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Methyl Bromide Fumigation of Farmers Stock Peanuts In Flat Storage[1,2]

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ABSTRACT

Farmers stock peanuts, bulk stored inside large warehouses, were fumigated for 24 hr with methyl bromide (bromomethane) after thorough sealing of the facilities. Temperature of the peanuts varied from 21.8° to 26.8° C and gas concentrations monitored in the headspace above the peanuts decreased from 20.1 to 12.2 mg/liter during fumigation. Gas concentrations in the mass varied considerably during fumigation, being highest at the bottom of the peanuts. Gas concentrations decreased to less than 1 mg/liter after 48 h of aeration. Although tremendous populations of insects existed before fumigation, no insects survived the treatment. Bromide residues were much below the tolerance on the peanuts, although looseshelled kernels accumulated slightly higher residues than did sound mature kernels from pods. The success of the fumigation was attributed to the good construction of the warehouses and to the thorough sealing performed before the fumigation.

Keywords: fumigation, methyl bromide, peanuts, bulk storage, residues, warehouses

The market price for in-shell (farmers stock) peanuts during the 1974 storage year was lower than the government support price in the southeastern peanut-growing area. Relocation of peanuts was necessary to provide storage space for the new peanut harvest of 1975. This relocation consisted of the movement of several thousand tons of in-shell (farmers stock) peanuts from warehouses in the growing area to other facilities not previously used for peanut storage. The Commodity Credit Commission (CCC) moved several thousand tons of these government-owned peanuts into temporary flat storage at Fort Gillim, GA. The relocated peanuts were stored for several months and became heavily infested with several species of stored-product insects.

The opportunity to participate in the fumigation of these peanuts became available when the CCC requested assistance. The major insect infestation was confined to 2 warehouses, each containing approximately 8000 metric tons of peanuts. It was decided that prompt fumigation of the peanuts *in situ* was required and methyl bromide (bromomethane) was selected as the fumigant. These circumstances allowed us to conduct research on the fumigation of peanuts in bulk storage areas, a subject which has received only limited attention.

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[2]This paper reports the results of research only. Mention of a pesticide in this paper does not constitute a recommendation for use by the U.S. Dep. of Agr. nor does it imply registration under FIFRA as amended. Mention of a commercial or proprietary product in this paper does not constitute an endorsement by the U.S. Dep. of Agr.

Materials and Methods

The 2 warehouses to be fumigated were brick, and each was equally divided by firewalls into 5 bays. The capacity of each warehouse was 59,570 m^3 (2,103,600 cu ft). The warehouses were built on raised concrete slabs 1.52 m above grade, were of good, tight construction, and were originally designed for humidity-controlled storage. The peak height of each warehouse was 9 m (29.5 ft). Their roofs were of asphalt composition and slightly curved. Farmers stock peanuts were either blown in by a pneumatic system or conveyed into bulk piles in each bay to heights ranging from 3.7 m (12.0 ft) to 5.5. m (18.0 ft). The peanut piles occupied approximately 1/2 to 2/3 of the total volume of each bay. The doors between the bays remained open during fumigation.

Fumigation was conducted by a team from a commercial firm. Before fumigation, a smoke generator was used inside each warehouse to locate inconspicuous cracks around skylights, windows, doors, etc. Areas that showed leakage were sealed with 4-mil polyethylene film which was taped or glued over each area.

Before fumigation, the authors collected samples of peanuts from each bay and introduced cages of insects and gas-sampling tubes to assay the fumigant efficacy and distribution. Each cage contained 25 adult red flour beetles, *Tribolium castaneum* (Herbst), which had emerged 14 ± 5 days earlier from laboratory cultures brought from the USDA, ARS, Stored-Product Insects Research and Development Laboratory, in Savannah, GA. Cages, 1.3 cm OD X 10 cm long, of metal construction, threaded at one end and pointed at the other end, were placed in the peanuts at the point of greatest depth in each bay. Each cage contained perforations along its length. One cage was probed to the bottom and another to 1.5 m under the surface by using 9.5-mm (1/8-inch) OD galvanized pipe. In addition, cages were placed (1) in the overspace 2 m above the peanuts, (2) on a windowsill at an outside wall, and (3) 1.5 m from an outside loading door at the floor level in approximately 1-m depth of peanuts. Insects were also placed in an untreated warehouse of peanuts at the same positions. The pipe (insect probe) was also used for taking gas samples by connecting polyethylene tubing that terminated on the loading docks outside each bay door. Likewise, a length of polyethylene tubing was placed 2 m above the peanuts in each bay for taking gas samples from the headspace.

Methyl bromide was applied into each bay from 3 cylinders, each containing 90.8 kg to produce a calculated concentration of 22.84 mg/liter (1.43 lb/1000 cu ft). One cylinder was positioned inside the door of each bay and was fitted with a 1.0-m length of 9.5-mm (3/8-inch) ID copper tubing to dispense at a 45° angle. Two cylinders were positioned on the loading dock outside each bay and fitted with 9.5-mm (3/8 inch) ID polyethylene tubing extending inside to a point 2-3 m above the peanuts near the center of each bay. A 3- x 3-m piece of 6-mil polyethylene film was placed in a depression on the surface of the peanuts directly under the discharge tube to catch any liquid methyl bromide that failed to vaporize during the applicaion. One fan with a capacity of 28.3-m^3/min (1000 cfm) was placed on the floor inside each bay near the methyl bromide cylinder and operated continuously throughout the fumigation. The first warehouse was fumigated at 10:30 a.m. and the second warehouse was fumigated at 5:30 p.m. that evening. About 20-30 min was required for the methyl bromide to be dispensed into each warehouse.

The air temperature above the peanuts during fumigation was recorded with a maximum-minimum thermometer. A probe thermometer was used to measure the temperature of the peanuts at various depths into the mass at each point where insects were exposed. The relative humidity in each warehouse was >80%, and moisture condensation was evident.

Throughout the 24-h fumigation gas samples were drawn periodically to monitor methyl bromide concentrations in the headspace, at depths of 1.5 m, and at the bottom of the peanut mass in each bay. Samples were collected by using a small vacuum pump to pull the gas (>100 cc/min) through the polyethylene lines into 125-ml gas-sampling tubes. The tubes were taken immediately to an adjacent building where the methyl bromide concentrations were determined with a Micro Tek 2000 gas chromatograph equipped with a flame ionization detector as described by Dennis et al. (1972). After 24 h under fumigation, the warehouses were opened for aeration. Gas concentrations were monitored during 42 to 48 h of aeration.

After aeration, samples of peanuts were taken from each bay at locations where the insects were exposed. The samples were collected from a 30-cm^2 surface area to approximately a 10-cm depth and also 1.5 m below the surface of the mass by using a peanut probe. Each sample weighed from 1 to 3 kg. The light samples were usually from the surface and contained a high percentage of peanut hulls. The samples were sifted, examined for live adult insects, and then incubated at 26±1^{0}C and 60% RH. After 6 weeks, each sample was reexamined to determine the adult emergence resulting from immature stages present at the time the samples were taken. After reexamination for insects, the loose-shell kernels (LSK) were removed from the in-shell peanuts. The in-shell (farmers stock) peanuts were then shelled in a laboratory peanut sheller, and the sound mature kernels (SMK) were separated. The meats (LSK and SMK) from the original samples were then analyzed for bromide residue by Dow Chemical Co., Inc., by using neutron activation for the analysis. Since this method is nonspecific for organic or inorganic bromide, the determination is for total bromide residues.

Several weeks after the fumigation, official grade samples removed from trucks during loadout of the peanuts were pooled and examined for insects. These samples were then analyzed to determine average total bromide residues resulting from the fumigation.

Results and Discussion

The air temperature above the peanuts ranged from 9^o to 23^o C. (Table 1). Although headspace temperatures regularly drop to about 4^o C during this time of year (November), the temperature of the peanuts was relatively high, probably due to factors such as the temperature at the time they were loaded into the warehouse, air tightness of the warehouse, and possibly insect activity as well as mold formation resulting from high moisture conditions near the surface of the peanuts.

Table 1. Mean temperature a/ of peanuts at various depths into the mass. b/

Building	°C of peanuts at indicated depths			
	30 cm	1 m	1.5 m	Bottom
I	26.8 (±1.6)	26.6 (±1.1)	23.6 (±1.6)	24.8 (±2.5)
II	21.8 (±3.8)	25.2 (±4.4)	23.8 (±2.0)	26.2 (±2.9)

a/ Mean values derived from 5 samples.

b/ The air space above peanuts ranged from 9°-23°C and 10°-23°C for buildings I and II, respectively, during fumigation.

Table 2. The mean concentration a/ (standard deviation in parentheses) of methyl bromide (mg/liter) in the headspace and at 2 depths into the peanut mass during fumigation and aeration.

Hours of indicated treatment	Position		
	Headspace	1.5 m	Bottom
		Building I	
Fumigation			
1.0	19.6 (±1.6)	6.95 (±9.0)	57.0 (±15.8)
3.0	18.2 (±1.3)	14.3 (±5.7)	58.1 (±10.0)
5.0	17.4 (±0.8)	15.3 (±4.6)	45.6 (±18.2)
6.5	16.0 (±0.5)	14.8 (±3.6)	39.9 (±19.4)
12.5	14.5 (±0.3)	14.0 (±2.0)	21.2 (±7.6)
22.5	12.2 (±0.4)	11.8 (±0.8)	12.3 (±0.6)
Aeration			
5.0	1.33 (±0.60)	9.25 (±2.14)	9.93 (±2.28)
27.0	<0.2	0.93 (±0.16)	1.05 (±0.39)
48.0	0.06 (±0.02)	0.31 (±0.07)	0.37 (±0.14)
		Building II	
Fumigation			
1.0	20.1 (±1.5)	13.7 (±11.3)	49.4 (±27.1)
3.0	17.6 (±0.8)	21.9 (±5.7)	66.6 (±23.9)
6.0	17.6 (±1.0)	22.1 (±10.7)	54.0 (±32.0)
16.0	14.7 (±0.4)	18.7 (±9.7)	42.6 (±28.5)
22.5	13.7 (±0.2)	16.7 (±7.2)	49.0 (±20.0)
Aeration			
17.0	1.21 (±0.40)	3.70 (±1.65)	3.67 (±1.78)
21.0 b/	0.79	5.46	4.13
42.0	0.08 (±0.04)	0.62 (±0.43)	0.57 (±0.30)

a/ Mean values derived from 5 samples.

b/ Values from single samples.

The gas concentrations achieved and sustained during the fumigation indicated that the warehouses were well sealed (Table 2). Provisions were available to add more fumigant if needed to sustain the concentration. Concentrations were relatively uniform and evenly distributed in the headspace and to a depth of 1.5 m in the peanuts. The rapid penetration and development of high concentrations of methyl bromide at the bottom of the piles of peanuts were at first surprising. However, considering the prevailing conditions, this development of high concentrations at floor level was a logical event. The air of the headspace averaged 12^{o}C and about 80% RH at the time of fumigant application which resulted in a visible "fog" over the peanuts for a short time after

Table 3. Mean number of insects/kg of peanuts sampled in each warehouse before and after fumigation

Insect stage	Mean no. insects/kg from			
	Building I		Building II	
	Surface	1.5 m	Surface	1.5 m
		Before fumigation		
Live adults	2583	269	3508	324
Immature reared	828	168	274	66
		After fumigation		
Live adults	0	0	0	0
Immature reared	0	0	0	0

Table 4. Mean (standard deviation in parentheses) a/ of total bromide residue found on peanut samples taken before, immediately after fumigation, and when the peanuts were removed from the warehouses (loadout).

Peanut sample	Mean bromide residue (ppm) on peanuts from			
	Warehouse I		Warehouse II	
	SMK b/	LSK c/	SMK	LSK
Prefumigation	1.5 (±0.70)	1.8 (±1.08)	1.4 (±0.58)	1.2 (±0.45)
Post fumigation:				
Surface (0-10 cm)	22.2 (±9.95)	48.4 (±22.57)	53.3 (±13.55)	68.0 (±21.77)
Subsurface (1.5 m)	15.4 (±2.07)	29.0 (±8.06)	31.0 (+17.69)	57.4 (±24.36)
Loadout (composite)	20.2 (±2.70)	31.6 (±12.8)	19.8 (±3.66)	30.7 (±9.77)

a/ Mean values derived from 5 samples.

b/ SMK - Sound mature kernels in unbroken shells.

c/ LSK - Loose-shelled kernels.

application. The cool fumigant gas which is also much heavier than air would tend to seek the lower levels in the warehouses. The fans operated in each bay aided in distribution of the gas, but they were inadequate to fully circulate the gas throughout the warehouse. Since the first warehouse was fumigated in the morning, the headspace heated up during the day, whereas the second warehouse (#II) was initially exposed to the colder temperatures of the night. This difference in the headspace temperatures after fumigation could have had an effect on the difference in the way concentrations accumulated and dissipated at the bottom positions. The tendency of methyl bromide gas to settle because of its high density is often used to advantage in fumigation. An example was its use by Hill and Armstrong (1956) to fumigate a 6-floor flour mill by applying most of the fumigant dosage into the upper floors of the mill.

Aeration of the peanuts was considered normal. Even the high concentrations at the bottom of the piles of peanuts dissipated to less than 1 mg/liter within 42 to 48 h after the warehouses were opened and cross-ventilated.

It is clear from the concentrations of methyl bromide achieved in the headspaces and in the peanuts that all insects would have been killed. Concentration multiplied by time (CT) product (Monro 1969) for each location monitored was greater than 300 mg/liter/h which is about 100 mg/liter/h higher than needed to kill most species and life stages of stored-product insects (Lindgren *et al.* 1954, Bond and Monro 1961, Vincent and Lindgren 1975, Lindgren and Vincent 1965, and Brown 1959). These high CT products indicate that effective fumigation probably could have been conducted either by using less fumigant or by reducing the time of fumigation.

The exposed insects, whether free-living in the peanuts or held in cages, were killed by the fumigation (Table 3). Insects in cages held in the untreated warehouse showed only 1-5% mortality. Samples of peanuts taken immediately after fumigation and several weeks later at the time of loadout yielded no live insects.

The number of insects in each bay before fumigation was tremendous, and the infestation had reached alarming proportions. Obviously, the fumigation saved much of the commodity from being rendered useless by the insects. Although no adults of the almond moth, *Ephestia cautella* (Walker), or the Indian meal moth, *Plodia interpunctella* (Hubner), were found before fumigation, a few live larvae of both species were present. The near absence of moths was apparently due to the daily operation of dichlorvos (2, 2-dichlorovinyl dimethyl phosphate) aerosol dispensers in the warehouses before the fumigation. The insect species found before fumigation in both buildings as percentages of the total were as follows: flat grain beetle (*Cryptolestes pusillus* (Schonherr)) -61.47%, red flour beetle -38.06%, Indian meal moth —0.5%, corn sap beetle (*Carpophilus dimidiatus* (F.)) -0.33%, almond moth -0.07%, and cadelle (*Tenebroides mauritanicus* (L.)) -0.01%.

In all cases, total bromide residues found were well below the 200-ppm tolerance level for bromide on peanuts. Residues on the peanuts resulting from the fumigation were higher in every case on loose-shelled kernels (LSK) than on sound mature kernels (SMK) (Table 4). Obviously, the shells of the SMK's protected the kernels from the accumulation of residue. Samples taken immediately after the fumigation and held for 6 weeks also showed that peanuts on the surface (0-10 cm) accumulated higher residues than those 1.5 m below the surface. The variation in residues on these samples was generally greater than that found on the loadout samples. This difference is probably due to the greater sample size represented by compositing the latter. The low residues on the loadout samples are probably the result of (1) the mixing of peanuts throughout the stacks during loadout and (2) the longer aeration of the peanuts before the loadout samples were collected and analyzed. In addition, samples taken immediately after fumigation were removed from near the surface where the high moisture could have been a factor in causing high residues. As Dhaliwal (1975) reported, moisture content of fumigated commodities seems to be directly correlated to the sorption of methyl bromide by the commodity.

It is hoped that the results reported here will provide a basis for future fumigations of large volumes of bulk peanuts or commodities stored under similar conditions.

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