mean incidence (average % from 7 cars) of fungi in peanuts before PH_3 treatment and after transit.

	Top		Bottom	
	Before	After	Before	After
Aspergillus flavus	57	56	42	40
Aspergillus niger	44	10	38	18
Other *Aspergilli*	63	65	93	87
Penicillium spp.	1	0	2	1
Fusarium spp.	1	1	1	0
Other fungi	21	16	23	31

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PHYTO EXPLO® FUMIGATION: IN TRANSIT GRAIN FUMIGATION IN THE HOLDS OF A TANKER/BULKER

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ABSTRACT

The procedure for in-transit fumigation of grain in ship-holds using the PHYTO EXPLO® fumigation system is described for a fumigation of maize in the tanker vessel "Marshal Grechko". A pre fumigation procedure to detect and seal leaks was followed by insertion of the perforated Phyto Explo shaft into the grain bulk. Fumigation was carried out by insertion of a band of aluminium phosphide into the shaft, after which the hold was sealed. Degassing is undertaken at the port of destination, decomposed residues are removed from the shaft and the shaft is then withdrawn from the grain.

PRE-FUMIGATION

Pre-fumigation is a quick and reliable way of testing the sealing integrity of holds in preparation for later treatments of the loaded grain bulk using fumigants. It is based on the introduction into the closed empty hold of a thermally produced insecticidal fog. This insecticide simultaneously destroys insects in the hold and permits any leaks to be detected. The most suitable insecticide for this purpose is dichlorvos (because of the high vapour tension obtainable).

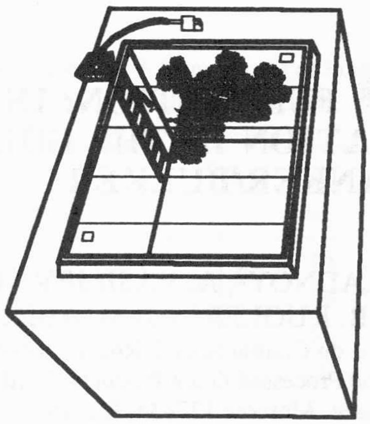

Fig. 1: Use of dichlorvos for testing seal integrity of ship-hold.

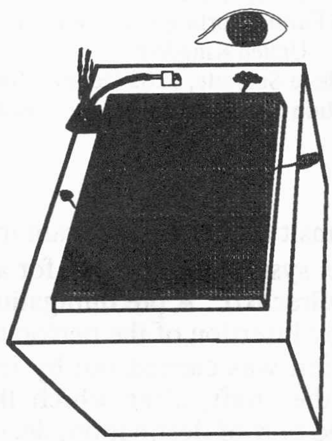

Fig. 2: Leak detection by visible inspection after introduction of dichlorvos.

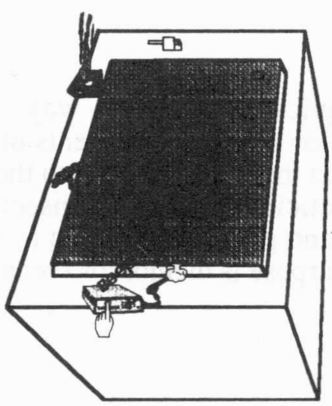

Fig. 3: Leak detection using ion-based device for detection of dichlorvos.

Leak detection begins with an initial rapid visual inspection to identify any major leaks that may be present

Leaks invisible to the naked eye can be traced using an ion-based detection device specially designed for this type of application. The area around the hold is inspected first, followed by the engine-room and forecastle.

FUMIGATION

The main advantage of the PHYTO EXPLO® system for the treatment of export grain in ships is that an effective fumigation can be carried out after the ship is loaded. If some insects are revealed during loading of the hold it is not necessary to unload the grain in order to carry out the treatment. Fumigation by the Phyto Explo system is carried out as shown in Fig. 4. The shaft is driven into the grain bulk by percussion and vibration. Then the direction of percussion and vibration is reversed enabling the Phyto Explo device to be returned to the grain surface while the shaft and cone are retained in the grain. During withdrawal of the Phyto Explo device the shaft consisting of a perforated tube expands.

Fumigation with phosphine (PH_3) is carried out after the insertion of the PHYTO SHAFT® into the hold. Then a long band of aluminium phosphide (ALP) is introduced into the shaft, the top of the shaft is closed, the hold is sealed and the ship is ready to sail.

At the port of destination, the hold is opened for degassing, the decomposed residue is removed, and the shaft can be used to sample for gas residues in depth of the grain bulk. If gas residues remain, the shaft can be used to aspirate them from the bulk. The shaft can then be removed manually by de-spiralization, or with the Phyto-pulley. In the latter case a portable winch termed a shaft-puller is employed. A hooked cable is inserted into the shaft and the hook attaches to the bottom of the shaft enabling the shaft puller to recompress the shaft as it is winched up through the grain bulk. If the grain is removed from the hold by aspiration, the shaft may be left in the grain and removed after the hold has been emptied. For phosphine treatment, the type of shaft employed is the perforated configuration.

Figs. 5-6 show insertion of Phyto-shafts for in-ship fumigation, and post-fumigation procedure in a hold of M/V "Marshal Grechko". Results of phosphine concentrations recorded during fumigation of a ship-hold are given in Fig. 7.