# Agricultural Chemical Hazards in Commercial Mushroom-Growing Operations

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## INTRODUCTION

Medical and industrial hygiene reports regarding the health hazards faced by mushroom growers have focused on cases of exposure to inhaled organic antigens which elicit a response termed "mushroom worker's lung",[1-5] which in France has been recognized as a compensatable disease. It has been demonstrated that protection from environmental dusts which may provoke allergic alveolitis can be provided by inexpensive industrial dust respirators.[2,6,7] However, other aspects of occupational health at these agricultural worksites are less well characterized.

The successful commercial cultivation of edible mushrooms requires a controlled environment with fastidiously maintained levels of temperature, humidity, carbon dioxide, and ventilation, as well as constant vigilance for diseases and insect infestations. Throughout the production cycle, a mushroom crop may be subjected to a variety of pathogenic organisms such as fungi, bacteria, viruses, nematodes, and insect larvae. At the present time, 73 commercial pesticide preparations are registered by Agriculture Canada for use on edible mushrooms, the majority of which have active ingredients which are organophosphate (OP) pesticides. Other chemicals such as formaldehyde are routinely used in a regimen of general plant hygiene designed to prevent the spread of biological activity from one area of the plant to another. The hazards to farm workers from OP pesticides have been well documented in the literature,[8,9] and three commercial mushroom farms have been the subject of past studies by the National Institute for Occupational Safety and Health (NIOSH).[10-12] A recent paper has presented the results of industrial hygiene surveys for atmospheric ammonia and formaldeyde in an insect-rearing facility.[13] In this paper, preliminary industrial hygiene surveys for pesticides and for formaldehyde conducted in three commercial mushroom-growing operations, typifying the uses of pesticides in the industry in Alberta, are described.

## PROCESS

The mushroom *Agaricus bisporus* is the most common commercial crop grown in seven plants in Alberta. The plants which were the subject of this study employed a standard five-step growing process using movable trays. Each firm employed between 25 and 150 workers, usually with more than one shift. A short description of the production steps and of the worker's tasks in each step will demonstrate the opportunities for chemical exposure.

**Step 1** — Heavy equipment operators mix the raw material, usually outdoors, and add water to begin the composting process. The operators were exposed to high heat and humidity, particularly during the summer season, as specially designed composting machines, called "turners", mechanically invert the compost stacks and add water every 2 to 3 d. In some areas of the country, pesticides such as diazinon, malathion, or dichlorvos may be added to the compost as a guard against mushroom fly infestation,[14] although this was not done in Alberta plants.

**Step 2** — The compost, which in some cases may be pesticide treated, is brought into the plant by a front-end loader, mixed with other ingredients in a separate soil shed area, and mechanically applied to trays or beds, usually made of wood. Before each application of soil, the mechanical tray line is manually washed and sanitized with a 2% formaldehyde solution, preceded in some plants by treatment of the tray- line room with pesticides such as diazinon. The soil shed is treated with formaldehyde solution before formulating the soil mixtures, usually by workers responsible for this part of the plant. Tray-line operators are employed during the filling of the beds, controlling the filling process, manually removing the excess soil from the sides of the beds, and stacking the beds before placement by forklift into cook-out rooms. Dermal exposure to treated soils is a possibility. A pasteurization of "cook-out" with steam eliminates parasitic organisms. Diazinon or dichlorvos may be sprayed in order to control flies during cool down of the compost. Methoxychlor, malathion, and/or pyrethrin may also be added to the compost immediately prior to the next step, for further fly control.

**Step 3** — After pasteurization, the nutrient bed is seeded with commercial mycelium/grain preparation called "spawn". Spawn is worked into the bed surface mechanically, on a freshly sanitized tray line, or by hand. Care is taken to maintain as hygienic conditions as possible by following a regimen of disinfection or pesticide treatment of the area. Diazinon and pyrethrin were sprayed by growing-area workers during spawning in two of the plants under study and dichlorvos has also been used to control pests at this stage.[10] Workers have ample opportunity for exposure to treated soils, as well as exposure during chemical treatments and during the cleaning/disinfection of equipment and work areas as part of the general hygiene procedures.

**Step 4** — A layer of pasteurized or chemically treated loam called the casing layer is applied to the beds in order to begin the change from the vegetative stage to the reproductive stage in which the fruiting or spore-bearing bodies of the mushroom are allowed to develop. Although the application of toxic chemicals such as methyl bromide to casing material has been discontinued, dichlorvos or pyrethrins are now used to treat casing soils. Recently, methoprene or malathion has also been recommended for application to the casing layer.[15] The treated mixtures are formulated by soil-shed workers, applied to the trays, and the trays returned to the growing rooms. Growing-area personnel may periodically apply benlate and/or zineb, especially where wooden beds are used, in order to prevent the growth of unwanted fungi. When mycelia reach the surface of the bed, ventilation rates are increased and temperature and carbon dioxide levels are dropped in the growing rooms, which causes the bundling of hyphae into pins, the reproductive body of the fungi. Provincial agricultural agencies recommend that diazinon, dimethoate, and/or malathion be used outside the growing rooms at this time, in hallways and corridors, to combat mushroom flies.

**Step 5** — The fruiting bodies of the mushrooms develop into crops which are termed flushes. Growing-area workers, called watermen, carefully soak the mushroom beds with water containing chlorine and, often, benlate. The mushroom crop is very carefully monitored at this stage for infestations of pests, and any control measures are taken by growers as needed (Table 1). The crops are normally harvested by hand, by picking crews, when the mushroom cap is at its maximum size. Any diseased or fly-damaged mushrooms are discarded at this point and the affected part of the bed is treated with pesticide (one of diazinon, methoxychlor, dimethoate, or zineb). Growers in one plant used malathion for powder dusting and liquid fogging in the growing rooms. To prevent the development of mushroom disease, most growers allow the production of only three to four flushes before the houses are emptied. Again, cross-contamination of the various growing rooms is prevented by the pesticide spraying of central hallways and doorways and by the use of foot trays containing salt in the growing room doorways. Workers' hands and footwear are frequently disinfected by rinsing in chlorinated water. Once the decision has been made to discard a crop, the growing house is steamed to terminate any residual biological activity in the beds. Waste materials are disposed of in an area remote from the plant. Growing rooms are cleaned and sprayed with pesticide and/or formaldehyde prior to the introduction of another crop.

In all plants examined, formaldehyde was dispensed into buckets, diluted to 1.5 to 2%, and used to disinfect the soil-shed areas and the tray lines following each mechanical application of compost, spawn, or casing mix. Spawn rooms, growing rooms, and delivery trucks or other mechanical equipment were steam cleaned or washed and then disinfected with formaldehyde solutions as part of the plant's general hygiene procedures.

Initial walk-through surveys indicated that such commercial growing operations generally relied on respiratory protection and some form of personal protective equipment to prevent overexposure of workers to pesticides and to formaldehyde. Applicators usually wore boots, aprons, or rubber jackets and full face-piece cannister masks approved for pesticides, or for organic vapors in the case of formaldehyde applicators. One plant, however, did use half face-piece, air-purifying respirators for formaldehyde spraying. Outer protective pants or coveralls, gloves, and hats were often not worn during spraying and there was no mandatory washup following the operation in order to minimize dermal exposures. Programs of respiratory protection, respiratory fit testing, and biological monitoring of high risk groups of workers (compost barn and soil-room blenders and tray-line sprayers, spawn-room and growing-room sprayers) did not exist. Areas recently treated with chemical were often not posted to restrict entry.

**TABLE 1**
**Diseases of Mushrooms, Their Causative Agents, and Treatments**

| Disease | Causative agent | Chemical treatment |
|---|---|---|
| Mycelial damage | Larvae of scarid, phorid, cecid flies | Diamethoate, diazinon<br>Dichlorvos, malathion, pyrethrin, methoprene |
| Mite contamination | *Tyrophagus* mite | Malathion |
| Casing soil mildew: | | |
| soft mildew and green mildew | *Dactylium dendroides*<br>*Trichoderma koningi* | Formaldehyde, zineb, calcium hypochlorite |
| Bacterial blotch, pit, and mummy | *Pseudomonas* sp. | Chlorinated water |
| Dry bubble, brown spots | *Verticillium fungicola* | Zineb, benomyl, calcium hypochlorite, formaldehyde |
| Wet bubble | *Mycogene perniciosa* | Benomyl at casing, calcium hypochlorite, formaldehyde |

## CHEMICAL SAMPLING METHODS

Personal samples for malathion, diazinon, benomyl, zineb, and formaldehyde were taken in 1985 during spraying operations, at the breathing zones of soil -room and tray-line sprayers and of spawn-room and growing-room personnel (lapel samples), including the watermen. Since the greatest chemical exposures would initially be expected in the soil-shed and growing-area applicators, during fly control programs, sampling was concentrated on these workers.

In the case of both full shift and short-term pesticide samples, the previously calibrated sampling pumps drew a known volume of air through a 37-mm Teflon filter which was followed in series with a glass tube containing 75/37 Chromosorb 102. These were then analyzed by gas chromatography for malathion/diazinon or by high-performance liquid chromatography for benomyl. Zineb was estimated by the analysis for total zinc using atomic absorption spectrophotometry.

All formaldehyde samples were taken by impinger sampling using a 1% sodium bisulfite absorbing solution, reaction with chromotropic acid, and colorimetric measurement in the Alberta Occupational Health and Safety Laboratory, as per the NIOSH method (P + CAM 125).

## RESULTS AND DISCUSSION

Personal samples in one plant were obtained from growers during malathion dusting and liquid fogging operations in the growing rooms and during benomyl fogging and watering operations executed by the watermen. At no time did the applicator's exposure levels, considering both individual pesticides and combined effects, approach the Alberta occupational exposure limit (OEL) of 10 mg/m$^3$ — time-weighted average for malathion and for benomyl. These workers' exposure levels were, in all cases, at least an order of magnitude lower than occupational health standards in effect at that time. Zineb levels were also extremely low (less than 0.3 mg/m$^3$ for STEL samples).

Data on the atmospheric concentrations of diazinon and formaldehyde in two commercial mushroom farms are presented in Tables 2 and 3. Short-term samples of growing-room applicators show a potential overexposure of the applicator to diazinon levels in excess of the 15-min OEL with one 15- to 20-min spraying of a growing room per applicator per day. At a frequency of application greater than this, for example, due to an infestation, daily chemical use at multiple sites would provide for a greatly increased applicator exposure, possibly resulting in depressed serum cholinesterase and neurological effects.

In Alberta, the hygienic limits for many OP pesticides carry the "skin" notation, as an indication that absorption through skin may provide a significant route of entry for that toxicant. Dermal exposure to pesticides would be significant for applicators wearing respirators, but not wearing protective clothing, as was seen during initial walk-through surveys.

**TABLE 2**
**Commercial Mushroom Farms — Diazinon Exposure Levels, Ranges, and Means by Operation**

| Operation | | Application time 8 h TWA[a] exposure (mg/m$^3$) | Application time 15 min TWA[a] exposure (mg/m$^3$) |
|---|---|---|---|
| Personal samples | | | |
| Growing room — fogging/dusting | Range | 0.004—0.031 | 0.23—1.79 |
| | Mean | 0.020 | 0.94 |
| | n | 5 | 13 |
| Area samples | | | |
| Spawn rooms/ growing rooms — fogging/dusting | Range | 0.004—0.027 | 0.042—2.0 |
| | Mean | 0.012 | 1.07 |
| | n | 4 | 8 |
| Alberta OELs for diazinon (mg/m$^3$) | | 0.1 | 0.3 |

[a] Time-weighted average.

**TABLE 3**
**Commercial Mushroom Farms — Ceiling Formaldehyde Exposure Levels, Ranges, and Means by Operation (All Results Expressed as ppm)**

| Operation | | Farm A | Farm B |
|---|---|---|---|
| Personal samples | | | |
| Tray-line washing | Range | 0.87—4.81 | 4.4—11.9 |
| | Mean | 2.7 | 7.4 |
| | n | 7 | 7 |
| Soil-shed washing | Range | 6.5—10.1 | — |
| | Mean | 8.4 | — |
| | n | 8 | — |
| Area samples | | | |
| Tray-line washing | Range | 0.46—69 | 0.45—15.4 |
| | Mean | 12.4 | 4.5 |
| | n | 7 | 10 |
| Soil-shed washing | Range | 5.5—15.3 | — |
| | Mean | 9.3 | — |
| | n | 8 | — |
| Alberta ceiling OEL (ppm) | | 2 | |

Complete suits of protective clothing and regular cleaning would prevent this. One plant's chlorinated rinse water used by growers showed detectable levels of malathion and diazinon. This practice of rinsing hands has been documented in others plants[10,11] and could provide additional exposure where significant pesticide contamination of the water is found. Rinsing under a flow of fresh chlorinated water which drains into the plant's waste system would prevent this exposure. It has been shown that excessively chlorinated water, some OP pesticides, and benomyl and zineb may be skin irritants and possible sources of sensitization.[10] Such exposures are easily prevented by the wearing of rubber gloves (unlined to facilitate removal of residues inside the glove), for example, by the watermen to prevent exposure to benomyl.

From the exposure of chemical applicators in mushroom-growing areas and given the amount of pesticide utilized, it is clear that programs of respiratory protection, including fit testing and biological monitoring of high-risk workers, are necessary. Use of protective clothing covering exposed skin, especially hands, must be mandatory and enforced, if necessary. Treated areas should be posted to prevent unauthorized entry, and accurate records should be kept of chemical use. Ample guidance from Departments of Agriculture and from Health and Safety Agencies is available concerning the use of agricultural chemicals and these should be strictly adhered to.

During the harvesting stage, the carbon dioxide levels in the growing rooms recommended by grower's guides commonly range between 800 and 1000 ppm, as opposed to 20,000 to 30,000 ppm during pinning, but these levels may become considerably higher in older plants built with roof vents or with meager ventilation in the houses. The growing rooms should be ventilated before growers or picking crews enter, to avoid headaches or other problems associated with exposure of workers to atmospheres containing elevated levels of carbon dioxide. It should be noted, however, that a number of such symptoms (headaches, weakness) may also be seen with chronic OP pesticide exposures.

As mentioned previously, the spray application of formaldehyde plays a major role in the routine hygiene of all commercial mushroom operations examined. On the basis of the measurements presented, it is not possible to conclude whether the workers responsible for plant hygiene in commercial mushroom farms as a job category are overexposed to formaldehyde. Interplant variability with respect to room sizes, etc. makes comparisons difficult. However, it can be seen that workers carrying out these general hygiene procedures have a high potential risk for overexposure to formaldehyde. Care must be taken in the mixing of dilutions for application and proper respiratory protective equipment and protective clothing must be worn by all workers involved in such operations. Air-purifying respirators are currently approved by NIOSH for use in atmospheres containing less than 30 ppm formaldehyde and a supplied air device will provide greater protection in those plant areas where high concentrations of formaldehyde are found. The potential solutions to worker overexposure include ventilation, personal protective equipment, and the substitution of less hazardous materials. The efficacy of other chemicals (quaternary ammonium compounds or chlorine or iodine-containing compounds) to replace formaldehyde as a topical disinfectant should be investigated. Departments of Agriculture have also warned of a possible reaction between hypochlorite and formaldehyde which may produce *bis*-chloromethyl ether, a potent carcinogen. This may be averted by administrative controls designed to preclude the mixing of these chemicals.

Last, some farms have turned to the use of metal trays for compost beds. Such trays are easily sanitized and would not be a source of larval or fungal contaminant as is often found in older commercial operations. In one such plant examined in Alberta, high efficiency filtered air and metal trays have eliminated most chemical use, except for the application of formaldehyde in general plant hygiene. However, the biological hazards, if any, which will arise from these operations should be investigated. Care must be taken that personal protective equipment and work practices eliminate worker exposure to biologically active materials during filter changes, maintenance, and similar operations.

## CONCLUSIONS

With some exceptions, the levels of agricultural chemical exposure in commercial mushroom operations did not exceed current occupational health standards. Measurements were made during the spraying of spawn rooms and growing rooms with OP pesticides such as diazinon and during the spraying of formaldehyde solutions in soil sheds and tray-line areas as part of general in-plant hygiene. Recognizing that samples were limited in number, sampling showed that presently accepted exposure limits were exceeded during spraying in these areas. In large commercial operations with insufficient personal protective equipment for applicators, these activities would give the workers multiple exposures via respiratory and skin routes. Attention should be paid to the quantitation of exposures to these agents on the basis of occupational hygiene data. Formal programs of respiratory protection, personal protective equipment, and biological monitoring must be instituted to ensure the health of workers. Consideration should be given to newly emerging technology and to recently registered agricultural chemical products, as these have the potential to adversely affect worker health.

## REFERENCES


1. **Sakula, A.,** Mushroom worker's lung, *Br. Med. J.*, 3, 708, 1967.
2. **Schulz, K.H., Felten, G., and Hausen, B.M.,** Allergy to the spores of *Pleurotus Florida* (letter), *Lancet*, 1, 29, 1974.
3. **Murphy, D.M.F., Atkinson, B.F., Nedwich, A., and Galgon, J.P.,** Mushroom worker's lung, *Am. Rev. Respir. Dis.*, 123, 97, 1981.
4. **Calderone, R.A., Russo, D., and Deahl, K.L.,** Serological studies of mushroom worker's lung disease, *Annu. Meet. Am. Soc. Microbiol.*, 82 (Abstr.), F32, 1982.
5. **Marland, P., Tabart, J., Bersay, Cl., Peninou-Gall, G., Bory, J., Labarre, C., and Elbaze, P.,** Le poumon du champignonniste, *Poumon Coeur*, 38, 371, 1982.
6. **Hendrick, D.J., Marshall, R., Fauxad, M.A., and Krall, J.M.,** Protective value of dust respirators in extrinsic allergic alveolitis. Clinical assessment using inhalation provocation tests, *Thorax*, 36, 917, 1981.
7. **Lacey, J., Nabb, S., and Webster, B.T.,** Retention of actinomycete spores by respirator filters, *Ann. Occup. Hyg.*, 25, 351, 1982.
8. **Popendorf, W.J. and Leffingwell, K.,** Regulating OP pesticide residues for farmworker protection, *Res. Rev.*, 82, 125, 1982.
9. **Griffith, J. and Duncan, R.C.,** Grower reported pesticide poisonings among Florida citrus fieldworkers, *J. Environ. Sci. Health*, 20, 61, 1985.
10. National Institute for Occupational Safety and Health, West Foods, Ventura, California, Health Hazard Evaluation Rep. No. HETA 81-366-1248, Cincinnati, OH, 1985.
11. National Institute for Occupational Safety and Health, Fillmore Dole Mushrooms, Castle and Cooke Foods, Fillmore, Utah, Health Hazard Evaluation Rep. No. HETA 81-138-1563, Cincinnati, OH, 1985.
12. National Institute for Occupational Safety and Health, Modem Mushroom Farms, Kennett Square, Pennsylvania, Health Hazard Evaluation Rep. No. HETA 84-255, Cincinnati, OH, 1985.
13. **Merkle, S.E.,** Ambient concentrations of formaldehyde and ammonia in a screwworm fly rearing facility, *Am. Ind. Hyg. Assoc. J.*, 46, 336, 1985.
14. **Cantello, W.W., Hendersen, D., and Argauer, R.J.,** Variation in sensitivity of mushroom strains to diazinon on compost treatment, *J. Econ. Entomol.*, 75, 123, 1982.
15. **Cantello, W.,** Control of a mushroom-infesting fly (Diptera: Sciaridae) with insecticides applied to the casing layer, *J. Econ. Entomol.*, 76, 1433, 1983.