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CARBON DIOXIDE FUMIGATION TRIALS IN INDIA

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ABSTRACT

First time carbon dioxide (CO_2) fumigation trials were conducted at the Food Corporation of India storage complex in Borivili, Bombay, India on two stacks of milled rice in jute bags, 126 and 147 metric tonnes each (moisture contents [m.c.] 12.2 and 12.6%, respectively) and in a concrete silo filled with 2200 metric tonnes of wheat (9.9% m.c.). For the first stack under a reinforced PVC cover 0.2 mm thick at a dosage of 2.4 kg CO_2/tonne of commodity, the initial concentration at the top was 76% which declined to 48% by the end of 15 days. A plain PVC cover 0.15 mm thick was used for the second stack, and the CO_2 dosage was 2.5 kg/tonne. Gas concentrations at the top in the beginning and by the end of 15 days were 82% and 76%, respectively. Complete mortality of all stages of *Oryzaephilus surinamensis, Tribolium castaneum, Ephestia cautella,* and *Liposcelis* sp. was achieved in both stacks. Costs and benefits of the two types of grain preservation systems, namely, storage under CO_2 and the conventional approach of fumigations and routine sprays were analysed and compared. The 3,822 m^3 concrete silo did not pass the pressure decay test. Nevertheless, at 1.84 kg/m^3 (7 tonnes CO_2), the gas concentrations after 15 days at the base, at the upper grain surface, and near the infeed chute in the headspace were 78%, 28% and 2%, respectively. Survivors were not present in post-treatment samples incubated for one month. However, inspection of samples from the silo at the end of 5 months showed infestation by *T. castaneum* and *Liposcelis* sp. There was no change in colour or odour of rice and wheat.

INTRODUCTION

In India, mainly phosphine and occasionally methyl bromide are used for disinfesting grains followed by prophylactic sprays with malathion and DDVP in the warehouses. However, insect resistance to phosphine and malathion is a serious problem of concern in stored-products insect control

(Rajendran, 1989). Therefore, there is an urgent need for alternative control techniques for grain preservation. In recent years, controlled atmosphere (CA) storage, particularly grain storage under enriched CO_2 atmospheres (> 35% CO_2) has gained prominence as a suitable alternative especially in tropical, humid climates. Moreover, it has been established that high concentrations of CO_2 have little effect on the quality of grains (Gras and Bason, 1990) and adversely affect mould growth and mycotoxin production in grains (Hocking, 1990). Recently, the CO_2 treatment technique for bag stacks has been standardised (Annis and van Graver, 1991) and is practised currently in Australia, Indonesia, Malaysia, Philippines, and Thailand. It is envisaged that in the coming years, the CO_2 technique will be expanded further for insect pest control since the system has the major advantage of leaving no residues (Ryland, 1991).

For the first time in India, CO_2 fumigation trials were conducted on two stacks of bagged milled rice and in a concrete silo filled with wheat in the storage complex of the Food Corporation of India, Borivili, Bombay. The findings are reported here.

MATERIALS AND METHODS

Treatment of bag-stacks

Bag-stack CA treatments were carried out in a warehouse that was clean, bird-proof, and rodent-proof, and had concrete flooring and a gabled asbestos roof. Adults of *Oryzaephilus surinamensis* and *Ephestia cautella* were seen moving/flying in the warehouse. Milled rice, superfine quality category B received from Jagdhari, Punjab, had been stored in the warehouse for one year. The commodity had undergone one phosphine fumigation, at 3 aluminium phosphide (AlP) tablets/tonne and 5 days exposure. Prophylactic sprays using malathion and DDVP had been carried out alternately at the recommended dosages on more than four occasions during the storage period. Nevertheless, 4-6 adults of *O. surinamensis*, 1-2 adults of *T. castaneum* and many psocids per kg of grain samples were observed before the CO_2 treatment.

Two stacks, one under a reinforced PVC cover and the other with a plain PVC cover sheet, were prepared for CO_2 fumigations. The fumigations were planned and carried out according to Annis and van Graver (1991) with slight modifications. The cover and floor sheets were inspected first for holes, tears, damages, and weak spots that were then rectified. Similarly, wooden pallets were checked for projecting nails and other sharp edges. The plain PVC sheet, 0.5 mm thick (supplied by M/s Ramdas Plastic Manufacturing Co. Pvt. Ltd., Pune) was spread on a cleaned floor. A jute cloth sheet measuring 12 m x 7.5 m was spread over the floor. Over this was spread a canvas tarpaulin of the same size. The jute cloth and canvas tarpaulin layers provided a protective cushioning effect for the expensive PVC bottom sheet. Single-decked wooden pallets, 34 in number, were laid down over which the stack was built following the block system. Stack-1 consisted of 126.16 t milled rice (1,380 bags in 12 layers), at 12.2% m.c. The stack measuring 9.5 m x 6.5 m x 5.2 m was enclosed by a 0.2-mm thick PVC cover reinforced with nylon fibres (M/s Bhor Wavelock Industries Ltd., Bombay). Necessary provisions for gas-inlet at the base and an inlet for pressure testing/gas sampling pipe at the top were made in the cover. The cover and floor sheets were bonded together using quick-drying PVC glue. A pressure decay test was conducted for a pressure halving from 500-250 Pascals using a water-filled manometer. CO_2 from inverted CO_2 cylinders (99.9% pure, 31 kg capacity) was introduced into the stack at 10 kg/min keeping the vent at the top open (Fig. 1). Gas concentration at the top was monitored using a "Riken" Infrared Gas Analyzer, Model RI 550A. When the CO_2 concentration reached 75%, gas addition was stopped, vent and gas-inlet port sealed. A gas sampling pipe was inserted into the inlet-port before sealing. CO_2 concentrations at the base and top were monitored daily for 15 days.

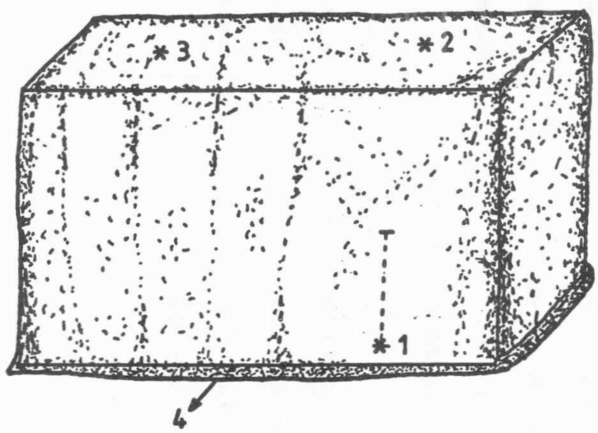

Fig. 1: Bag stack of milled rice in an enclosure. (1) Evacuation point/gas-inlet port; (2) Inlet for pressure testing tube/Top gas sampling tube; (3) Vent; (4) Cover and floor sheets joined together to form a skirt.

In the second stack, there were 1,610 bags (147.15 tonnes) of milled rice (12.6% m.c.) stacked under the block system with 14 layers of bags. The cover sheet was plain 0.15 mm thick PVC (M/s Ramdas Plastic Manufacturing Co. Pvt. Ltd., Pune). Due to temporary trouble with the instrument, the CO_2 purge continued until the top concentration reached about 82% (Table 1).

On the 16th day, grain samples were drawn from both stacks, m.c.s were checked, and the samples sieved for live insects. The samples were then incubated in the laboratory and examined after a month for survivors.

Table 1: Details of CO_2 fumigation of milled rice in bag-stacks at 29±3°C and 50-75% r.h.

Stack	Infestation	Floor and cover sheets	Pressure test	CO_2 dosage	Result
1. Milled rice at 12.2% m.c. 1,380 bags, 126.16 tonnes, 153 m^3	*O. surinamensis* *T. castaneum* *E. cautella* *Liposcelis* sp.	660 GSM, 0.5 mm PVC floor sheet; 225 GSM 0.2 mm PVC reinforced cover sheet	8.0 min (500 to 250 Pascals)	310 kg, 2.4 kg/tonne (initial concentration on top, 76%), 15 days exposure	100% mortality recorded
2. Milled rice at 12.6% m.c. 1,610 bags, 147.15 tonnes, 204 m^3	*O. surinamensis* *T. castaneum* *E. cautella* *Liposcelis* sp.	660 GSM, 0.5 mm PVC floor sheet; 220 GSM 0.15 mm PVC cover sheet	8.0 min (500 to 250 Pascals)	372 kg, 2.5 kg/tonne (initial concentration on top, 82%), 15 days exposure	100% mortality recorded

Treatment of silo

A fumigation trial was conducted in a 3,822 m^3 concrete silo built in 1967 that was holding 2,200 t Indian wheat (9.9% m.c.), and had a 30% headspace. During the storage period of one year, the grain had been fumigated on 4 occasions with phosphine at 2 AlP tablets per tonne. However, prior to CO_2 application, adults of *T. castaneum, Rhyzopertha dominica* and larvae of *E. cautella* were detected in the wheat samples from the silo.

The silo had an underground tunnel that opened into 7 air ducts inside the silo. Pressure testing of the silo as well as introduction of CO_2 was effected through the aeration ducts. A gate-valve was fixed in order to prevent reverse flow of gas from the aeration ducts (Fig. 2). Initially, a pressure decay test was conducted to check the gas-tightness of the silo that was already filled with the grain. The test for the decay of positive pressure from 500-250 Pascals revealed that the silo was not sufficiently gastight (pressure halving time: 3 minutes only). Nevertheless, the trial was carried out to study the logistics of CO_2 application and gas distribution in the silo under the existing conditions (Table 2).

Table 2: Details of CO_2 fumigation of wheat in 3,822 m^3 concrete silo.

Commodity and infestation	Pressure decay test	CO_2 dosage	Results
Wheat with 9.9% moisture, 2200 tonnes. *T. castaneum* *R. dominica* *E. cautella*	3 min (500 to 250 Pascals)	3.18 kg/t > 15 days exposure (initially during purge phase 6 tonnes CO_2 & during the maintenance phase an additional 1 tonne)	100% mortality of adults at all levels noted on 16th day, but survivors of *T. castaneum & Liposcelis* sp. noted at the end of 5 months

The disinfestation technique involved lifting the atmosphere out with a CO2 purge from the bottom (Jay, 1980) as described by Guiffre and Segal (1984). Six tonnes of liquid CO2 delivered from a tanker (M/s Bombay Carbon Dioxide Gas Corporation, Bombay) were introduced into the silo through the inlet tunnel of the silo via a heat exchanger or CO2 vapouriser. The gas was purged for 80 min (2.05 kg/hr/t). Gas sampling pipes were inserted into the silo through the infeed chute before sealing. During the purge, an inspection window in the roof was kept open for venting out ambient air. The gas-inlet point and the vent were sealed at the end of CO_2 addition. Gas concentrations at the base in the tunnel, grain surface and in the headspace near the vent were monitored daily. Grain temperatures at different

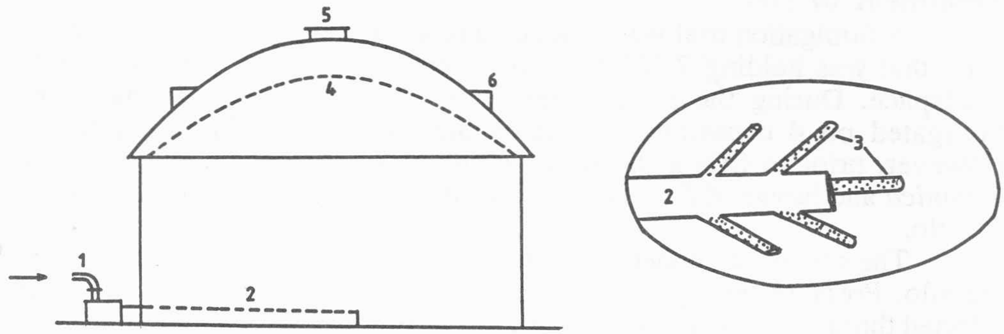

Fig. 2: The concrete silo and the tunnel with aeration ducts. (1) CO_2 inlet with a gate valve; (2) Tunnel; (3) Aeration ducts; (4) Grain surface level; (5) Infeed chute; and (6) Inspection window/vent. 1, 4 and 5 were the gas sampling points.

depths were also recorded. As the gas concentrations at the grain surface level declined to less than 35% by the 10th day, 1 t of CO_2 was added to make up the gas loss, keeping the vent open. Then, the openings were sealed and gas monitoring continued till the 15th day. In total, 7 tonnes of CO_2 were used in the treatment of the silo. On the 16th day, grain samples were drawn from up to 2 m below the grain surface level and examined for infestation and m.c. Samples were incubated for a month to reveal hidden infestation (Table 2).

RESULTS AND DISCUSSION

Bag-stack fumigation

According to Annis and van Graver (1991), a successful CO_2 fumigation of a bag-stack passing the pressure test is predicted based on the initial concentration at the top exceeding 75% and a target concentration exceeding 35% throughout the 15-day treatment period . In the present trials, he initial top concentrations in both the stacks exceeded 75% and on stubsequent days remained always above 35% (Fig. 3). Furthermore, survivors were not found in the grain samples drawn from the stacks and incubated for a month. A slight increase in grain m.c. was noted. Both types of covers were found satisfactory for CO_2 fumigations.

Four distinct phases were noted during CO_2 treatment. These were the ballooning phase, mixing or equilibration phase, sorption phase, and dilution or leakage phase. During the discharge of CO_2 from the cylinders, gas concentrations at the top of the stack increased slowly for the first 5 cylinders and thereafter there was a steady increase of 10% for the discharge of every cylinder (Fig. 4) resulting in ballooning or billowing of the enclosure. Data on gas concentrations reveal that the first 3 days of gas introduction was the period when equilibration/ mixing of CO_2 took place. Consequently, ballooning subsided gradually from the top downward. It was followed by a sorption phase during which CO_2 was absorbed heavily by the grains, resulting in negative pressure within the enclosure. This was visible from the outside as the cover sheet was pressed snug to the bags resembling skin-packing. Thereafter, the leakage or dilution phase took place slowly due to air entering into the enclosure and/or CO_2 escaping. During the latter phase, the cover sheet peeled away from the bags and the enclosure almost regained its normal appearance.

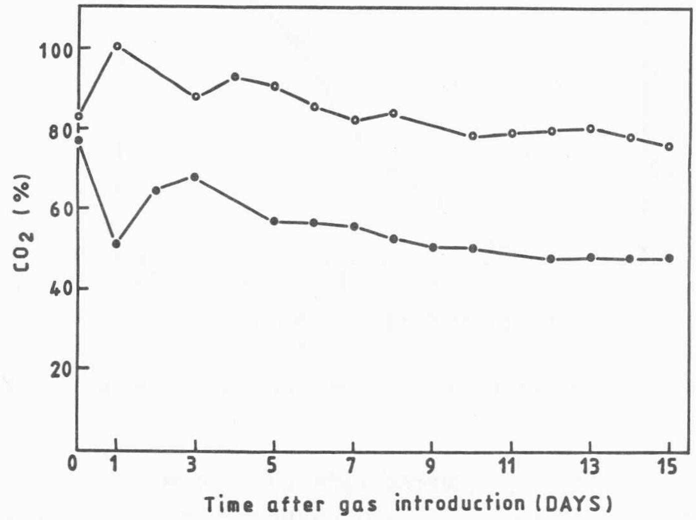

Fig. 3: Top gas concentrations in stack-1 (-•-) and stack-2 (-o-) during CO_2 treatment.

Khapra beetle larvae (*Trogoderma granarium*) and *Sitophilus* spp are tolerant to CO_2 atmospheres (Annis, 1987). However, in both the bag stacks they were not present.

There was no change in colour or odour of the grain, but there were slight increases in the m.c. of rice following CO_2 treatment. In stack-1, the initial m.c. was 12.2 and at the end of 15 days it was 12.3% but in stack-2 the initial and final m.c. were 12.6 and 13.2%, respectively. The sudden increase in moisture in Stack-2 during the treatment period of 15 days was quite unexpected. Increases in moisture levels in commodities stored for a long period under CO_2 have been reported by Annis *et al.* (1984), Nataredja and Hodges (1990), and Sukprakarn *et al.*,(1990). Furthermore, Nataredja and Hodges (1990) observed a slight increase in the number of yellow grains and broken grains. Aroma and cohesiveness of the grains were retained following 8 months storage under CO_2 but some changes in palatability were noted (Sukprakarn *et al.*, 1990). By contrast, Gras and Bason (1990) observed few changes in grain quality including yellowness and organoleptic quality. Thus,

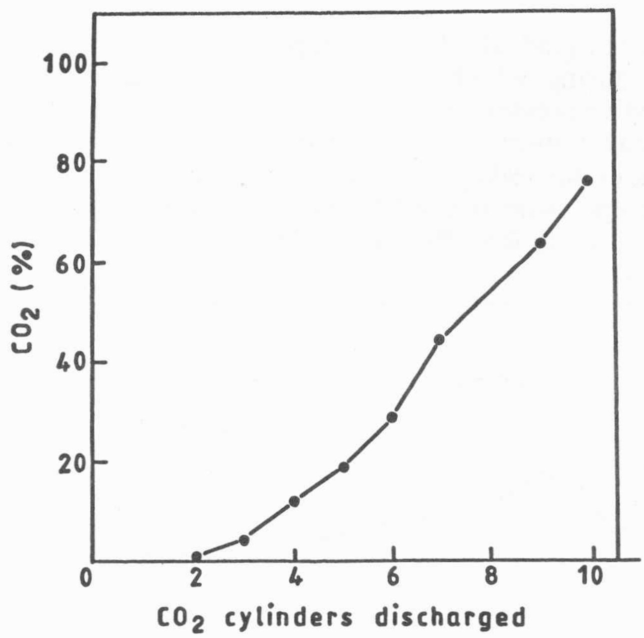

Fig. 4: Changes in CO_2 concentrations at the top of stack-1 during gas addition.

the reports on the quality of rice stored under CO_2 for more than 6 months are equivocal. However, it appears that any changes observed in the quality of rice were not so important as to affect its commercial value or consumer acceptance.

A cost comparison of conventional and CO_2 treatments under the prevailing cost structure and storage management practices in the warehouses (Tables 3 and 4) indicates that CO_2 treatment is two-times more expensive, for a single treatment. However, if the technique is adopted for long-term storage the CO_2 treatment costs are competitive with conventional long-term storage treatments. While comparing storage under CO_2 and the conventional approach in Indonesia, Conway *et al*. (1990) observed that grain storage under CO_2 involved heavy initial expenditure followed by low maintenance cost for the remainder of the storage period, whereas the conventional regime required a modest initial investment but higher operating/maintenance costs afterwards. They also noted that a storage period of 14 months and above was cost-advantageous for the CO_2 technique in Indonesia. In addition, the CO_2 system offers environmental and health benefits over the conventional system. The Threshold Limit Value - Time Weighted Average (TLV-TWA) limits for phosphine, methyl bromide, and CO_2 in the atmosphere are 0.3 ppm (in some countries 0.1 ppm), 5 ppm, and 5,000 ppm respectively. In India, the tolerance residue limits in whole grains are 0.05 ppm for phosphine, 25 ppm inorganic bromide for methyl bromide, 4.0 ppm for malathion, and 1.0 ppm as dichloroacetaldehyde for DDVP. By contrast, CO_2 or other atmospheric gases have been exempted by the EPA from the requirement of tolerance on raw or processed agricultural commodities (Storey, 1990).

The success of grain preservation using the CO_2 technique is dependent on good house-keeping, hygiene, and rodent control in the warehouses (Annis, 1990). Cases of control failures during long-term storage of milled rice under CO_2 have been reported from Indonesia (Nataredja and Hodges, 1990), Philippines (Annis, 1990), and Thailand (Sukprakarn *et al.*, 1990). Besides other factors, the failures were attributed to the damage of the cover sheet by rodents, birds and insects (*R. dominica*). Therefore, even in the CO_2 storage system there will be a need to protect the cover from mechanical damage and for occasional prophylactic sprays to protect the cover from insects.

Silo treatment

In the silo dosed initially with 6 tonnes CO_2, the required concentration of 35% CO_2 could not be maintained at all levels during the treatment period because of leaky conditions. There were practical difficulties in making the silo completely gas-tight before starting the trial. Immediately at the end of the CO_2 purge, the CO_2 concentration near the infeed chute was only 14%. Furthermore, 100% CO_2 concentration was recorded for up to 5 days at the bottom in the gas-inlet tunnel (Fig. 5). Concrete is known to absorb CO_2 heavily (Banks and Annis, 1980). Besides leakage, gas absorption by the grain as well as the concrete wall resulted in heavy reduction in CO_2 concentration near the infeed chute and a steady decline in concentration at the upper grain surface. After the addition of 1 tonne CO_2 on the 10th day, the situation improved but not sufficiently to meet requirements for long-term storage. Very low concentrations of $\leq 2\%$ were recorded near the infeed chute for most of the days. A slight increase in the temperature (1-1.5^{o}C) of the silo in the central region was noted during the treatment period.

Grain samples drawn from the silo up to a 2-metre depth below the grain surface did not reveal survivors even after a post-treatment holding period of one month. Nevertheless, at the end of 5 months wheat in the silo showed infestation by *T. castaneum* and *Liposcelis* sp. The trial revealed that: (1) the CO_2 purge rate (2.05 kg/hr/t) was too high for proper displacement of air from the silo; (2) proper sealing should be done before loading the silo; and (3) after the CO_2 purge, gas circulation of CO_2 from top to bottom through an external duct is recommended to bring the accumulated CO_2 at the bottom to the top. The latter is very important as 100% CO_2 is less effective against insects and, therefore, is not desirable, as pointed out by Jay (1980).

Table 3: Cost of fumigating a 147 tonne stack (stack 2) of milled rice with CO_2.

	Rupees
Labour	
1. Man-day charges for 2 Asst. Managers and 2 Tech. assts. for 2 days	3,000
2. Labour charges for checking, arranging pallets, sheet handling and stacking	3,200
Materials	
3. Floor sheet, 70 m^2, at Rs 70/m^2 plus taxes	5,000
4. Cover sheet, PVC plain, 236 m^2 at Rs 27.5/m^2	6,500
5. Sealants, CO_2 delivery pipes, gas sampling tubes, etc.	1,500
6. CO_2, 372 kgs, at Rs 6.00 per kg	2,230
Total cost of treatment per stack	21,430
Total cost of treatment per tonne	146

Table 4: Cost analysis for conventional treatments of a 147 tonne bag-stack of milled rice.

	One time Rupees	No. of tretments	for 1 year Rupees
A. Phosphine fumigation			
a. Fumigation cover	6,500		6,500
b. Sand snakes	1,200		1,200
c. Cost of AlP (3 tablets/tonne (Rs 180/kg))	250	(5)	1,250
d. Labour charges	500	(5)	2,500
e. Man-day charges for 1 Asst. Manager + 1 Tech Asst., 2 days	750	(5)	3,750
B. Prophylaxis			
a. Malathion cost and labour charges	110	(12)	1,320
b. DDVP cost and labour charges	130	(12)	1,560
Total	9,440		18,080
Total per tonne	64.2		123

Note: Under Indian storage conditions, prophylaxis of the stack and premises is necessary; however, the frequency of sprays will depend on the hygienic condition of the warehouse.

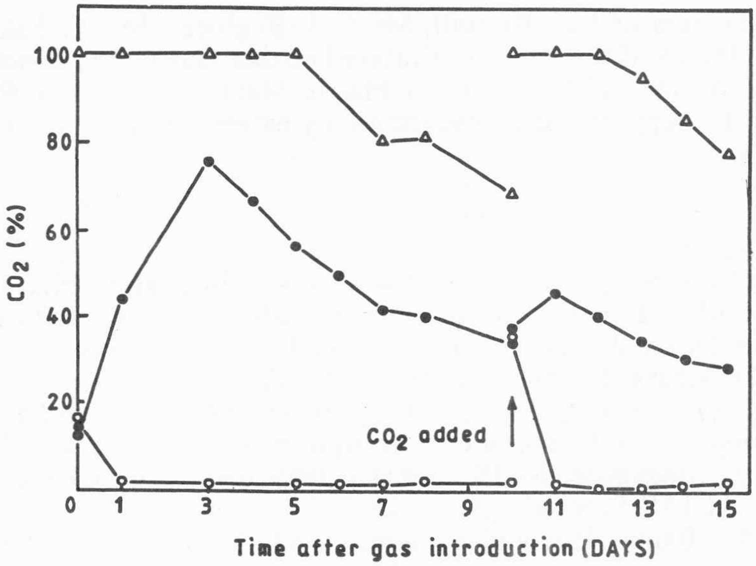

Fig. 5: Gas concentrations at the bottom (tunnel) (-Δ-), grain surface level (-●-), and (-O-) in headspace near the infeed chute of the silo during CO_2 treatment.

CONCLUSION

The trials conducted on bag stacks and in a silo demonstrated the feasibility of protecting grain with CO_2 atmospheres in India. The necessary infrastructure, including manpower, fumigation sheets, sealants, and CO_2 are available in this country. The tropical climate is an added advantage for the efficacy of CO_2 against stored-product insects. At the same time, the inadequacy of the technique at low temperatures occurring in the northern parts of the country during winter and the exceptionally high tolerance of the Khapra beetle larvae, *T. granarium,* one of the serious grain pests in India, are not to be overlooked. More trials are necessary under different climatic conditions and on grains where *Sitophilus* spp. are also present. In conclusion, the adoption of the technique and the extent of use of the CA storage of grains involving CO_2 in India depends on: (1) the availability of buffer stocks of grains for long-term storage; (2) consumer awareness about or aversion to pesticides and their residues in food commodities; and (3) management decision to introduce an alternative to the conventional approach of routine fumigations and prophylactic sprays.

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