

GUEST EDITORIAL



Christopher Hugh Bell, born 1945. Research team leader and Senior Research Consultant, Central Science Laboratory (CSL), Dept. of Environment, Food and Rural Affairs, at York, UK. B.Sc. Brunel U. (1968). 1968–1983, Research scientist, Pest Infestation Laboratory at Slough, UK. Ph.D. on stored product moth biology and control by fumigation (1975) from Brunel U. 1983–1992, Head of Physical and Chemical Control Branch, Storage Pests Dept., Slough, UK; 1992–96, Research Team Leader at CSL, Slough and, from 1996, York. *Other activities:* 1973–, Fellow of the Royal Entomological Society of London; 1983–84, Technical Secretary to the UK MAFF Crop Protection Research Consultative Committee; 1985–87, Member of British Standards Institute Committee FHB/8 (Design of Farm Bins); 1990–, Editorial Board member of the *Italian Journal of Food Science* and of *Postharvest Biology and Technology*; 1991–, Regional Editor for Europe and Africa of the *Journal of Stored Products Research*. *International activities:* 1989–, Member of the Permanent Committee for International Conferences on Fumigation and Controlled Atmospheres; 1993–97, Member of the Organising Committee for Council of Europe Fora on Stored Product Protection and Post Harvest Treatments; 1996–, Member of the Methyl Bromide Technical Options Committee (MBTOC) of the U.N. Environment Programme (UNEP) Montreal Protocol, Co-Chair of MBTOC Durables Sub-Committee; 1996–, International consultant for U.N. Industrial Development Organisation, missions in Tunisia, Syria and Iran. *Main field of interest:* Efficacy of fumigation and physical control methods for stored-product protection, their safe application and effects on arthropod biology.

Fumigation – The Few Remaining Compounds

With the forthcoming withdrawal of methyl bromide (MB), the field of fumigation will lack the compound of first choice for an amazingly wide spectrum of operations ranging from preplant soil treatments to quarantine treatment of fresh fruit, fumigation of sheeted bag stacks of durable food commodities, space fumigation of food-processing facilities, fumigation of premises against structural pests and fumigation of transport. A previous editorial has discussed some of the options under investigation (15). For soil, the largest volume use of MB, a wide variety of cultural and physical practices including development of soil-less media, application of organic amendments, solarization and soil steaming, are likely to replace MB, together with the increased use of chemical cocktails comprising methyl isothiocyanate-releasing compounds, fungicides and/or liquid fumigant mixtures of chloropicrin and 1,3-dichloropropene. This move away from gases into the realm of physical methods, volatiles and sprays arguably sees the end of true fumigation in this area. In other areas some alternative gases are available and indeed MB itself may persist for a while for use as a quarantine or pre-shipment control measure. Because of difficulties in establishing new standards for international quarantine regulations in the short term, these uses are currently exempt from the controls of the Montreal Protocol, the United Nations

Environment Programme (UNEP)-sponsored treaty on ozone-depleting chemicals which listed the fumigant in 1992. Phase-out of all other uses of MB is scheduled for 2005 in all developed (Article 2) countries and in 2015 in all developing (Article 5) countries.

Methyl bromide will join a long list of fumigants that were withdrawn in the last quarter of the 20th Century because of concerns over toxicology, safety of application or the formation of toxic residues. Only two compounds have the potential to remain in widespread use: phosphine, used today mainly on bulk cereals and durable stored products, and sulfuryl fluoride, used principally for control of structural pests but now undergoing registration for some food uses. Many other compounds have been considered for use as fumigants at one time or another and some are still being investigated. Carbonyl sulfide is under consideration for registration for use on grain in Australia (2). Sorption of carbonyl sulfide by wheat is very low, stored cereals contain natural levels of the gas and mammalian toxicity is low. The fumigant is highly penetrative and has shown activity against many stored-product pests. Cyanogen is under consideration as an alternative grain fumigant and sterilant in Australia. It has been patented for this use. Ethyl formate is also under investigation in Australia for reinstatement as a fumigant for grain. It is still in use in some countries for treatment of dried fruit, particularly during packaging, and also for processed cereal products. Methyl iodide has properties similar to MB as to efficacy but is more expensive to synthesize. It is under consideration as an alternative to MB for use on soil in the USA, and also for use on stored products (10,16). Methyl isothiocyanate, introduced over 40 years ago as a nematicide, has more recently been found to be effective against grain weevils and the codling moth (9). The compound is, however, highly sorbed on grain. Methyl phosphine has been investigated in the UK as an effective countermeasure to phosphine resistance. It has specific action against phosphine-resistant strains, being more toxic to these than to susceptible strains, but again has a short half-life on commodities (8).

With or without MB, fumigation will remain an important control measure in the food industry for the treatment of incoming raw materials, either before leaving the country of origin or on arrival at the dockside before distribution. It is the primary control procedure applied on discovery of infestation in bulk commodities in store or during transport, and for whole-site treatment of food-processing premises. For effective application, fumigation relies on achieving an effective seal on the bulk commodity or building to be treated. Plastic enclosures are in use for bagged products, either as ready available kits with zip seals (11,14) or as tents constructed and glue-sealed on site (1). Polyethylene is often used as fumigation sheeting but better gas retention is obtained with nylon or PVC materials or laminates (6).

For most fumigants, dosages are expressed as concentration time (Ct) products. A particular Ct product, derived from a gas concentration level in g m^{-3} multiplied by time of exposure in hours, gives a similar level of kill whether or not a higher or lower concentration (and corresponding shorter or longer exposure period) is employed. Some fumigants, such as phosphine, however, require an initial period to gain access to cellular chemistry and commence toxic action, and in this case time of exposure is more important than concentration in contributing to overall efficacy (3,5). Furthermore, with phosphine there is a wide difference between insect developmental stages in tolerance, and in tolerant stages development proceeds under gas. Hence, the efficacy of longer exposures is further enhanced when the exposure spans a tolerant stage.

For all fumigants the gas concentration applied and retained must exceed a minimum

level for an effective treatment. For both time of exposure and concentration, the minimum levels to start toxic action are strongly influenced by temperature (4,5). At higher temperatures metabolism is faster and the concentration level that can be metabolized or excluded from the site of toxic action is greater than that at lower temperatures.

The more specific a pesticide is in action, the greater the prospect for the development of resistance, because if the treatment leaves some species or stages unaffected, then mechanisms must exist that render the chemical's mode of action ineffective. Most fumigants have been regarded as non-specific in their mode of action but it should be remembered that resistance to one fumigant, hydrogen cyanide, appeared very early in the modern history of chemical control (13). Today there is a problem of widespread resistance to phosphine. The natural spectrum of tolerance to a toxicant is an excellent indicator of the potential for resistance to develop among pest species. Phosphine has a very wide spectrum of toxicity among insect species and even, as mentioned above, among stages of the same species, and acts specifically *via* the oxidative cycle for energy production (7). High levels of resistance to the fumigant phosphine have been identified in several species of stored-product beetle pests from parts of Africa and the Indian subcontinent, following frequent misuse of the fumigant in conditions of poor gas retention (12,16). There have been control failures attributable to this resistance. Short fumigation periods (*e.g.* less than 3 days) employing low concentrations of phosphine at high ambient temperatures, provide the ideal conditions for insect resistance to develop. Sale of phosphine formulations is largely unrestricted, especially in developing countries. It is important for high standards of product stewardship to be introduced for fumigants to avoid misuse and the spread of resistance.

Although the ability to fumigate commodities and structures is much relied upon in every country, the market size in any one country or state is very small from the perspective of the multinational chemical manufacturers. Each country has its own registration procedures and acceptable daily intake levels and maximum residue levels may differ from country to country, together with many other data requirements. The cost of registration of a new active ingredient can thus prove prohibitive for a particular market. The stored product and food sector is furthermore very much subdivided on a commodity basis, requirements differing between commodities and products. Although this problem has been foreseen, governments have generally not provided support for minor use areas and as registrations of fumigants lapse or are withdrawn, no replacements are forthcoming. Unless urgent action is taken it may be too late to avoid many gaps appearing in the pest control armory for a wide range of products.



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