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A new method of ensuring even distribution of a fumigant in flexible fumigation chambers using external fans

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Abstract

A series of commercial fumigations to control narcissus fly larvae in bulbs for export was carried out to determine the effectiveness of a gas distribution method that utilizes external fans positioned outside the chamber. The principle is to generate air motion using the flexibility of the PVC liner. This is done by directing an air-flow along the walls of the liner, thus creating a ripple motion that generates an internal turbulence which mixes the air with the fumigant inside the chamber. With fans placed opposite the corners of the bubble it was possible to divide the airflow along all sides of the bubble wall. Methyl bromide concentrations recorded over the 4-h fumigation period, were compared with previous results obtained when the fumigant was mixed by recirculation. The use of external fans in combination with flexible PVC chambers enabled an even gas distribution to be achieved within the chambers in 1–1.5 h whereas under recirculation, even distribution was not reached during the entire 4-h fumigation period. Post-fumigation mortality data on narcissus fly larvae revealed 100% kill.

Keywords: Methyl bromide; Gas-distribution; Phytotoxicity; Narcissus flies; Recirculation

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1. Introduction

Conventional fumigations under tarpaulins or inside fumigation chambers suffer from a number of limitations. Chief among these for tarpaulin fumigation are inefficient sealing and the phenomenon of gas-layering, while chamber fumigations incur high installation and maintenance costs, have the drawback of immobility, and also are subject to gas-layering. The use of gas-tight flexible PVC envelopes can obviate the sealing limitation for commodities in sacks or crates, but the problem of gas-layering persists, especially when using methyl bromide (MB) that is 3.5 times heavier than air. The problem is compounded if the fumigation is undertaken for quarantine purposes, since these require relatively high fumigant concentrations over short exposure periods.

In this paper we exemplify the quarantine fumigation of narcissus bulbs to control the narcissus fly (*Merodon eques* F.) as a model to emphasize the importance of rapidly creating a uniform gas distribution during fumigation. The relatively high concentration of MB required to kill the fly larvae over a short exposure period increases the danger of creating temporary pockets of high concentration within the chamber during dosage. This is liable to produce phytotoxic effects on the bulbs (Zumreoglu and Erakay, 1978; Donahaye et al., 1997) unless measures are taken to obtain prompt mixing. These commercial fumigations are mandatory for growers of narcissus bulbs who are required to comply with quarantine requirements set by importing countries against infestation by narcissus flies. MB is still the only suitable fumigant due to its effectiveness over short exposure times. Success therefore, depends on the ability to achieve an even distribution of MB within a short time so as to avoid the phytotoxic effect of high initial concentrations, and also to obtain a concentration of $25 \pm 5\,g/m^3$ over the 4-h exposure period in order to achieve 100% mortality of fly larvae (Donahaye et al., 1997).

Flies belonging to the genera *Merodon* and *Eumerus* (Family Syrphidae) attack narcissus bulbs, and growers are obliged to fumigate their bulbs in order to comply with quarantine requirements set by importing countries where those species endemic in Israel do not exist. MB is presently the only recommended fumigant for use with narcissus and other bulbs to control narcissus bulb fly (Bond, 1984). Over recent years numerous commercial fumigations carried out in rigid fumigation chambers, based on fumigation schedule N in the "Manual of Fumigation for Insect Control" (Bond, 1984) were found to cause phytotoxic damage to the bulbs. Navarro et al. (1997) suggested three possible explanations for the phytotoxic phenomenon: a lack of uniform gas distribution within the fumigation chamber, an insufficient aeration after fumigation, and excessive dosage levels of the gas.

Several methods were proposed to minimize the effect of the layering. Navarro et al. (1997) used closed-circulation fumigation to accelerate the gas distribution within the flexible PVC fumigation chambers, which were introduced to replace the poorly sealed and high-volume fumigation rooms used previously. However, major problems were encountered, namely: low airflow rates and gas leakage via the gas circulation ducting, and the extreme inconvenience of placing electric fans within the fumigation chambers due to the narrow passageways between the palleted crates. The idea of using outside fans as an option for mixing the fumigant with the air inside the fumigation chamber, by producing a ripple effect on the flexible chamber walls was first proposed and demonstrated by the late Avigad Cohen. Therefore, in order to examine the efficacy of this method, a series of commercial fumigations of narcissus bulbs were carried out and monitored.

Here we report on these trials to demonstrate the effect of using external fans on the distribution of MB within the flexible PVC fumigation chambers, and propose their use as an effective method of ensuring even fumigant distribution. Practical considerations prevented us from carrying out parallel control fumigations according to the previous method, so we have used results from earlier published trials for comparative purposes.

2. Materials and methods

2.1. Fumigation procedures

The flexible fumigation chambers. These are "Rentokil® fumigation bubbles" consisting of flexible PVC over- and under-liners of 0.8 mm thickness that are zipped together to form a sealed enclosure that envelopes the commodity to be fumigated. Each bubble is 7.5 m long, 7.5 m wide and 1.9 m high with a volume of 107 m^3. The bubbles are connected to an application unit consisting of a MB dispenser and a fan that is employed to inflate the chamber initially, to introduce the gas into the bubble, and to aerate it after fumigation. When non-inflated, the liner clings to, and takes the shape of the stack to be fumigated due to the weight of the plastic material. During fumigant introduction, the liner inflates, the top rises above the stack, and the sides of the liner billow away from the stack walls reaching a volume of 160 m^3 when fully inflated.

Crate stacking. In the packing houses, the bulbs are placed in plastic crates stacked nine layers high on wooden pallets, each layer consisting of five crates containing 18–20 kg of bulbs each. The pallets are then trucked to holding sheds at the port where the fumigations are carried out.

Loading and sealing. Forty to forty-two crates are placed in each fumigation bubble, the gross volume of pallets per fumigation bubble being 93.2 m^3. The lower section of the bubble is laid on the ground, and pallets are placed on it with a forklift. Two PVC sampling tubes are then laid out to sample gas from the top and bottom center of the stack and threaded through a gasket in the liner membrane. The over-liner section is then drawn over the stack and attached around its periphery to the under-liner by means of a tongue-and groove gas-tight zipper (Fig. 1).

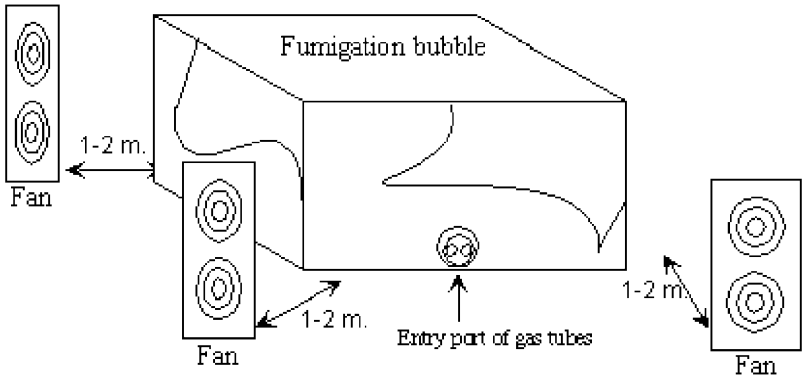

Fig. 1. Schematic view of a fumigation bubble and the position of three external fans facing the bubble.

Gas application. MB is delivered from gas canisters that are punctured inside the fumigant applicator. The dose is calculated on the basis of the number of 681 g capacity MB canisters to be used and the dispenser fan is operated to blow the gas-air mixture into the bubble and inflate it. Seven and half canisters each containing 681 g MB, give the required initial concentration of 32 g/m^3 of the total inflated space as determined in previous studies (Donahaye et al., 1997; Navarro et al., 1997). In these laboratory and commercial scale studies it was shown that a Ct product of 80 g h/m^3 gave complete kill of *M. eques* larvae, and that taking into account sorption by the bulbs, this requirement is met when 30 g/m^3 are applied over a 4-h exposure period. The canisters are punctured one after the other, and the gas is released into an expansion chamber in the ventilation duct from which it passes into the bubble. The additional unused half canister was disposed of by the fumigation company according to local regulations. Today the company has the ability to fill the canister with the exactly predetermined concentration so there is no need for disposal.

Gas mixing during conventional fumigation. In the conventional fumigation used before the trials reported here, gas was introduced from the dispenser fan to the top of the bubble, thereby inflating it. A return duct from the bubble to the dispenser enabled the dispenser fan to be used for recirculation of the gas for an initial half-hour period after which it was turned off.

Gas mixing during modified fumigation. In these trials gas was introduced as previously. However, after introducing the gas, the applicator fan was turned off. Three external fan-units designed for greenhouse ventilation, each consisting of two 2500 kW 0.75 HP, 230 V axial fans (Vemat Montore Asimcrono, Italy) mounted one on top of the other, were located at a distance of 1 to 2 m from three corners of the fumigation bubbles. These were operated during the entire fumigation process in order to create wave-like undulations along the plastic walls, thereby producing turbulence within the fumigation bubble (Fig. 1). When two bubbles were fumigated side by side, one fan was positioned between the bubbles so that 5 fans were sufficient for simultaneous fumigations of the two bubbles. The airflow rates of each external fan were measured using a hot wire Newtron anemometer (M.R.C. Ltd. USA).

Post-fumigation procedure. After a 4-h fumigation, operators wearing gas masks opened the zipper of the bubble to allow the gas to desorb from the bulbs and to dissipate. Forced aeration was carried out with the same large axial fans used during the fumigation. Two to three units were re-located facing the pallets at a distance of about 2 m and were run all night to remove the desorbing gas, and to prevent accumulation of gas concentrations in the interstices between bulbs inside the crates.

2.2. Monitoring procedures during the modified fumigations

During the 2001 season, a total of 19 commercial fumigations were carried out implementing this technology, represented here by the data obtained in 4 fumigations (Tables 1 and 2). Of these, time-staggered concentration measurements were taken during the first two fumigations in order to establish concentration decay during exposure. In the other fumigations, MB concentrations were measured 60 min after the start, and 30 min before the end of each treatment in order to evaluate the success of the fumigation process.

Bulb samples. Before each fumigation, 2 kg samples of narcissus bulbs were placed at the center-bottom position of each fumigation bubble for analysis of fixed inorganic bromide within the

bulbs after fumigation. Non-fumigated bulbs served as controls. These analyses were carried out by a commercial laboratory (“AminoLab” Israel) using bromine analysis of the homogenized bulbs in water, by ion chromatography. Results were expressed in mg inorganic bromide per kg of the tested bulbs. In addition, bulbs removed during sorting at the packing station, suspected of being infested, were placed within the bubbles before fumigation. After fumigation they were taken to our laboratory and checked for insect mortality. Each bulb was opened, larvae were dissected out and examined under a stereo-microscope, and those that failed to move under a strong light were counted as dead. All bulbs were examined within 24 h of fumigation.

Calibration of the MB gas monitor. Measurement of MB concentration was carried out using a Bedfont MB gas monitor Model 415, equipped with a thermal conductivity (TC) detector. This monitor uses a TC detector that is also sensitive to carbon dioxide (CO_2). Since it has been previously found that bulb respiration liberates CO_2 during fumigation, recalibrations of the MB scale had to be made to take into account the rising CO_2 concentrations. A set of laboratory fumigations was conducted at room temperature using different combinations of MB and CO_2. The tests were conducted in fiberglass vacuum desiccators equipped with two sampling ports. One sampling port was connected to the Bedfont monitor to measure the concentration of MB. At the same time, the concentration of CO_2 inside the desiccator was measured from the other port using an infrared CO_2 analyzer (Riken Model RI 550A Japan) whose reading is not influenced by the presence of MB. Four or five different dosages of MB were injected separately into the chambers previously flushed with concentrations of 0, 0.5, 1.0, 2.0 and 3.0% CO_2. Readings on the Bedfont MB monitor were recorded separately at each concentration of MB and of CO_2. At each reading gas samples were then withdrawn using a pressure lock syringe. These samples were injected into a gas chromatograph equipped with an FID detector calibrated for MB to obtain the actual MB readings (Tracor model 565, FID 200 °C and chromosorb 101 filled columm). Calibration curves at each CO_2 concentration were then prepared by plotting readings of MB concentrations obtained from the Bedfont monitor against actual MB concentrations recorded by the gas chromatograph, and regression lines were calculated. Linear equations obtained from regression analysis enabled determination of absolute MB concentrations from readings recorded by the Bedfont monitor.

Gas sampling and monitoring of MB and CO_2. MB measurements were taken at set time intervals throughout the fumigation process. The sampling system used two plastic 2 mm i.d. PVC sampling lines terminating at the top and bottom center of the bubble. It is assumed that the turbulence created by the ripple movement along the walls would initiate gas mixing at the periphery so that the central sampling points would be the last to stabilize. This assumption would justify the paucity of sampling points, although in practical terms this was determined by technical difficulties in the field. Sampling lines were connected to the pump of the Bedfont monitor through a multi-channel control valve welded onto the bubble by the manufacturer. Concentrations within the bubble were measured using the Bedfont MB gas monitor while CO_2 concentrations were measured using the Riken infra-red CO_2 analyzer. MB concentration readings of the Bedfont monitor at a certain CO_2 concentration were then converted to absolute MB concentrations using the calculated lines shown in Fig. 2.

Data available from previous fumigation trials. Gas concentrations monitored during fumigations that were carried out according to the previous procedure have been published by

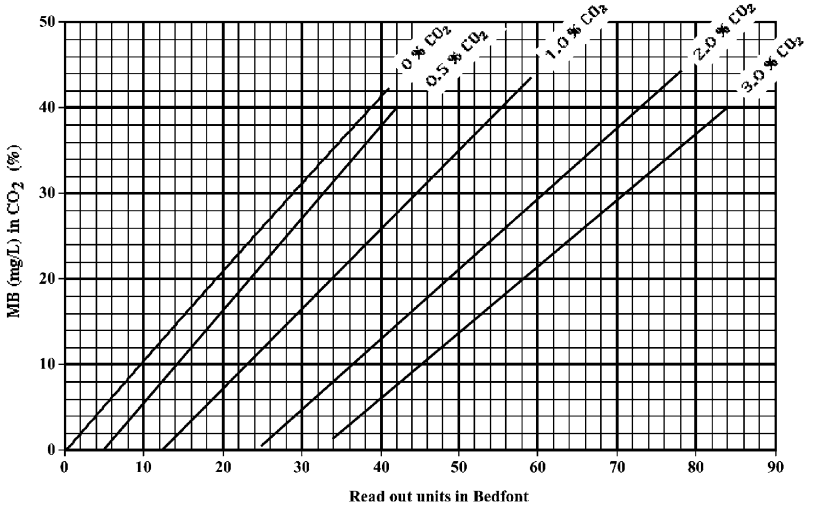

Fig. 2. Calculated lines used to convert MB concentration readings at certain CO_2 concentrations using a Bedfont gas monitor to absolute MB concentrations.

Navarro et al. (1997). They provide a base-line for comparison with the results of the improved fumigation procedure described above.

3. Results and discussion

The external fans used in the trials provided an airflow averaging 209 m/min.

The drawback in the previous method of using the flexible PVC fumigation chambers was the difficulty of creating rapid fumigant circulation within the confined space where the absence of a headspace effectively prevented the installation of internal circulation systems. Previous attempts (Navarro et al., 1997) to provide rapid circulation within the chambers were only partially successful.

In the first of these fumigations, the pattern of MB distribution at the two central sampling positions within the fumigation bubble is presented in Fig. 3. It can be seen that initially the MB concentration increased rapidly at the bottom of the bubble, reaching a momentary maximum of 52 g/m^3 within 30 min, and thereafter decreased sharply to 19 g/m^3. On the other hand, the concentration of MB at the top increased gradually reaching a maximum of 18 g/m^3 within an hour. After 1 h, the concentrations at the top and bottom of the bubble became uniform and stabilized at about 19 g/m^3 and remained fairly uniform at this value throughout the remainder of the fumigation. Thus, the results indicate that MB concentrations became uniformly distributed within the bubble after one hour. To provide a comparison, Fig. 4 taken from a previous study (Navarro et al., 1997) shows gas mixing carried out by recirculation.

From Table 1 it can be seen that after 60 min there was no marked difference in MB concentration at the bottom and top of the bubbles during the remaining time for all of the fumigation trials. However the slightly higher concentrations recorded in Trial 3 and the higher

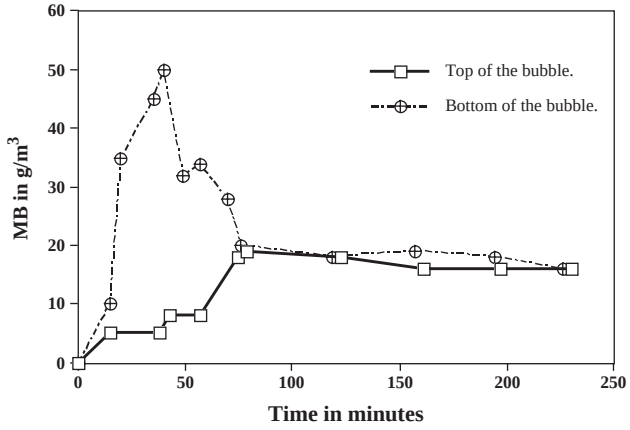

Fig. 3. The variations of MB concentration levels at two different positions within the fumigation bubble during the fumigation time period when applying the new method (Fumigation-1).

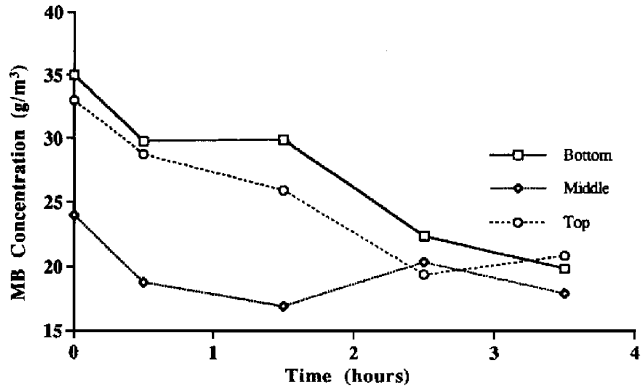

Fig. 4. The variations of MB concentration levels at different positions within the fumigation bubble during the fumigation time period when using the previous method (Navarro et al., 1997).

bromide residues indicate the possibility that a higher initial dosage was applied in this treatment. Towards the end of the exposure period (230 min.) it was observed that although the concentration had dropped to an average of 16 mg/L, uniform concentrations within the bubbles remained throughout the fumigation trials. The number of larvae exposed to fumigation in each trial differed since the larvae were only dissected out of the bulbs after treatment. However, the laboratory checks revealed complete mortality of all *M. eques* larvae in each of the four fumigations.

Fixed inorganic bromide content measured in samples of bulbs taken from each fumigation, together with samples of non-fumigated bulbs, are given in Table 2. They indicate that there was no noteworthy difference in inorganic bromide levels between samples of fumigated and non-fumigated bulbs.

Table 1
Calculated concentration of methyl bromide (g/m^3) in the bubble measured at the fumigation site for different fumigations

Fumigation	Calculated concentration of MB in the bubble (g/m^3)			
	After 60 min		After 230 min	
	Bottom	Top	Bottom	Top
Fumigation—1	20	19	16	16
Fumigation—2	22	22	16	16
Fumigation—3	29	25	18	15
Fumigation—4	27	25	16	15

Table 2
Fixed inorganic bromide content detected in sample of bulbs after fumigation taken from the center bottom of the bubbles

Fumigation	Inorganic bromide (mg/kg)
Fumigation –1	23
Fumigation –2	29
Fumigation –3	32
Fumigation –4	18
Control	23

The results show that the mean concentration of about $20\,g/m^3$ needed to kill the narcissus flies was accomplished by this method of using external fans to produce turbulence within the fumigation bubble. By this method, the time needed to reach about $20\,g/m^3$ in all fumigation bubbles took 1–1.5 h, and in consequence very low increments in fixed inorganic bromide concentrations in the fumigated bulbs were recorded.

In conclusion, this novel method of using external fans to create turbulence within the fumigation bubble provided uniform fumigant concentrations within a short time. This method is not only suitable for the fumigation of narcissus bulbs but can also be similarly applied for fumigation of other commodities in bubbles. The method does rely on the know-how of the pest control operator on where to best position the external fans in order to achieve the most effective ripple effect on the PVC chamber walls.

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