USE OF NON-CHEMICAL METHYL BROMIDE ALTERNATIVES IN THE USA

A. K. DOWDY
United States Department of Agriculture, Animal & Plant Health Inspection Service, USA
alan.k.dowdy@aphis.usda.gov

INTRODUCTION

About 30% of the methyl bromide (MB) used in the United States is for post harvest and structural treatments. Much of the post harvest use is to meet phytosanitary standards for international trade. The United States Department of Agriculture, Animal & Plant Health Inspection Service, Plant Protection and Quarantine (USDA, APHIS, PPQ) supports the continued use of MB for quarantine and pre-shipment treatments as exempted under the Montreal Protocol. The agency believes it is important, however, to develop and adapt alternative technologies that can lead to reduced gas emissions and overall use. This position has been adopted, in part, due to uncertainty as to how the U.S. Environmental Protection Agency will define both quarantine and pre-shipment applications (US EPA 2001). Thus, PPQ and the Agricultural Research Service (ARS) have active research programs for developing MB alternatives, both chemical and non-chemical. While some of the technologies are in their infancy, others have matured and are currently in use or will be approved for use this year.

The national phytosanitary organization for the United States is PPQ which approves all treatments that meet quarantine standards for commodities being imported into the country and for certain commodities, such as propagative plant material, and agricultural equipment moving within the country. The PPQ Treatment Manual currently lists heat, cold and irradiation as acceptable non-chemical treatments that meet quarantine standards (USDA 2002). Some of these treatments are alternatives to methyl bromide fumigation while others are used on commodities that are sensitive to the treatment. Non-chemical MB alternatives also are in use for non-quarantine applications such as those used for structural treatments. During the search for effective alternatives to MB, PPQ will systematically review all approved treatments to ensure they continue to work properly.

NON-CHEMICAL ALTERNATIVES

High Temperature

High temperature treatments are being evaluated and adopted as non-chemical alternatives for both quarantine and structural treatments. Several high temperature quarantine treatments were developed in the 1980s as an alternative to ethylene dibromide fumigation, which was considered to be carcinogenic. MB was not adopted at that time due in part to phytotoxic effects of the gas. Other heat treatments were developed specifically to be alternatives to MB.

Some winter wheat fields in Texas were infected with Karnal bunt, *Tilletia indica*, in 2001. When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. Once emptied, MB fumigation of contaminated storage bins requires a dose of 6.8 kg for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is effective when surface temperatures attain 77°C.

The golden nematode (*Heterodera rostochiensis*) is a potato pest of quarantine significance that occurs in a few isolated areas of the northeastern United States and in other countries. Used farm equipment, construction equipment, and containers infected with the nematode require a MB treatment of 6.8 kg for 24 hours to meet quarantine standards. Heat treatment using steam is effective for treating golden nematode infected equipment. Brodie and Norris (2001) injected live steam into a tent containing a tractor that was contaminated with all life stages of the nematode. A one-hour treatment at temperatures above 60°C resulted in 100% mortality of all life stages. The specific treatment parameters are being developed and the alternative will be approved for use. A preliminary test using the same technology to kill an introduced Mediterranean snail, *Cernuella cisalpina*, infesting maritime shipping containers (MilVan) resulted in 100% control when temperatures exceeded 54° C for 20 minutes (Mack and Norris unpublished data). The current treatment schedule for quarantine significant snails is 3.6 kg MB for 24 to 72 hours.

Dry heat is an effective non-chemical alternative and can be used in situations where the use of steam is not practical or there are concerns about water damage that may occur from steam treatment. Heat treatment is not a new technology and its use to disinfest flourmills predates MB fumigation (Goodwin 1922). Heat treatments were abandoned when fumigants became economically practical and due to fire safety concerns and perceived damage to wooden equipment. With the impending phase out of MB, however, the milling industry revisited this technology and its use is increasing. Recent advances have increased the effectiveness of the treatments and documented that modern food processing facilities, as well as older wooden structures and equipment, can be safely heat treated to temperatures of 50 to 60°C (Dowdy 1999, 2000; Dowdy and Fields 2002; Fields *et al.* 1997; Mueller 2002).

Low Temperature

Temperatures at or slightly above 0°C are effective for controlling a variety of insects, especially fruit flies, with minimal impact on commodity quality. A drawback of low temperature treatment is the length of time necessary for adequate control. While high temperatures in a matter of minutes can kill most insects, low temperature treatments may require several weeks or months to achieve the same level of control (Fields 1992). Further, low temperatures have little if any effect on the viability of most plant pathogens. Low temperature treatments conducted in-transit are not as limited by the time requirements needed for control and have been effective for many years. Recent failures of low temperature in-transit treatments, however, have resulted in a re-evaluation of the treatment with an emphasis on adequate distribution of the treatment temperature throughout the container or ship hold.

Irradiation

The use of irradiation as a commodity treatment has been discussed for several years but has yet to develop into a widely adopted method for safeguarding agriculture and natural resources. Its use as a quarantine treatment was conceptualized in 1930 (Koidsumi 1930) but was not commercially demonstrated until 1986 when shipments of mangoes from Puerto Rico were irradiated with 750 Grays and sold in Florida (Hallman 1998). Although irradiation was effective, a hot water immersion treatment was developed as the official mango treatment. In 1995, tropical fruits were shipped from Hawaii to Chicago for irradiation and distribution to markets. Since then, an irradiator has been built near Hilo, Hawaii that treats tropical fruits for unrestricted distribution on the mainland. Market surveys and approval in 2000 by the U.S. Food & Drug Administration for the irradiation of meat products indicate consumer acceptance of irradiated foods.

The objective of using irradiation, as with any quarantine treatment is to prevent the establishment of exotic pests. To accomplish this task, pest mortality is not always necessary, particularly with insects. Rather the prevention of reproduction should be the goal, which can be accomplished at lower doses than 100% mortality.

Presently, PPQ has approved irradiation quarantine treatments for three tropical fruits from Hawaii only. These are papaya, carambola and lychee for the pests Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)), melon fly (*Bactrocera cucurbitae* Coquillett) and Oriental fruit fly (*B. dorsalis* Hendel) (Treatment Schedule T105-a). The schedule requires a minimum dose of 250 Grays and a maximum of 1,000 Grays with documented dose mapping for each commodity, fruit size and box configuration. Additionally, irradiated commodities are to be safeguarded after treatment to ensure that they do not become reinfested.

The USDA APHIS published a proposed rule to establish phytosanitary requirements that will allow the use of irradiation treatments for imported fruits and vegetables (USDA 2000). The key elements of the rule address critical control points including irradiation doses and safeguarding after treatment. The proposed rule establishes irradiation doses for 11 fruit flies and one seed weevil (Table 1). The treatment is based on the pest requirements rather than on the commodity. This means that any commodity can be irradiated at the proper minimum dose for any of these species. For commodities where more than one pest is present, the highest dose is required. If other pests of quarantine significance are also of concern on a particular commodity but are not listed in the rule, then irradiation is not considered to be an adequate quarantine treatment for that pest. For example, if the quarantine pests of concern for a particular host are the melon fly that is listed in the rule, and a noctuid moth that is not listed, then a different approved treatment must be used to mitigate the risk caused by the moth. A supplemental proposed rule is currently being developed that concerns the use of radiation indicators on packaging of treated articles and additional provisions for monitoring of foreign facilities that provide the treatments.

TABLE 1: Irradiation dose for fruit flies and seed weevil in imported fruits and vegetables[1]

Common name (scientific name)	Dose (gray)
Oriental fruit fly (*Bactrocera dorsalis*)	250
Mediterranean fruit fly *(Ceratitis capitata)*	225
Melon fly *(B. cucurbitae)*	210
South American fruit fly *(Anastrepha fraterculus);* Caribbean fruit fly *(Anastrepha suspensa);* Mexican fruit fly *(A. ludens);* West Indian fruit fly (*A. oblique)*; Sapote fruit fly *(A. serpentina);* Queensland fruit fly *(B. tryoni); B. jarvisi*; Malaysian fruit fly *(B. latifrons*)	150
Cryprorhynchus mangiferae Mango seed weevil	100

[1] Adapted from USDA 2000

CONCLUSIONS

The non-chemical alternatives in use today are not new technologies but need to be revisited and re-engineered as potential alternatives to MB. Although new fumigant chemistry offers some alternatives, there will be no "drop-in" replacement for all uses of MB. Non-chemical alternatives can be as effective but adequate monitoring and verification are needed to ensure that treatments are efficacious and properly applied. The use of heat, cold and irradiation require closer attention for proper treatment than MB because pests may not be dead after application and a treatment failure may not be recognized until a commodity is widely distributed. Further, greater effort will be needed in crop production, such as the effective use of integrated pest management and systems approaches, to minimize the number of pests present in a commodity at harvest. Such practices will reduce the number of pests challenged by a treatment while maintaining or enhancing commodity quality.

REFERENCES

Brodie, B.B.; Norris, R. 2001: The development and transfer to end user of a methyl bromide alternative treatment to decontaminate items infested with the golden nematode. *Proc. Ann. Int. Res. Conf. On Methyl Bromide Alternatives and Emissions Reductions*, San Diego, California, paper 27.

Dowdy, A.K. 1999: Mortality of red flour beetle, *T. castaneum*, exposed to high temperature and diatomaceous earth combinations. *J. Stored Prod. Res.* 35: 175-182.

Dowdy, A.K. 2000: Heat treatment as an alternative to methyl bromide fumigation in cereal processing plants. *Proc. 7th Int. Working Conf. Stored Prod. Prot.*, Beijing, China 7: 1089-1095.

Dowdy, A.K.; Fields, P.G. 2002: Heat combined with diatomaceous earth to control the confused four beetle (Coleoptera: Tenebrionidae) in a flour mill. *J. Stored Prod. Res.* 38: 11-22.

Fields, P.G. 1992: The control of stored-product insects and mites with extreme temperatures. J. Stored Prod. Res. 28: 89-118.

Fields, P.; Dowdy, A.; Marcotte, M. 1997: Structural pest control: the use of an enhanced diatomaceous earth product combined with heat treatment for the control of insect pests in food processing facilities. Canada - United States Working Group on Methyl Bromide Alternatives. 25 p.

Goodwin, W. H. 1922: Heat for control of cereal insects. *Ohio Agricultural Experiment Station Bulletin* 354. 18 p.

Hallman, G.J. 1998: Ionizing radiation quarantine treatment. *An. Soc. Entomol. Brasil* 27: 313-323.

Koidsumi, K. 1930. Quantitative studies on the lethal action of x-rays upon certain insects. *J. Soc. Tropical Agr.* 2: 243-263.

Mueller, D. 2002. Alternatives to methyl bromide for disinfestation of structures and food facilities. Proceedings of the International Conference on Alternatives to Methyl Bromide, page 74: 3pp

USDA. 2000: Proposed rule: Irradiation phytosanitary treatment of imported fruits and vegetables. *Federal Register* 65 (103): 34113-34125.

USDA. 2002: Treatment Manual. USDA, APHIS, Plant Protection and Quarantine. www.aphis.usda.gov/ppq/manuals/pdf_files/TM.pdf (01/01/2002).

US EPA. 2001: Protection of stratospheric ozone: Process for exempting quarantine and preshipment applications of methyl bromide: final rule. *Federal Register* 66 (139): 37752-37768.

LOW TEMPERATURE STORAGE OF FOOD AND OTHER ALTERNATIVES TO METHYL BROMIDE

J.A. JACAS MIRET[1] & M.A. DEL RÍO GIMENO[2]
[1]Departament de Ciències Experimentals, Universitat Jaume, Spain;
[2]Departament de Postcollita, Institut Valencià d'Investigacions Agràries, Spain
Corresponding author: jacas@exp.uji.es

ABSTRACT

Cold treatments are predominantly used to inhibit decay of stored commodities and to extend their shelf life. Recently, cold treatments have been used successfully to control insect pests, mainly in tropical commodities, providing chilling injury can be avoided. This paper summarises the main uses of cold storage as a quarantine treatment.

Keywords: low temperature food storage, quarantine, chilling injury.

INTRODUCTION

Insects are poikilothermic animals. Their development is only possible between lower and upper temperature thresholds. Beyond these values, and depending on the time of exposure, temperature becomes lethal. Cold storage of food takes advantage of this physiological response of insects and can be a useful alternative to the use of methyl bromide (MB) as a postharvest treatment.

Low temperature storage is primarily used to inhibit decay and extend the shelf life of food commodities. Modern fresh fruit industry greatly depends on technology providing refrigerated facilities and transportation. When a combination of temperature and time of exposure exists that assures quarantine requirements (probit 9: 99.9968% mortality) (Baker 1939), and does not lead to unacceptable fruit damage, cold has a potential as a quarantine treatment, especially for those commodities where low temperature storage is used as part of the regular distribution and marketing practice.

Research on the use of low temperatures to control insect pests began at the end of the nineteenth century and expanded to cover a variety of food pests early in the twentieth century. Pests of stored products, such as the webbing clothes moth, *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae), the dark mealworm beetle, *Tenebrio obscurus* F. (Coleoptera: Tenebrionidae), or the cabinet beetle, *Trogoderma tarsalis* (Melsh) (Coleoptera: Dermestidae) were among the first to be tested (Gould 1994). Nevertheless, the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) soon atracted most of the attention. This pest was becoming established in new areas and was a serious concern for many import countries.

Cold storage was used as a quarantine treatment for the first time against *C. capitata* in Florida in 1929 (Richardson 1958). Since then, low temperature storage has been developed and successfully applied as a quarantine treatment against fruit flies (Diptera: Tephritidae) occurring mainly in temperate fruits (Table 1). A standard cold treatment against *C. capitata* requires a temperature of 2.22ºC (or below) for 16 days, and this is usually applied in transit (Anon 1992).

There are strict requirements for temperature monitoring in cold storage facilities in order to certify compliance with the required cold treatments. Cold quarantine has also been successfully applied to other insect taxa (Table 1), but problems have arisen from either the occurrence of extraordinarily cold-resistant stages (Moffit & Albano 1972), or cold habituation (Meats 1976; Czajka & Lee 1990).

Studies involving tropical fruit, such as mangoes, guavas and longans have usually resulted in unacceptable cold damage and have not been commercially used (Burditt & Balock 1985; McGuire 1998a). To prevent this kind of damage, preconditioning of fruit can be important (Hatton & Cubbenge 1982; Wild & Hood 1989; Houck *et al.* 1990; Miller *et al.* 1990; Crisosto & Smilanick 2000). Chilling injury may also be prevented by use of plant growth regulators (Ismail & Grierson 1977; McDonald *et al.* 1988), other chemical treatments resulting in curing the fruit (Schiffmann-Nadel *et al.* 1972; Wardowski *et al.* 1975; Chalutz *et al.* 1985; McDonald *et al.* 1991), and plastic wrapping (Ben-Yehoshua 1985; Yokohama *et al.* 1999b). Harvesting fruit in a less susceptible stage of ripeness can also reduce chilling damage (Chan 1988; Crisosto & Smilanick 2000) and pest incidence in the field. Besides this, cold storage can be part of a multiple quarantine treatment including the combined use of temperature and controlled atmospheres, fumigation, or irradiation (Anon 1994; Anon 2001).

Low temperature storage has been used for a long time as a quarantine treatment, mainly for those commodities where cold storage was already part of their marketing procedure. Use of this technology should increase as research provides new ways of preventing chilling injury.

REFERENCES CITED

Anon. 1992: Animal and Plant Health Inspection Service. Plant protection and quarantine treatment manual. T 107-Cold treatment. *U.S. Governement Printing Office. Washington, D.C*.

Anon. 1994: Certification of apples for export for the presence of apple maggot, Rhagoletis pomonella (Walsh). Directive D-94-02. Canadian Food Inspection Agency. www.inspection.gc.ca/englishplaveg/protect/dir/d-94-02e.shtml (27/12/01).

Anon. 2001: Postharvest quarantine control of codling moth (*Cydia pomonella* L.). www.ippc.orst.edu/codlingmoth/quarantine/ (27/12/01).

Baker, A.C. 1939: The basis for treatment of products where fruitflies are involved as a condition for entry into the United States. *USDA Circular 551*.

Benschoter, C.A. 1987: Effects of modified atmospheres and refrigeration temperatures on survival of eggs and larvae of the caribbean fruit fly (Diptera: Tephritidae) in laboratory diet. *J. Econ. Entomol. 80*: 1223-1225.

Ben-Yehoshua, S. 1985: Individual seal-packaging of fruit and vegetables in plastic film – A new postharvest technique. *HortScience 20*: 32-37.

Burditt, A.K.; Balock, J.W. 1985. Refrigeration as a quarantine treatment for fruits and vegetables infested with eggs and larvae of *Dacus dorsalis* and *Dacus cucurbitae* (Diptera: Tephritidae). *J. Econ. Entomol. 78*: 885-887.

Chalutz, E.; Waks, J.; Schiffmann-Nadel, M. 1985: Reducing susceptibility of grapefruit to chilling injury during cold treatment. *HortScience 20*: 226-228.

Chan, H.T. 1988. Alleviation of chilling injury in papayas. *HortScience 23*: 868-870.

Crisosto, C.H.; Smilanick, J.L. 2000: Table grapes: postharvest quality maintenance guidelines. www.uckac.edu/postharv/PDF files/tablegrapes.pdf (27/12/01).

Czajka, M.; Lee. R.E.J. 1990: A rapid cold-hardening response protecting against cold shock injury in *Drosophila melanogaster*. *J. Experimental Biology 148*: 245-254.

Gould, W.P. 1994: Cold storage. *In:* J.L. Sharp; Hallman, G.J. *ed.* Quarantine treatments for pests of food plants. Westview Press, Boulder, USA. Pp. 119-132.

Gould, W.P.; Hennessey, M.K.. 1997. Mortality of Anastrepha suspensa (Diptera: Tephritidae) in carambolas treated with cold water precooling and cold storage. Florida Entomol. 80: 79-84.

Hatton, T.T.; Cubbenge, R.H. 1982: Conditioning Florida grapefruit to reduce chilling injury during low-temperature storage. *J. American Soc. Hortic. Sci. 107*: 57-60.

Houck, L.G.; Jenner J.F.; Mackey, B.E. 1990: Seasonal variability of the response of desert lemons to rind injury and decay caused by quarantine cold treatments. *J. Hort. Sci. 65*: 611-617.

Ismail, M.A.; Grierson, W. 1977: Seasonal susceptibility of grapefruit to chilling injury as modified by certain growth regulators. *HortScience 12*: 118-120.

Johnson, J.A.; Valero, K.A.; Hannel, M.M. 1996: Effect of low temperature storage on survival and reproduction of indianmeal moth (Lepidoptera: Pyralidae). www.nal.usda.gov/ttic/tektran/data/000007/62/0000076245.html (27/12/01).

McDonald, R.E.; Greany, P.D.; Shaw, P.E.; Schroeder, W.J.; Hatton, T.T.; Wilson, C.W. 1988: Use of gibberellic acid for caribbean fruit fly (*Anastrepha suspensa*) control in grapefruit. *In* R. Goren; Mendel, K. *ed*. Proceedings 6th International Citrus Congress, Tel Aviv, Israel. Pp 37-43.

McDonald, R.E.; Miller, W.R.; McCollum, T.G. 1991: Thiabendazole and imazalil applied at 53ºC reduce chilling injury and decay of grapefruit. *HortScience 26*: 397-399.

McGuire, R. 1998a: Response of longan fruit to cold and gamma irradiation treatments for quarantine eradication of exotic pests. www.nal.usda.gov/ttic/tektran/data/000008/57/0000085701.html (27/12/01).

McGuire, R. 1998b: Response of lychee fruit to cold and gamma irradiation treatments for quarantine eradication of exotic pests. www.nal.usda.gov/ttic/tektran/data/000007/90/0000079069.html (27/12/01).

McGuire, R.G. 1999: Appearance of curry leaves exposed to quarantine treatments of cold, gamma irradiation, and methyl bromide fumigation. www.nal.usda.gov/ttic/tektran/data/000010/27/0000102757.html (27/12/01).

Meats, A. 1976: Thresholds for cold-torpor and cold-survival in the Queensland fruit fly, and predictability of rates of change in survival threshold. *Insect Physiology 22*: 1505-1509.

Miller, W.R.; Chun, D.; Risse, L.A.; Hatton, T.T.; Hinsch, R.T. 1990: Conditioning of Florida grapefruit to reduce peel stress during low-temperature storage. *HortScience 25*: 209-211.

Miller, W.R.; McDonald, R.E.; Trunk, M. 1998: Ethylene treatment of carambolas prior to quarantine cold treatment. www.nal.usda.gov/ttic/tektran/data/000007/60/0000076074.html (27/12/01).

Moffit, H.R.; Albano, D.J. 1972: Effects of commercial fruit storage on stages of the codling moth. *J. Econ. Entomol. 65*: 770-773.

Richardson, H.H. 1958. Treatments of various fruits and vegetables to permit their movement under fruit fly quarantines. *Proceedings X International Congress of Entomology* (1956) 3: 17-23.

Schiffmann-Nadel, M.; Chalutz, E.; Lattar, F.S. 1972: Reduction of pitting of grapefruit by thiabendazole during long term cold storage. *HortScience 7*: 394-395.

Scott, N.; De Barro, P. 2000: Report on Pierce's disease and the glassy winged sharpshooter. www.gwss.ucanr.org/csrio.pdf (27/12/01).

Wardowski, W.F.; Albrigo, L.G.; Grierson, W.; Barmore, C.R.; Wheaton, T.A. 1975. Chilling injury and decay of grapefruit as affected by thiabendazole, benomyl, and carbon dioxide. *HortScience 10*: 381-383.

Wild, B.L.; Hood, C.W. 1989: Hot dip treatments reduce chilling injury in long-term storage of "Valencia" oranges. *HortScience* 24: 109-110.

Yokohama, V.Y.; Miller, G.T.; Crisosto, C.H. 1999a: Low temperature storage combined with sulphur dioxide release pads for quarantine control of omnivorous leafroller *Platynota stultana* (Lepidoptera: Tortricidae). J. Econ. Entomol. 92: 235-238.

Yokohama, V.Y.; Miller, G.T.; Hartsell Hartsell, L.; Eli, T. 1999b. On-site confirmatory test, film wrapped bales, ans shipping conditions of a multiple quarantine treatment to control hessian fly (Diptera: Cecidomyiidae) in compressed hay. www.nal.usda.gov/ttic/tektran/data/000009/87/0000098772.html (27/12/01).

TABLE 1: Pests and food commodities for which cold quarantine treatments are feasible.

Target pest	**Commodity**	**Country of origin**	**Observations**	**References**
Mediterranean fruit fly, *Ceratitis capitata* (Dip.: Tephritidae). Fruit flies in general.	Apple, apricot, cherry, etrog, grape, grapefruit, kiwi, loquat, lychee, nectarine, orange, passion fruit, peach, pear, persimmon, plum, pomegranate, quince, tangerine	Many (>68)		Several: Annon. 1992; Clayton 1993
Caribbean fruit fly, *Anastrepha suspensa* (Dip: Tephritidae)	Lychee Carambolas Citrus	Florida, USA Florida, USA USA	 +cold water treatment + harvesting practices	McGuire 1998b Gould & Hennessey 1997; Gould & Sharp 1991; Miller et al 1998 Benschoter, 1987
Omnivorous leafroller, *Platynota stultana* (Lep: Tortricidae); Black widow, *Lactrodectus mactans* (Araneae: Theridiidae)	Table grapes	California, USA	+SO_2	Yokohama et al. 1999a
Glassy winged sharpshooter, *Homalodisca coagulata* (Hom: Cicadellidae)	Table grape	California, USA		Scott & De Barro 2000
Hessian fly, *Mayetiola*	Hay	USA	+ harvesting,	Yokohama et al. 1999b

Target pest	Commodity	Country of origin	Observations	References
destructor (Dip: Cecidomyiidae)			handling and shipping practices	
Asian citrus psyllid, *Diaphorina citri* (Hom: Psyllidae)	Curry leaves	Florida, USA		McGuire 1999
Apple maggot, *Rhagoletis pomonella* (Dip: Tephritidae)	Apples	Canada	+ controlled atmosphere	Annon. 1994
Plum curculio, *Conotrachelus nenuphar* (Col: Curculionidae);blueberry maggot, *Rhagoletis mendax*; apple maggot, *R. pomonella*;	Apple, apricot, blueberry, cherry, hawthorne, huckleberry, nectarine, peach, pear, plum, prune, quince	USA		Stout and Roth 1983 in Gould 1994
Indianmeal moth, *Plodia interpunctella* (Lep: Pyralidae)	Dried fruits an nuts	USA		Johnson et al 1996
Codling moth, *Cydia pomonella* (Lep: Tortricidae)	Pome fruits, stone fruits and walnuts	USA	+ controlled atmosphere	Annon. 2001

ALTERNATIVES TO METHYL BROMIDE FOR USE AS QUARANTINE AND PRE-SHIPMENT TREATMENTS IN DEVELOPING COUNTRIES

R.T. DEANG
Member, Methyl Bromide Technical Options Committee, Philippines
rtd@compass.com.ph

ABSTRACT

While the use of methyl bromide (MB), an ozone depleting substance, is being phased out, its use for Quarantine and Pre-Shipment (QPS) treatments are exempted from the freeze, reductions and phase out schedules. About 21% of the estimated global consumption for QPS are consumed in developing countries. Alternatives to MB currently used as well as those under development include phosphine, sulphuryl fluoride for timber, carbon dioxide for stored grain, heat treatment, hermetically sealed storage, controlled atmospheres, irradiation and combined treatments such as protein coating with steam for spice and vacuum steam flow processes for leaf tobacco. Contractual obligations should be reviewed in the light of the development alternatives to promote non-MB uses in developing countries as soon as they become available.

Keywords: methyl bromide alternatives, quarantine and pre-shipment treatments, developing countries.

INTRODUCTION

Methyl bromide (M)B was listed as an ozone depleting substance in 1992 and a phase out schedule was agreed in succeeding meetings of the Parties to the Montreal Protocol. In the same year, developing countries (see the list of more than 120 developing countries on UNEP website on www.unep.org) accounted for about 20% of global consumption. In 1996 MB consumption increased to 25% and gross consumption in each region was: Latin America and the Caribbean 6,616 tonnes (38%), North and South Africa 4,269 tonnes (25%), Asia and the Pacific 4,177 tonnes (24%), Middle East 2,120 tonnes (12%) and CEIT[1] developing countries 141 tonnes (1%). MBTOC is currently undertaking a review of consumption in developing countries and will report the results in the MBTOC 2002 report to be released at the end of the 2002.

MB is used under diverse geographical conditions found in developing countries; for soil treatments (70%), for fumigation of durable and perishable commodities (27%), and structures (3%).

Quarantine and Pre-shipment[2] (QPS) treatments, accounting for 23 –26% of global consumption, are exempted from the freeze, reductions and phase out schedules. Of the estimated 15,350 to 17,500 tonnes recorded from various sources in 1996, 21% are estimate use in QPS in developing countries. There may be inconsistencies on reported QPS data as some countries combined quarantine data with pre-shipment data while others reported them separately (MBTOC 1998).

MBTOC (1998) noted that MB was used mostly on cash crop exports such as tobacco, cut-flower, strawberry, banana and vegetable crops. MB was also used for QPS as a condition of entry by importing country, usually at the request of developed countries.

METHYL BROMIDE FUMIGATION OF DURABLE COMMODITIES AND STRUCTURES

MB is frequently used in the treatment of commodities such as grains, beans, dried spices, wood, timber and wood products, bamboo crafts and tapioca, prior to import and export because of QPS requirements. Specifically, in some parts of Southern and Eastern Africa, the commodities treated were reported as dried spices, timber and wood products, coffee and grain and in some Latin America

---

[1] Countries with Economies in Transition

*[2] See definitions of QPS in paper by Batchelor, page ** of these Proceedings. MBTOC has also provided a logic diagram to assist in determining whether a MB treatment should be categorised as quarantine or pre-shipment (MBTOC 1998 Assessment, Annex 8.1, p. 303).*

countries the list included coffee, rice, cotton maize, wheat, beans peanuts, soybean, sorghum and timber. On an annual basis, the total quantity of MB used in developing countries for durable commodities is about 20%.

MBTOC noted that purchasers frequently required in the contract the use of MB at very high rates to insure pest free quality that exporting countries have to follow. To a lesser extent purchase contracts require the use of phosphine for pre-shipment fumigation. When the fumigant was not specified in the contract, often MB was selected in preference because of the short time for the treatment. Some countries, however, also specified that MB was not to be used.

Small quantities of MB (less than 3% of developing country consumption) were used for the treatment of empty structures, including warehouses, flour mills, ships, aircraft and other transport vehicles.

ALTERNATIVE FOR MB ON DURABLES AND STRUCTURES

There are many alternatives to MB (Table 1) and phosphine is one of the more effective alternative fumigants for durables and structures that has been proven commercially. It can directly substitute for MB in treatments of many durable commodities when properly used and applied. It is used in the protection of stored products in developing countries. Good management strategies and practices are observed in using phosphine to prevent further pest species becoming resistant to phosphine and thereby prolong its usefulness as a fumigant.

Rice stocks were reported to be routinely fumigated with carbon dioxide on a large scale for many years in Indonesia where there are stocks to be carried over from one season to the next.

Other alternative technologies used for treatment of durable commodities include sulphuryl fluoride (timber in China), carbon dioxide (stored grains in bag stacks in Zimbabwe, Indonesia, Philippines and Brazil and vertical silos in Kenya), heat treatments, hermetically sealed storage, controlled atmospheres, irradiation and combined treatments such as protein coating with steam for spice and vacuum steam flow processes for leaf tobacco.

Table 1: Use of Alternatives for durable commodities in developing countries

Commodity	Alternative	Countries	Comments
Black pepper	Phosphine	Malaysia	Registered for use; widely used-storage
Coconut products	Phosphine	Philippines	Registered for use; mostly for export
Coffee	Phosphine	Vietnam	Registered for use; widely for export
Grain (rice)	Ca rbon dioxide	Indonesia	Long term storage for carryover stocks
Grain (rice)	CO_2 + Phosphine	Philippines	Long term storage for security reserves
Grain (rice)	Carbon dioxide	Vietnam	Use increasing
Grain (barley)	Pre-mixed CO_2 & Phosphine	Cyprus	Currently in use
Grain	Controlled atmosph.	China	Adopted and use expected to increase
Grain	Diatomaceous earth	China	Experimental – used to avoid fumigation
Grain	Phosphine	Dev Country	Use continues to increase
Grain (rice and barley)	Hermetic sealing/ Storage	Philippines & Cyprus	Technology available for adoption
Peanuts	Nitrogen	India	Commercial –retail packages
Rice	Irradiation	Indonesia Thailand	Indonesia –limited commercial use Thailand – experimental use
Rice	Carbon dioxide	Thailand	Commercial – retail package
Timber	Heat	China	Limited use
Timber	Sulfuryl fluoride	China	Use increasing, but trials needed
Tobacco	Phosphine	Many dev. countries	Widely used
Wheat	Carbon dioxide	Kenya	Experimental in silos

Source: MBTOC 1998 Assessment

Potential chemical alternatives for pest control in structures include fumigants such as sulphuryl fluoride (not registered for structures containing foodstuffs), surface spray pesticide such as chlorpyrifos-methyl, pirimiphos-methyl, fenitrothion, malathion and other contact insecticides (Table 2).

Table 2. Use of alternatives for structural pests in developing countries

Commodity	Alternative	Countries	Comments
Grain mills	Cold CO_2+phosphine	Argentina	Experimental
Grain mills	Hot CO_2+phosphine	Chile	Commercially used
Empty containers & buildings	Sulphuryl fluoride	China	Widely used

Source: MBTOC 1998 Assessment

Alternatives that are in use in many developing countries vary according to pesticide registration requirements, commodity, capital investment and the need for additional research.

MB FUMIGATION OF PERISHABLE COMMODITIES

The majority of MB usage in perishable commodities is dictated by the quarantine and other phytosanitary requirements of importing countries. Perishable commodities include cut flowers, stem cuttings, bud-wood, rooted plants, bulbs, corms, rhizomes, fresh fruits, including grapes bananas and vegetables. About 8% of MB in developing countries is used in traded perishable commodities.

ALTERNATIVES FOR MB TREATMENT ON PERISHABLE COMMODITIES

Alternative quarantine treatments, such as a cold treatment, are already used for apples exported from Chile, Jordan, Mexico and Uruguay to the USA; for plums and apricots from Morocco to the USA; and for kiwifruit from Chile to Japan. Heat treatments are also used to disinfest papaya, mango, citrus, eggplant, zucchini, squash, and bell pepper and could be developed for other perishables. Combination treatments, such as soapy water with wax, are used for cherimoya exported from Chile and vapor heat with cold treatment for lychee exported from Taiwan (Table 3).

Table 3: Use of alternatives for perishable commodities in developing countries

COMMODITY	ALTERNATIVE	COUNTRY	COMMENTS
Apples	Wax coating	Chile	Widely used
Apples	Pre-shipment inspection & Certification	Chile	Approved for exports to USA
Apples	Cold treatment	Mexico, Chile, South Africa	Approved for exports to USA
Cherries	Cold treatment	Chile	Approved for exports to USA
Cherimoya	Soapy water + Wax coating	Chile	Approved for exports to USA
Citrus	Wax coating	Chile	Widely used
Citrus	Cold treatment	South Africa	Approved for exports to Japan
Citrus	Cold treatment	Many countries	Approved for exports to USA
Cut flowers (orchids)	Chemical dips	Thailand	Experimental
Cut flowers	Pressure water spray + insecticide	Several countries	Approved for exports to USA
Garlic	Phosphine	China	Widely used
Guava	Hot water dipping	Vietnam	Experimental
Lychees	Vapor heat + cold	Taiwan	Approved for exports to Japan
Mangoes	Heat treatment	Taiwan	Approved for exports to Japan
Melons	Certified pest-free zones	China(one region)	Approved for exports to Japan
Orange	Irradiation	China	Experimental – for imported fruit
Stone fruit – peaches plums apricots	Cold treatments	Morocco	Approved for exports to USA
Stone fruit	Double inspection	Chille	Widely used

Source: MBTOC 1998 Assessment

Other quarantine treatment/procedures approved by certain countries include pre-shipment inspection, pest-free zones or periods, the system approach, controlled atmospheres and physical removal of pests or soil. Each treatment is dependent upon the commodity, the target pest and the geographical area of origin and the requirements of importing countries.

PROBLEMS ENCOUNTERED IN ADOPTING ALTERNATIVES

Phosphine has been used as one of the main alternatives to MB for QPS uses in developing countries. MBTOC identified constraints in the use of phosphine for structural fumigation including:

Longer fumigation period than MB in achieving full effectiveness which may delay importation/exportation period. The use of phosphine with carbon dioxide and heat can reduce the period for fumigating structures.

Potential for fire during application if solid phosphide formulations get wet or are handled carelessly.

Currently available solid formulations generating phosphine gas are not suitable for very dry conditions because of longer time release of gas.

Reacts with and corrodes copper containing materials and chemically similar metals in machinery and ancillary electrical equipment in structures to be fumigated.

Some of these characteristics can be overcome using new phosphine formulations and application practices (see Mueller 2002; Page 74 of these Proceedings).

Other alternatives have limitations such as registration of chemical alternatives, high capital investment for infrastructure and operational costs, lack of country-specific research, lack of technical know-how, technology transfer, activities to sustain adoption, few regulatory and advisory staff and the need for quarantine acceptance of alternatives by the importing countries (TEAP 2001).

MBTOC noted that fumigation with MB could become more frequent in developing countries as a result of developed country phase out and requirements to fumigate before export.

REFERENCES

Batchelor, T.A. 2002. International and European Community controls on MB and the status of MB use and alternatives in the EC. Proc. Int. Conf. On Alternatives to Methyl Bromide, Sevilla, 5-8 March 2002: Page 28.

Mueller, D. 2002. Alternatives to MB for disinfestation of structures and food facilities. Proc. Int. Conf. On Alternatives to Methyl Bromide, Sevilla, 5-8 March 2002: Page 74.

MBTOC. 1998. Assessment of alternatives to methyl bromide. UNEP Ozone Secretariat Publication 354 pp.

TEAP. 2001. Report of the Technology and Economic Assessment Panel. UNEP Ozone Secretariat Publication: 65-81.

NON-METHYL BROMIDE QUARANTINE AND PRE-SHIPMENT TREATMENTS IN SPAIN

E. SANTABALLA
Sanidad Vegetal. Ministerio de Agricultura Pesca y Alimentación, Valencia, Spain
esantaba@teleline.es

ABSTRACT

The use of fumigants, especially methyl bromide (MB), is practical and economical method to eradicate pests from horticultural commodities in quarantine treatments. Only a minor number of imports e.g. treatments of oak log or wood packages from conifers that have not been treated at origin, and a minor number of our exports e.g. garlic destined to Brazil and chestnut to Mexico, receive quarantine treatments with MB in Spain. Quarantine treatments in Spain consumed in recent years 5-6 tonnes per year for these purposes. Banning MB has encouraged the search for alternative procedures. In wood imports, fumigation with MB has been substituted by mechanical methods such as debarking or by physical methods such as heat treatments. Phosphine and fog systems of aqueous solutions of phosphorate products have substituted for MB in pre-shipment treatments for export grain (cereals and leguminous) and the equipment that carry these exports. Cold treatments have been used in fruit exports to countries that require a quarantine treatment for fruit fly *Ceratitis capitata* (Wiedeman).

Keywords: Spain, quarantine treatments, import, exports, pre-shipment, methyl bromide

INTRODUCTION

Submitting horticultural commodities to quarantine treatments is surrounded by an number of serious concerns such as the treatments may not as efficacious and as convenient as methyl bromide (MB) and because the cost of application is borne by the country of export.

Chemical treatments with fumigants are a practical and convenient way to eradicate pests in crops and vegetable products. Several aspects favour their use. Fumigants kill a broad range of pests, they are economic and easy to apply in different types of facilities, lorries, railcars or ship holds, or fumigation facilities can be inexpensively built. In addition, treatments can be applied in a short time, usually in a few hours.

However, fumigants are not free from inconvenience. Their extreme toxicity to humans for some fumigants requires some security measures to be taken to protect fumigant applicators and handlers from the treated commodities. Consumers perceive that residues of fumigants on fresh products constitute a high health risk. This perception has been recognised in the regulations of different countries that establishes low Acceptance Residue Levels (ARL) or has banned the use of some fumigants. This limits or restricts the use of specific fumigants on vegetable products destined for certain markets.

Only a minor number of imports e.g. treatments of oak log or wood packages from conifers that have not been treated at origin, and a minor number of our exports e.g. garlic destined to Brazil and chestnut to Mexico, receive quarantine treatments with MB. Quarantine treatments in Spain consumed in recent years 5-6 tonnes per year for these purposes.

The banning of use of ethylene dibromide due to its carcinogenic effects, and the limitation of use of MB due to its negative environmental effects, requires the search for alternative treatments to MB.

QUARANTINE TREATMENTS IN SPAIN

Quarantine treatments used in Spain are divided into those required for import and those required for export that are required by the importing country.

Imports

The required treatments are listed in Directive 2000/29/CEE and in the Spanish legislation RD 2071/1973 and its later modifications. The liberal policy of EU has reduced these treatments very much and limited them to the treatment of wood and citrus from certain countries and when certain conditions are given.

In wood, required treatments are mechanical methods such as debarking and/or physical methods such as heat treatments. Wood of conifers (Coniferales) except of *Thuja* originating in Canada, China, Japan, Korea, Taiwan and the USA must be treated by an appropriate heat treatment (HT) to achieve a minimum wood core temperature of 56ºC for 30 minutes. Wood conifers originating in non-European countries other than Canada, China, Japan, Korea, Taiwan and USA; wood of *Accer saccharum* Marsh, *Castanea* Mill, and *Quercus* L., originating in North America countries; must be treated by kiln-drying (KD) to below 20% moisture content, expressed as a percentage of dry matter at the time of manufacture, achieved through an appropriate time-temperature schedule.

In the case of citrus originating from areas where is known the presence of Kanker citrus *Xanthomonas campestris* pv *citri* (Hasse), the fruit must be treated with sodium orthophenilphenate.

Exports

Exports are subject to the disinfestation requirements of the importing country. Exports of significant volume for treatment are grains (cereals and leguminous), fruit and vegetables.

In shipment of grain by sea, treatments are applied to the product as well as the ship. As a consequence of the Protocol of Montreal and the Directives of the International Maritime Organisation (IMO), MB has been substituted by generator granules of phosphamine, and disinfestations of ships is being made with contact pesticides in thermal fogging.

Main exports of our fruits and vegetables are forwarded to European countries where no quarantine treatments are required. However, Spanish citrus exports to different non-European countries (USA, Japan, Australia, New Zealand) are severely restricted unless certified free of fruit fly *Ceratitis capitata* (Wiedemann). Quarantine treatments must be carried out in order to certify the exports as free of fruit fly. Treatments applied are based on the application of cold treatment, which in our case the most used is the 16-day cold treatment with temperatures that that never exceed 2.2ºC. The treatment is made in-transit on ships or previously approved containers. The treatment is started on departure and the records are checked on arrival to ensure that the approved disinfestation temperature has not been exceeded.

CONCLUSIONS

Quarantine treatments using fumigation of MB have been substituted by other mechanical and physical methods for both imports and exports. In wood imports, fumigation with MB has been substituted by mechanical methods such as debarking or by physical methods such as heat treatments. Phosphine and fog systems of aqueous solutions of phosphorate products have substituted for MB in pre-shipment treatments for export grain (cereals and leguminous) and the equipment that carry these exports.

APPLICATION OF VACUUM TO SEALED FLEXIBLE CONTAINERS: A VIABLE ALTERNATIVE TO DISINFESTATION OF DURABLE COMMODITIES WITH METHYL BROMIDE

S. FINKELMAN[1], S. NAVARRO[1], A. ISIKBER[3], R. DIAS[1], A. AZRIELI[1], M. RINDNER[1], Y. LOTAN[2] & T. DEBRUIN[2]

[1]Department of Stored Products, Agricultural Research Organization, The Volcani Center, Israel
[2]Haogenplast Projects Ltd., Israel; [3]Department of Plant Protection, Faculty of Agriculture, University of Kahramanmaras Sutcu Imam, Kahramanmaras 46060, Turkey
Corresponding author: simchaf@volcani.agri.gov.il

ABSTRACT

This study forms part of a project aimed at eliminating the need for fumigation with methyl bromide (MB) to control stored product insects through the development of novel, vacuum-hermetic technology. First objective was to study the effects of low air pressures, temperature and exposure time on insect mortality in stored cocoa beans. A second was to study the potential of an innovative, transportable, sealed storage system as a practical tool for controlling insect pests at low air pressures. Two insects, both major pests of cacao beans in producer countries were used: *Ephestia cautella*, and *Tribolium castaneum*. The experiments conducted in the laboratory showed that the eggs were the most resistant stage to storage under a low air pressure of 55 ± 10 mm Hg at the two studied temperatures of 18°C and 30°C. Times needed to obtain 99% mortality of *T. castaneum* eggs at 18°C and 30°C were 96 and 53 hours respectively. For *E. cautella* eggs 99% mortality at 18°C and 30°C was obtained after 149 and 41 hours respectively. Two experiments were carried out in the field trial, each using 15 m^3 capacity plastic containers termed the "GrainPro Cocoon™" or "Volcani Cubes™", specially adapted to facilitate low pressure ("vacuum cube"). The pressure in the vacuum cube was established within the range of 23 to 75 mm Hg. In one cube, the low pressure was held for 3 days and in the second, for 7 days. In both cubes 100% mortality of all test insects was obtained.

Keywords: vacuum-hermetic technology, cacao, low pressure, *Ephestia cautella, Tribolium castaneum,* storage.

INTRODUCTION

Back and Cotton (1925) were the first to explore the possibility of using low pressures in post-harvest storage, followed by Bare (1948), and later by Calderon *et al.* (1966). However, to achieve the extremely low pressures necessary to obtain insect mortality, a prohibitively expensive investment in massively constructed vacuum chambers was required. The new terms of the Montreal Protocol, ending the use and production of methyl bromide (MB) in developed countries by the year 2005 and worldwide by 2015 (UNEP 1998), prompted us to re-examine the possibilities of using low pressures as a fumigation replacement to control stored-product insect infestations.

In a recent study by Navarro *et al.* (2001), a PVC-based, sealed, flexible storage system was developed to maintain low pressures. In this storage structure, low pressures of 25-30 mm Hg were achieved and maintained continuously for more than two months. These gas-tight, flexible structures were originally developed for long-term hermetic storage of grain, particularly for storage in developing countries, but they were also shown to be suitable for quarantine treatments using either modified atmospheres or the hermetic storage method. They are now in use on a commercial scale in several countries (Navarro *et al.* 1988, 1994; Navarro *et al.* 1990). The structures are made from plastic liners manufactured to specifications that provide a level of gas tightness that precludes significant loss of modified atmosphere or fumigant (Navarro *et al.* 1995). They are termed "Volcani Cubes™" or "GrainPro Cocoons™" (Navarro *et al.* 1999) and have potential for use in small-scale applications, particularly for high-value crops such as cocoa, coffee, and spices. In our field trial we used two of these structures, each of 15 m^3 capacity.

For our study, cacao beans were the chosen commodity and two insect species that are among the major pests of cacao beans: the tropical warehouse moth, *Ephestia cautella* (Walk.), and the red flour beetle, *Tribolium castaneum* (Herbst) were used for bioassay.

MATERIALS AND METHODS

Laboratory trials

Exposure of insects to low air pressure and temperature combinations: The sensitivities of the test insects were tested in chambers consisting of 3-liter desiccators filled with 1 kg cacao beans, and connected to a vacuum pump. The test chambers were held in an incubator kept either at 18°C or 30°C. Air pressures ranged between 45 mm Hg and 65 mm Hg (55 ± 10 mmHg) at a constant relative humidity of 55 ± 3%.

Test insects: Laboratory colonies of the moth *E. cautella* and the beetles *T. castaneum* were maintained in a rearing room at 28 ± 2°C and 70 ± 5% relative humidity.

Bioassay: Insects for the bioassay were chosen as follow: Eggs from each species were used within 0-2 days of oviposition. Larvae of *E. cautella* were 14-15 days old and *T. castaneum* larvae were 18-19 days old. Pupae of *E. cautella* were 1-2 days old and pupae of *T. castaneum* were 0-1 days old. *T. castaneum* adults were 30-31 days old and *E. cautella* adults were 1-2 days old. Each Bioassay contained two Perspex slides each holding 50-drilled "wells" that were used to place 100 eggs individually from each of the studied species, and were then covered with a cover glass to retain the eggs (Navarro and Gonen, 1970). In addition, 50 individuals (larvae, pupae or adults) from each of the studied species were placed in a small glass vial (4 ml), covered with paper or metal mesh and placed in each of the test chambers with the cacao beans.

Post fumigation procedures: Mortality of the test insects was determined as failure to reach the next developmental stage. Eggs of the two species were held in the rearing room for 10 days, after which the hatched larvae and un-hatched eggs were counted. Larvae and pupae were held for 2-3 weeks and observed three times each week. Survival of adult beetles was determined after 15 days, and of *E. cautella* 4 days after exposure, since their life expectancy is only about 4-6 days at 28ºC.

Statistical analysis: Probit analysis of log concentration against mortality of the treatments was carried out (Daum 1979). Where a significant probit line was not obtained, the shortest exposed time needed to achieve 100% was used.

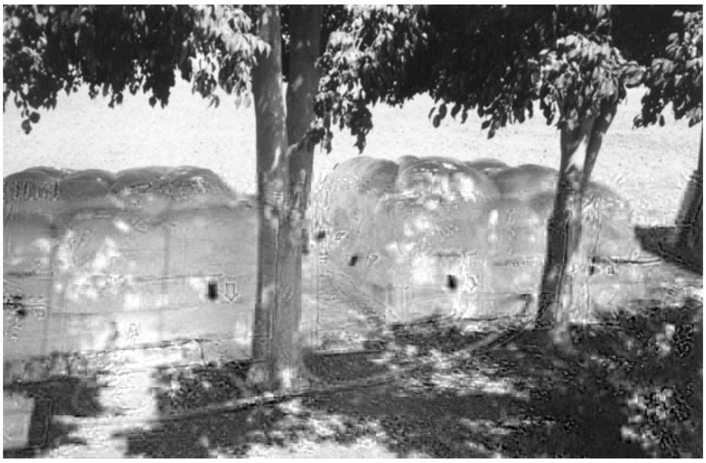
Field trial

Background: The field trial was conducted on March 2001 in Israel, at the Agricultural Research Organization (ARO) campus. Two vacuum cubes of 15 m^3 capacity, adapted to facilitate low pressure, were used. The pressure in the cubes was established using a rotary-vane, oil-lubricated vacuum pump (3 hp Becker model U 4.70, Germany) to within the range of 23 and 75 mm Hg for duration of 3 days in one cube and 7 days in the other. The commodity was cacao beans originating from the Ivory Coast (previously fumigated with methyl bromide). Each cube contained 100 jute bags each weighing 65-kg (total 13,000 kg per cube). Each cube was loaded manually and stacked with six layers of bags (Figure 1).

The vacuum cube system: In order to adapt the standard cubes to low pressure use, a quick-release hose and one-directional valve were incorporated. In addition, the system was connected to the pump using flexible 1.5” connecting tubes. The system was designed to be modular enabling the user to connect several cubes to the same vacuum pump, or to disconnect one of the cubes without changing the pressure in the other connected cubes.

Bioassay: Five sets of bioassay replicates were placed in each of the cubes, each set containing all life stages of *E. cautella* and *T. castaneum*. Four of the bioassay sets were located, one on each side of the four cube walls at mid-center height, and one at the top-center. The control bioassay was placed on the top, above the liner of the 7-day cube in an open plastic container filled with cacao beans. Temperatures at the top and at the four side faces of the cubes were recorded during the trials using data-loggers (HOBO Pro Series).

FIGURE 1: the two cubes (3 days exposures on the right and 7 day exposures on the left) connected together to the pump at the trial site under a pressure of 50 mm Hg.



RESULTS AND DISCUSSION

Laboratory trials

Cacao-beans are stored in burlap backs in the production countries of the tropics, and are subsequently shipped from the tropics to various ports in the Northern Temperate Zone from were they are transported to the processing plants. During the interim, the cacao beans are treated against insect infestation in both climatic zones and are exposed to different ambient conditions. In the tropics the commodity temperature fluctuates at around 30°C, while in the Northern Temperate Zone the commodity temperature can drop to below 20°C. It was therefore deemed necessary to study the influence of low pressures on insect mortality at both these temperature ranges. The exposure periods of low pressure required to control the life stages of *E. cautella,* as expressed in LT_{99} mortality values at 18°C and 30°C are presented in Table 1 and for *T. castaneum* in Table 2.

Table 1: The effect of low pressure (55 ± 10 mm Hg) on mortality as expressed in LT99 (hours to obtain 99% mortality) values for the developmental stages of *Ephestia cautella* at 18°C and 30°C

Developmental Stage	LT_{99}[1] at 30°C (range)	LT_{99}[1] at 18°C (range)
Egg	40.7 (36.16 - 50.34)	148.8 (172.22 - 133.23)
Larva	< 28	43.6 (76.63 - 32.33)
Pupa	< 8	26.2 (139.87 - 17.48)
Adult	< 10	76.7 (180.35 - 54.88)

[1] Numbers in brackets are the 95% confidence limits.

TABLE 2: The effect of low pressure (55 ± 10 mmHg) on mortality as expressed in LT99 (hours to obtain 99% mortality) values for the developmental stages of *Tribolium castaneum* at 18°C and 30°C

Developmental Stage	LT_{99}[1] at 30°C (range)	LT_{99}[1] at 18°C (range)
Egg	53.0 (46.51 - 63.98)	96.3 (139.8 - 73.29)
Larva	< 28	36.8 (58.08 - 28.69)
Pupa	< 38	71.8 (102.70 - 58.53)
Adult	< 28	29.9 (151.67 - 26.62)

[1] Numbers in brackets are the 95% confidence limits.

The results show that for both species, the egg was the most resistant stage at both 18°C and 30°C. For *E. cautella* the time needed to obtain 99% egg mortality at 18°C was 149 hours and at 30°C it was 41 hours. The times needed to obtain 99% mortality of *T. castaneum* eggs were 96 hours and 53 hours at 18°C and 30°C, respectively. The influence of temperature on mortality was more dramatic for *E. cautella,* with a one third reduction in the time needed for control of all life stages at 30ºC. At 18°C, *E. cautella* showed a higher resistance to low pressure then *T. castaneum* while at 30°C this tendency was reversed and *T. castaneum* was more resistant to the treatment at all life stages.

Field trial

Pressure within the two test cubes was regulated at of 23-75 mm Hg for the two time durations. Subsequent bioassays revealed complete mortality within three days of exposure for all life stages of the two insect pest species, *E. cautella* and *T. castaneum.*

The pump required 55 minutes to reduce the pressure in the two cubes to 23mm Hg. The suspension time between pumping was 10 min at the first day of the trial. For the three-day exposure cube, temperature at the top of the cube was 28.0 ± 0.5^{0}C and the relative humidity stabilized at 65%. At the northern cube-wall face the temperature was 27.9 ± 1^{0}C and the relative humidity stabilized at 69.5%. For the seven-day exposure cube, the temperature at the top was 27.9 ± 0.5^{0}C and the relative humidity stabilized at 69.9 ± 0.5% at the top and the northern cube-wall face of the cube.

In conclusion, the low-pressure/vacuum treatment was successful in providing total mortality of the insects pests and in protecting the commodity from re-infestation. Furthermore the cube provided protection for the cocoa beans from loss or increase in moisture during storage. These results indicate that effective control can be obtained in less than three days.

ACKNOWLEDGMENTS

We thank Dr. S. Angel, BioPack, and Dr. P. Villers, president of GrainPro Inc. for making useful suggestions. This work was funded in part by a grant from the United States-Israel Science and Technology Foundation, Israel Agricultural Research Organization Project No. 5288.

REFERENCES

Bare, C. O. (1948). The effect of prolonged exposure to high vacuum on stored tobacco insects. *Journal of Economic Entomology.* 41, 109-110.

Back, E. A. and Cotton, R. T. (1925). The use of vacuum for insect control. *Journal of Agricultural Research* 31, 1035-1041.

Calderon, M., Navarro, S., and Donahaye, E. (1966). The effect of low pressures on the mortality of six stored product insect species. *Journal of Stored Products Research* 2, 135-140

Daum, R. J. (1979). A revision of two computer programs for probit analysis. *Bulletin of the Entomology Society of America* 16, 10-15.

Navarro, S., Donahaye, E., R., D., Azrieli, A., Rindner, M., Phillips, T., Noyes, R., Villers, P., DeBruin, T., Truby, R., and Rodriguez, R. (2001). Application of vacuum in transportable system for insect control. *International Conference on Controlled Atmospheres and Fumigation in Stored Products*

Navarro, S., Donahaye, J.E., Rindner, M., Azrieli, A. and Dias, R. (1999) Protecting grain without pesticides at farm level in the tropics. In: *Quality assurance in agricultural produce. Proc. 19th Asean/1st APEC Seminar on Postharvest Technology,* (Edited by Johnson, G.I., Le Van To, Nguyen Duy Duc and Webb, M.C.), Ho Chi Minh City, Vietnam 9-12 Nov. 1999. ACIAR Proceedings No. 100. 353-363.

Navarro, S., Donahaye, E. and Fishman Svetlana (1994) The future of hermetic storage of dry grains in tropical and subtropical climates. In: *Proc. 6th Int. Working Conf. on Stored-Product Protection* (Edited by Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R.) Canberra, Australia, 17-23 April 1994, CAB International, Wallingford, Oxon, UK, 130-138.

Navarro, S. and Donahaye, E. (1990) Generation and application of modified atmospheres and fumigants for the control of storage insects. In: *Fumigation and Controlled Atmosphere Storage of Grain: Proc. Int. Conf.* (Edited by Champ, B.R., Highley, E. and Banks, H.J.), Singapore, 14-18 Feb. 1989 ACIAR Proceedings No. 25. 152-165.

Navarro, S., Donahaye, E. and Silberstein, B. (1988) Apparatus and method for storing grain. Israel Patent No. 87301.

Navarro, S., and Gonen, M. (1970). Some techniques for laboratory rearing and experimentation with *Ephestia Cautella* (WLK) (Lepidoptera, Phycitidae). *Journal of Stored Products Research* 6, 187-189.

UNEP (1998). Montreal protocol on substances that deplete the ozone layer, 1998 Assessment of alternatives of methyl bromide. Methyl Bromide Technical Options Committee. *United Nations Environment Programme. Nairobi, Kenya*.

CASE STUDY: SULFURYL FLUORIDE FOR DISINFESTATION OF TIMBER AND STRUCTURES

M.J. DRINKALL[1] and B.M. SCHNEIDER[2]
Dow AgroSciences, [1]Hitchin, UK; [2]Indianapolis, USA
mdrinkall@dow.com

ABSTRACT

The fumigant sulfuryl fluoride, SO_2F_2 (SF), is currently used to control wood-destroying and household insect pests and is recognised as an alternative to methyl bromide (MB) for the control of stored product insects. SF, as the product Vikane[3] Gas Fumigant, is used for the disinfestation of timber and non-food structures and is licensed or registered for use in a number of countries including Germany, Sweden and the USA. SF is effective on all life stages of insect pest and contains no chlorine or bromine and therefore does not contribute to stratospheric ozone depletion. Dow AgroSciences enforces a strict product stewardship policy to augment the training and certification required by government authorities. SF, as the product ProFume[6] Gas Fumigant, is under development as a post-harvest fumigant on food products with registrations expected in the USA in 2002/3 and in Europe in 2003/4.

Keywords: Sulfuryl fluoride, Vikane, ProFume, fumigation, stored products

INTRODUCTION

The fumigant sulfuryl fluoride, SO_2F_2 (SF), is currently used to control wood-destroying and household insect pests. It has been recognised as an alternative to methyl bromide (MB) for the control of stored product insects (Bell, 2000; USDA, 2000). SF, as the product Vikane[*] Gas Fumigant, is used for the disinfestation of timber and non-food structures and is licensed or registered for use in a number of countries including Germany, Sweden and the USA. In the USA it has been used since 1961 primarily for drywood termite control. Over one million buildings have been fumigated including homes and museums. In Europe, the main use is in Germany to eliminate wood destroying beetles e.g. *Anobium punctatum* and *Ptilinus pectinicornis* from structures. In Sweden, SF is used in shipping containers and for the disinfestation of homes and wooden artefacts. SF, as the product ProFume[4] Gas Fumigant, is under development as a post-harvest fumigant on food products with registrations expected in the USA in 2002/3 and in Europe in 2003/4.

FORMULATION AND PROPERTIES

SF is a non-flammable, colourless, and essentially odourless gas. It is an inorganic compound and is essentially non-reactive with structural materials. SF has a low boiling point (-55^oC) and a high vapour pressure (13,442 mm Hg at 25^oC) and readily vaporises under normal fumigation conditions enabling rapid dispersion following introduction. The gas rapidly penetrates porous materials like wood and has low sorption on fumigated materials. SF also rapidly aerates from materials and commodities and does not react with materials to form unpleasant odours. Although of low reactivity as a gas, SF at temperatures exceeding 400^oC will beak down and react with water to form hydrogen fluoride which can etch metals, glass or other polished surfaces. Therefore, prior to fumigation all open flames should be extinguished and glowing heat filaments disconnected.

ENVIRONMENTAL FATE

SF is fully oxidised and does not interact with or contribute to local ozone formation (Bailey 1992; Chambers & Millard 1995). It contains no chlorine or bromine and does not contribute to stratospheric ozone depletion (Thoms & Scheffrahn 1994). The relatively small amounts of SF released are calculated to have virtually no impact on global atmosphere and the environment. SF is broken down mainly through hydrolysis to release fluoride and fluorosulphate ions (Bailey, 1992).

---

[3] Trademark of Dow AgroSciences. ProFume is not currrently available for sale. Registration is pending.

[4] Trademark of Dow AgroSciences. ProFume is not currrently available for sale. Registration is pending.

EFFECTIVENESS

Mode of action

Studies have been completed which indicate that SF has several biochemical effects on target insect pest species. Mortality is achieved by disruption of the glycolysis cycle depriving the insect of metabolic energy (Meikle *et al*. 1963). SF is effective on all life stages of insect pests. Larvae, pupae and adult insects are highly susceptible to SF while eggs and diapausing life stages require higher doses. Research has indicated that the lower activity on eggs is primarily due to reduced penetration through the eggshell. Effective dosages for all insect life stages can be obtained by varying concentration and exposure time.

Studies on stored insect pests in structures

To validate laboratory chamber fumigations with SF on stored product insects (SPI) fifteen trials were completed in empty food milling/processing structures in Germany, Italy, UK and the USA during 1997 – 2001. These studies confirmed excellent efficacy on all life stages of SPIs' including *Tribolium castaneum*, *T. confusum*, *Plodia interpunctella* and *Ephestia kuehniella*.

Studies on timber pests

Thoms and Scheffrahn (1994) explained the technical foundation of SF dosages for insect pests as well as describe the tools and techniques for properly using this fumigant to control structural insect pests. Binker (1993) described a customised Vikane fumigation process, including introduction, exposure, and aeration, that Binker Materialshutz has used for several years to control wood-infesting pests in churches in Germany. Scheffrahn *et al.* (1992) reported on the penetration of SF into wood, which is more rapid than for MB when the wood is not hydrated. Soma *et al.* (2001) demonstrated that SF sorption into wood is substantially less than MB sorption. The use of SF as an alternative to MB for control of structural (non-food) insect pests is summarised in a case study published by the Environmental Protection Agency of the United States (1996). Derrick *et al.* (1990) provide a thorough review of SF use as fumigant to control pests of museums and historical structures and artefacts.

STEWARDSHIP

SF is for use by professional, licensed fumigators. Dow AgroSciences enforces a strict product stewardship policy to augment the training and certification required by government authorities. In common with other fumigants, SF has hazards that require full understanding and correct execution of application and safety measures to ensure effective pest control with minimal risk to fumigators and the public.

REFERENCES

Bailey, R.E. 1992: Sulfuryl fluoride – Fate in the Atmosphere. Dow Chemical Company, DECO-ES Report 2511 Midland Michigan.

Bell, C.H. 2000: Fumigation in the 21st century. Crop Protection, 19: 563-569.

Binker, G. 1993: (Hozshadlingsbekampfung durch Begasung) Fumigation as a means of wood pest control. Conference Proceedings – Restoration Studios of the Bavarian State Conservation Office, Munich, October 22, 1993, Pp: 90-100.

Chambers M.; C. Millard, 1995: Assessing the global use potential of sulfuryl fluoride. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego 1995, Pp: 6-8.

Derrick, M. R.; Burgess H. D.; Baker, M. T.; Binnie N. E. 1990: Sulfuryl fluoride (Vikane): A review of its use as a fumigant. JAIC 29: 77-90.

Environmental Protection Agency – United States of America. 1996: Stratospheric Ozone Protection Case Study – Methyl Bromide Alternative. Structural fumigation using sulfuryl fluoride: DowElanco's Vikane Gas Fumigant. EPA-Office of Air and Radiation (6205-J), 7 pages.

Meikle, R.W.; Stewart, D.; Globus, O. A. 1963: Drywood termite metabolism of Vikane fumigant. J. Agric. Food Chem., 11: 226-230.

Scheffrahn, R. H.; Su, N-Y.; Hsu,R-C. 1992: Diffusion of methyl bromide and sulfuryl fluoride through selected structural wood matrices during fumigation. Material und Organismen 27 Bd. Heft 2, Pp: 147-155.

Soma, Y.; Haito, H.; Misumi, T.; Mizobuchi, M.; Tsuchiya,Y.; Matsuoka, I.; Kawakami, F. 2001: Effects of some fumigants on Pine Wood Nematode, *Bursaphelenchus xylophilus* infecting wooden packages. Res. Bull. Pl. Prot. Japan 37: 19-26.

Thoms, E.M.; Scheffrahn, R.H. 1994: Control of pests by fumigation with sulfuryl fluoride. Down to Earth, 49: 23-30.

United States Department of Agriculture. 2000: Sulfuryl fluoride: The post harvest fumigant of the future? Methyl Bromide Alternatives 6 No.4. Pp: 4-5.

ALTERNATIVES TO METHYL BROMIDE FOR TREATMENT OF GRAIN AND SEEDS

J. RIUDAVETS
Institut de Recerca i Tecnologia Agroalimentàries, Cabrils (Barcelona), Spain.
jordi.riudavets@irta.es

ABSTRACT

A review of alternative control methods for grain and seeds shows that no single alternative is available to replace methyl bromide (MB). Phosphine, and a limited number of other pesticides, are currently available. However, at present there is concern with regard to the effectiveness and toxicity of these products. The future approach will be an integrated pest management system that considers all chemical and nonchemical (biological, physical, hygiene) methods adapted to each specific situation. Among chemicals, new classes of insecticides that are more specific and environmentally acceptable, botanical fumigants and repellents, and carbon dioxide, seem to be the best alternatives.

Keywords: Grain, seeds, stored product pests, integrated pest management, fumigation.

INTRODUCTION

Since ancient times cereals and seeds have been stored in different types of facilities. The presence of pests in stored products is documented from the time of the early Egyptian Dynasties. Although losses in stored grain or seeds due to pests are difficult to calculate, estimates of losses in developing countries are always about 20-30% (Gwinner *et al.* 1996). In developed countries, losses in quantity are not as important as losses in quality and the main concern is damage to the product which can be seen by customers, and pesticide residues. Standards in food safety increasingly demand the absence of insects, mites, microorganisms, mycotoxins, allergens and other contaminants.

Up to now, pest control has depended almost entirely on pesticides and the fumigant methyl bromide (MB) is one of the most important among them. Replacements for MB are urgently needed since it is scheduled to be phased out for general use worldwide due to its depleting effects on the ozone layer (UNEP 2001). Fumigations with phosphine (magnesium/aluminium phosphide preparations) and a limited number of synthetic organic insecticides are commercially available. All these pesticides are also highly toxic and harmful to the environment. International food safety legislation tends to prohibit or restrict pesticides suspected of remaining in food as toxic residues.

Phosphine appears to be effective for the control of several pest species. However, it requires longer treatment periods than those used with MB. In recent years, there has been some concern over the misuse of phosphine which has resulted in resistance in several pest species. It is highly important to establish and respect the most appropriate concentrations and exposure times in each particular situation. A cylinder gas formulation of phosphine and specific application technologies have been developed in Australia (Banks 1994). Advantages of these recent technical developments are shorter exposures, ease of application and reduced risk of uncontrolled leakage.

Minor fumigants have been used for many years such as chloropicrin, sulfuryl fluoride and cyanhydric acid registered in some European countries for structural treatments. A number of other potential fumigants have been studied for decades: carbonyl sulfide, carbon disulfide, ethyl formate and others (Banks 1994). However, their widespread use has been impeded by concerns over residues, environmental safety and, in general, their toxicology. Therefore, currently there is no single alternative to substitute for MB and possible restrictions on the use of phosphine.

NEW PEST CONTROL STRATEGIES

Pests that affect grain and seeds have a cosmopolitan distribution. In our area in Spain, a total of twenty-two species of arthropods were found in six types of grain cereals and seeds (Riudavets *et al.* 2001). Coleoptera and Lepidoptera were the main groups of arthropods collected, but psocids, wasps, thrips and mites were also present. Usually a high diversity of organisms is present at the same time in a storage facility. Knowledge of the interactions between them and the stored material is crucial to understanding the whole ecosystem. A pest management strategy must address the complex of organisms present and also take into account the management of abiotic factors such as temperature and relative humidity that affect their development.

An advanced approach to pest control, as an alternative to the regular use of pesticides, is known as integrated pest management (IPM) or more broadly, integrated commodity management. Chemical and nonchemical control methods are selected that complement each other thereby minimising the negative effects to human health and the environment in order to achieve economic protection from pest damage. Management strategies, hygiene, building design, inspection, biological and physical control methods are all useful to reduce pest populations, and whenever possible the use of pesticides is limited and much more effective.

There are many examples in the literature where successful pest control is economically achieved without the use of pesticides (Zuxun *et al.* 1999). Among physical control methods, meshes are set up to restrict the movement of pests, inert dusts are applied to protect the boundary layers of grain storage structures and mechanical devices are used to destroy insect eggs during the milling process.

Several insect parasitoids and predators are known to control stored product pests. However, very few natural enemies are commercially available in stored product protection. Microbial biocontrol agents based on *Bacillus thuringiensis*, fungus or viruses are already commercially available. However, their use in grain or seed storage facilities is not yet registered. Future research is needed on their practical application for control of stored product pests.

Chemical alternatives to classical pesticides include growth regulators (juvenile hormone mimics, ecdysone agonists and inhibitors of chitin synthesis), biofumigants (phytochemical compounds from plant products investigated as fumigants or repellents of pests) and atmospheric gases.

Among potential new fumigants for controlling stored product pests, carbon dioxide seems to be one of the best alternatives. Its advantages include no residues, existing registration, use for the food industry without a safety interval following treatment, and it is recyclable. The application of carbon dioxide under pressure, and preservation by modified atmospheres with high-carbon dioxide concentration, are two control methods useful for the agro-food industry. The effectiveness of both alternative technologies has been determined for the control of the main insects and mites found in grain or seeds (Table 1). Pressure treatments require short time periods and are highly effective. Modified atmospheres are easily applied to the packaging of manufactured products or when raw materials are stored. Furthermore, effective treatments require long periods and gastight systems.

Table 1: Conditions established for the control of main insect and mite pests of stored products using modified atmospheres and CO_2 under pressure.

	MODIFIED ATMOSPHERES	
CO_2 concentration	O_2 concentration	Exposure times
50% - 90%	<5%	4 days – 20 days
	CO_2 under PRESSURE	
Pressure	Exposure times	Decompression
15 atm – 20 atm	15 minutes – 120 minutes	0.5 minutes – 10 minutes

ACKNOWLEDGEMENTS

The author thanks the Comisión Interministerial de Ciencia y Tecnologia (FEDER 2FD97-0736) and S.E. de Carburos Metálicos S.A. for economic support.

REFERENCES

Banks, H.J. 1994. Fumigation – an endangered technology?. *In*: Highley, E.J.; Wright, E.J.; Banks, H.J.; Champ, B.R. Stored Product Protection. Proc. 6th International Working Conference on Stored-product Protection. Vol. 1. CAB International, UK. Pp. 2-6.

Gwinner, J.; Harnisch, R.; Mück, O. 1996. Manual of the prevention of post-harvest grain losses. Post-Harvest Project, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany. 338 p.

Riudavets, J.; Lucas, É.; Pons, M.J. 2001. Insects and mites of stored products in the northeast of Spain. Bull. OILB/WPRS. (In press)

UNEP 2001. United Nations Environment Programme. The ozone secretariat. www.unep.org/ozone/. 7 November 2001.

Zuxun, J.; Quan, L.; Yongsheng, L.; Xianchang, T.; Lianghua, G. 1999. Stored Product Protection. Proc. 7th International Working Conference on Stored-product Protection. Sichuan Publishing house of science & technology. China. 2003 p.

MICROWAVE ENERGY AS A VIABLE ALTERNATIVE TO METHYL BROMIDE AND OTHER PESTICIDES FOR RICE DISINFECTION INDUSTRIAL PROCESSES

D. SÁNCHEZ-HERNÁNDEZ[1], J.V. BALBASTRE[2] AND J.M. OSCÁ[2]
[1]Tech. University of Carthagene, Cartagena, Spain;
[2]Technical University of Valencia, Valencia, Spain;
Corrresponding author: david.sanchez@upct.es

ABSTRACT

Methyl Bromide (MB) is the pesticide commonly used for both food products and soil disinfecting processes. The main drawback for MB use is its contribution to the depletion of the ozone layer and it is a tremendous hazard for human health. Rice must be properly disinfected after harvesting prior to commercialisation. Since MB use will be forbidden from 2005 onwards in developed countries, it is necessary to search for a viable and equally effective alternative. The use of microwave energy in domestic applications has now become commonplace and its viability for many other industrial heating, thawing, drying and disinfecting processes has already been demonstrated. The aim of this paper is to describe the use of a pre-industrial microwave applicator for rice disinfestation. The applicator is the result of a 4-year R&D project that involved both academia and industry. The patent-protected modular system allows for continuous treatment at a user-customised speed for economic viability.

INTRODUCTION

An effective way of killing insects of all kinds is to elevate their body temperature above a certain lethal value using microwave energy. Previous studies have shown that the adequate temperature range required to achieve a 100% insect mortality in a commodity lies between 45 and 60°C [1]. Microwave heating is closely linked to the dielectric properties of the material being heated. Hence, the success or failure of disinfecting treatments using microwaves strongly depends on precise knowledge of the material to insect ratio of the dielectric properties and the dielectric properties themselves. For rice disinfecting, it becomes very important to achieve selective heating, namely, to induce a lethal temperature in the insects while not modifying neither the appearance nor the nutritive value of the commodity. The parameter upon which the behaviour of a material respect to microwave heating is based is the complex dielectric permittivity,

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \qquad (1)$$

where ε' and ε'' are the dielectric constant and loss factor, respectively.

The dielectric properties at 2.45 GHz of rice weevils and four different varieties of rice where studied. Long rice grain (Puntal), medium size pearled rice grain (Senia), medium size crystalline rice grain (Thainato) and short rounded rice grain (Bomba) were selected due to their large consumption in Spain. Measurements were performed based upon reflection measurements of partially filled WR-340 waveguides and perturbational formulae taken with the use of a HP-8720-B Network Analyser. The ratio between the rice and the weevils loss factor was found high enough to ensure process viability and selective microwave heating. Providing a way of avoiding insect migration to cold areas had to be incorporated into the design.

APPLICATOR DESIGN AND SIMULATION

The tool employed for the applicator design has been the 3D electromagnetic suite MAFIA (Maxwell Finite Integration Algorithm), where important trade-offs between accuracy and computational requirements were found. Practical design of the multimode cylindrical applicator is based upon three main factors: heating uniformity, mutual coupling and mode distribution.

Heating uniformity is main problem for multimode ovens. A way to improve uniformity and thus heating effectiveness is to employ several low-power feeder waveguides rather than one high-power input. This also helps lower maintenance costs since a high-power magnetron source usually costs much more than a few low-power magnetron sources [2] (Figure 1). Similarly, a cylindrical cavity was used as this is often appropriate for microwave applications due to its simplicity and because it improves the heating efficiency [3]. Strong mutual coupling, on the other hand, may lead to undesired energy within a magnetron head cavity, and hence lead to the destruction of the head. In order to avoid strong mutual coupling, the feeding waveguides must have different orientations when feeding the main cavity. Finally, an appropriate mode distribution depends on cavity size and shape, dielectric properties and position within the applicator.

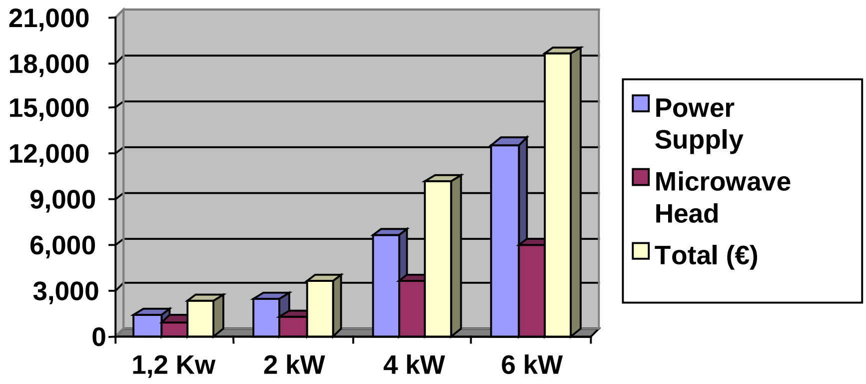


Figure 1: Comparison of cost for low- and high-power microwave energy sources.

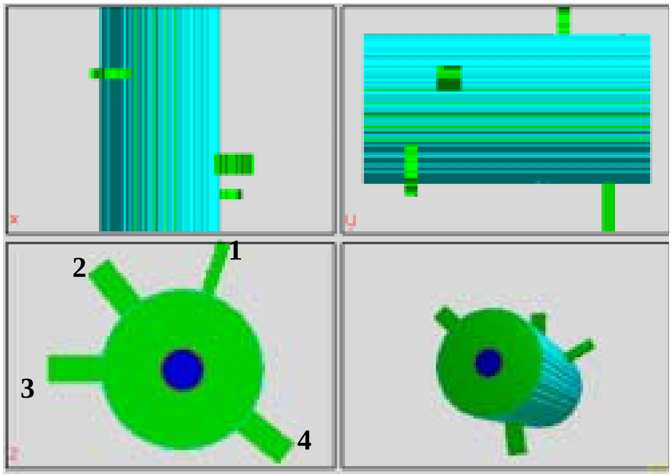
Taking into account that the system has to provide an economically viable disinfecting regime, with maximum heat transfer and uniformity within the cavity, the applicator was designed at the Technical Universities of Carthagene and Valencia, and built at Rymsa-Cixmo S.A. From all different simulations, the combination that best conform to specifications using eight feeder waveguides (only four are depicted) is shown in Figure 2 where a modular building block that can easily be combined to form parallel or series arrangements is illustrated. The electromagnetic performance of the building block in terms of both VSWR and mutual coupling is shown in Table 1.

Table 1: The electromagnetic performance of the building block in terms of both VSWR and mutual coupling.

VSWR			
S_{11}	**S_{22}**	**S_{33}**	**S_{44}**
2.45	2.75	2.14	1.76

Mutual Coupling (dB)					
S_{21}	**S_{31}**	**S_{41}**	**S_{32}**	**S_{42}**	**S_{43}**
-31.5	-22.7	-32.78	-23.7	-22.7	-15.5

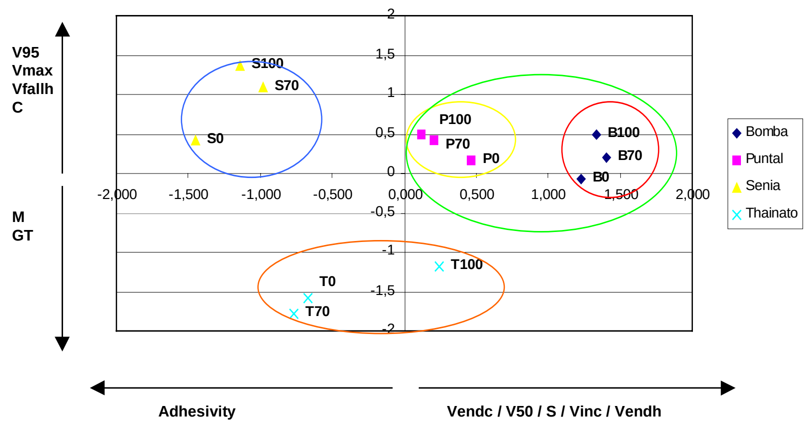
Figure 2: Building block for the rice disinfecting applicator.



It has also been demonstrated that the minimum energy requirements for a 100% mortality in rice disinfecting processes using the applicator type described in this paper is around 100 J/g [4], and thus testing procedures were prepared for 70 J/g (under treatment) and the correct 100 J/g at a laboratory scaled down applicator prototype. Several quality criteria parameters for rice were tested both before and after treatment, and compared to untreated samples. Moisture content (ISO712), water uptake, colour, response to heating, cooking and cooling (AACC-061), gelatinisation consistency, temperature and time of rice starch (ISO 14864:1998E), amylose content, decomposition of rice kernel, optimum cooking time and texture (TA XT2i) were tested, among some others.

Due to limited publication space, only the results of the statistical analyses that were performed for each variety with all its different test results will be depicted here. In the multi-variable analyses, significant correlation values from below –0,7 and above 0,7 were accounted for. bIn the statistical analyses, two factors accounted for 86,64% of the standard deviation, while the rest was attributed to a third factor. The results for factors 1 and 2 are depicted in Figure 3. Figure 3 shows that more differences can be found between varieties than between samples treated and untreated with weevil mortality-effective microwave energy within each variety. Bomba and Puntal varieties were grouped closer to factor 2, wherein consistency, maximum viscosity, 95°C viscosity and viscosity attributed were considered. Senia variety was grouped to the adhesivity attribute of factor 1, like Thainato variety, although this last one was more disperse and approached factor 2.

Figure 3:	Results of statistical analyses.



V, Viscosity; V50, viscosity at 50°C (cooling); V95, viscosity at 95°C (heating); Vmax, maximum viscosity; Vendh, final viscosity after heating; Vfallh, viscosity fall after heating (Vmax-Vendh); Vendc, final viscosity after cooling; Vinc, viscosity increase after cooling (V50-Vendc); S, setback (Vmax-V50); C, consistency; M, moisture content; GT, gel temperature.

CONSTRUCTION

With the scaled-down data and the modular approach, a full-size pre-industrial applicator able to treat 250 kg per hour was designed and built. The centre of the cavity consisted of a hollow doped-PTFE tube to prevent rice from spilling over the whole applicator and keep it within the concentrated and uniform high field distribution. The radius of this hollow doped-PTFE tube had been designed considering both regime and penetration constraints. The final applicator is illustrated in Figure 4, and with a total height of 3.8 meters and width of 1.1 metres, it contained eight 850 W microwave sources, requiring an electrical supply of 8.5 kW/h for proper operation. Figure 4 at the end of the paper shows the industrial user-customised applicator.

CONCLUSIONS

A complete pre-indsutrial applicator for rice disinfecting eliminating Methyl Bromide has been designed and manufactured. The use of microwave energy for industrial rice disinfecting processes slightly modifies rice quality parameters while completely eliminating the use of Methyl Bromide. Found changes depend upon variety, although these are so petty that no commercial drawbacks are foreseeing qualitywise. Likewise, standard deviation in quality parameters is higher between varieties than between treated and untreated samples within varieties. More research is been carried out to find out whether standard deviation in quality parameters can also be compared to standard deviation within variety batches.

ACKNOWLEDGEMENTS

This research was partially funded by *Roca Defisán, Cooperativa Virgen del Campo, Rymsa, Dacsa* and the European Regional Development Fund (ERDF) Programme of the EU. The authors wish to thank CST GMBH and Agilent Technologies for their generous educational discounting, and Carmen Benedito-Mengod from IATA (Spain) for making some quality analyses. The applicator presented in this paper is patent protected.

REFERENCES

[1]Tilton, E.W., 'Ionizing radiation for insect control in grain and grain products', *Cereal Foods World,* 1987, Vol. (32), No. 4, pp. 330-335.

[2]T.V. Chow et al., 'Modelling of Modes and Perspectives on Multiple-Feeds in Microwave Ovens', *Journal of Microwave Power and Electromagnetic Energy*, 1996, Vol. 31, No. 4.

[3]Milovanovic, B. et al, 'The Loading Effect Analysis of the Cylindrical Cavities with various cross-sections', *Journal of Microwave Power and Electromagnetic Energy*, 1998, Vol. 33, No.1.

[4]Sánchez-Hernández, D., et al., 'Electromagnetic Design of a Microwave Applicator for Industrial Rice Disinfection Processes', 7th Int. Conf. on Microwave & High Frequency Heating, Valencia, Spain, 1999, pp. 477-480.

Figure 4: Industrial user-customised applicator.

HERMETIC STORAGE OF GRAIN IN CYPRUS

A. VARNAVA
Cyprus Grain Commission, Nicosia, Cyprus
a.varnava@cgc.com.cy

ABSTRACT

In Cyprus, five different structures for Hermetic Storage of grain collectively have an 85,000 tonne capacity which represents approximately 30% of the total storage capacity of the country. The “Bunkers and Platforms under PVC” liners, and the “Airtight Concrete Bins”, were the more important of these hermetic structures. Bunkers and Platforms under PVC liner were low cost grain storage structures (approximately US$8,5/tonne). The labour needed for filling and emptying one Bunker of 12,000 tons capacity required approximately 650-850 man-hours for each operation. The cost for filling, emptying, grain protecting, providing liner materials and maintenance of one Bunker of 12,000 tons was approximately US$1.83/tonne. Loading and out-loading machines of 300 tonnes/h were used. The introduction of hermetic Bunkers in the grain storage system provided the possibility for a) receiving the local production for safe storage in a short time b) taking advance of low prices in the international market c) increasing the grain storage capacity and grain stock using minimal capital d) successful protection of grain against insects, rodent contamination, bird attacts and losses caused by rain e) reduction in the use of insecticides including methyl bromide. The combination of hermetic storage with grain aeration, advanced fumigation technologies like Siroflo and good management will be essential for profitable and ecologically-friendly grain handling.

Keywords: grain, storage, hermetic, airtight, bunkers, silo, plastics, alternatives, methyl bromide

INTRODUCTION

In many ancient civilizations people used to store grain in different structures like clay jars, mud-plastered underground pits, above-ground oven-shaped mud-plastered domes and other structures. In some of them, a thick layer of earth and well-sealed openings provided a certain degree of airtightness. The combination of hermetic conditions with low grain moisture could protect the grain for a long time. Similar structures were used in many countries even some decade's years ago for grain storage. For example, in Cyprus in some villages until the first decades of 20th century, wheat was stored in oven-shaped mud-plastered structures with both openings well-sealed and in mud-plastered underground cavities called "Gouffes".

Modern hermetic storage is based on the same principal, but new materials and technologies are used. Cement, polymers like PVC and polyethylene liners, iron, fiberglass and sealants like silicone are some of the new materials used in building structures for hermetic storage of grain. A great variety of these hermetic structures can be seen in many countries: underground pits, bunkers and platforms covered by plastic liners, mobile plastic bag-silos, metal bins and sheds, concrete silos with plastered their inner walls with sealing materials, large domes built by using cement, plastic and fiberglass. The capacity of some of these hermetic structures is 50-100 thousand tonnes each.

HERMETIC STORAGE OF GRAIN IN CYPRUS

In Cyprus, five different structures for hermetic storage of grain are used of a total 85 thousand tons capacity, representing approx. 30% of the total storage capacity of the country. The so-called "Cyprus Ctessifon underground pits" were the first hermetic stores built in Cyprus in 1956. Their capacity is 1,200 tons each and, at that time, they served as an experiment for building storage silos in other countries based on the idea of airtightness.

In 1987, four hermetic Mobile Silos of 1,000 tons capacity each and two hermetic Platforms of 7,000 tons total capacity were erected in Cyprus, in co-operation with Volcany Center, Israel. In Mobile Silos, consisting of an UV PVC bag in an iron-made round frame, wheat and barley were stored up to one year without using insecticides. The O_2 concentration could be reduced by up to 5% and the CO_2 by up to 14%. An aeration system was used to minimize the condensation on the top.

The two hermetic Platforms are 25m wide and 75m long, with a concrete base and 1.2m height concrete walls. The floor is covered with a 250 mm polyethylene. Grain is covered with an UV PVC liner of 720 mm thickness. Liner is non-permeable to water, O_2, CO_2 and PH_3. Barley of max. 11.5% moisture is stored in these Platforms up to 3 years without using any insecticides. Grain is successfully protected against insects, rodent and bird's attacks and contamination. If Platforms are well sealed, the O_2 concentration is reduced up to 3-6% and the $C0_2$ is increased up to 12%. At the end of storage no samples containing live insects are recorded. The germination of grain remains above 88% even after 3 years of hermetic storage. In addition to the low structural cost and ecological advantages, storage losses can be compared favorably with weight losses in conventional structures. Total storage losses represent after 1 year storage approx. 0.3%, after 2 years approx. 0.5% and after 3 years of storage approx. 0.9%. Total of fixed cost (including the building of Platforms, a Stacker of 300tons/hour and liners) and current cost for 1 year storage of 4,000 tons barley are approximately US$4.50/tonne.

The fourth type of hermetic structure used in Cyprus is a complex of 3 airtight Concrete Silos of 2,500 tons capacity each. These bins are used not for long-term storage, but for fumigation of grain using broken (crushed) phosphine tablets followed by aeration. This has the following advantages: a) successful fumigation using very low Phosphine doses b) no need for liquid insecticides or methyl bromide (MB) c) no insecticide residues in grain.

The fifth type of hermetic structure used in Cyprus is a system of 6 hermetic Bunkers of total 70 thousand tons capacity. This technology was introduced in Cyprus in 2001 in co-operation with SACBH, Australia. Each Bunker is 130m long, 30m wide and approx. 10m height and set on an east-west axis (west is the main direction of wind). Bunker walls are formed by joint one to another 3m long and 1,3m height corrugated steel walls with fabricated "A" metal frame support. The walls are secured to the ground by pegs through the frames. The Bunker base is of compacted crushed rock of 200mm thickness. Before filling the Bunker with grain, the floor is covered with a polyethylene liner of 200µ thickness. Walls are covered by polyethylene coated fabric which extends from the ground and interlocks with the top trap creating a gas and water sealed structure. The grain is loaded using a Over Drive Hopper and a Stacker of 300 tonnes/hour capacity. Grain is covered with a 520µ thickness reinforced PVC of 3-years service life. The liner is not permeable to water, O_2, $C0_2$ and PH_3. This cover successfully stood up during last December to gale of 20-25 m/sec at 2 and 10 m height and heavy rainfall of 70mm in one day. The sheets have an ice-blue colour, friendly to the environment.

Four 18.5 kW fans are used for grain aeration, controlled by a computer operating on the difference between the wet-bulb temperatures of grain and ambient air. Aeration of Bunkers is an innovation and it is expected to minimize condensation at the apex of Bunker and enable the storage of grain of higher than 12.5% initial moisture content. Bunker is an excellent structure for grain fumigation with Phosphine. In fumigations of Barley using a dose of 0.5 g ai/tonne, the PH_3 concentration was maintained for 15 days above 60 ppm. Good sealing of the Bunker is very important. After the end of fumigation, the grain is aerated to remove Phosphine residues and to reduce the grain temperature.

The total expenditures for building 6 Bunkers of total capacity 70 thousand tonnes (including 17ha of land of US$0.5 million, building and roads) was US$1,777,000 or US$25/tonne. The cost for the Bunkers' machinery, apparatus, walls, sheets, aeration system and data loggers was US$577,000 or US$8.2/tonne (Table 1).

Table 1: Per item cost of building six hermetic Bunkers of 70,000 tonnes capacity in Cyprus

Type of Expenditure	**US Dollars**	**Life in years**
Bunkers walls, supporting frames, corrugated sheets etc	93,000	20
Drive Over Hopper, Stacker	178,000	15

Type of Expenditure	US Dollars	Life in years
Aeration fans and Ducts, Aeration controller	52,000	10-20
Data loggers, Software	13,000	5
Top-cover PVC sheets	79,000	3
Floor-cover polyethylene sheets	5,000	1
Packing, Insurance, Erection, Testing, Design, Training etc.	154,000	-
TOTAL	**577,000**	

For filling and emptying one Bunker of 12,000 tonnes, 8 persons were needed (one grain inspector, one person for weighing, two techniciants, 4 workers). The labour for filling one Bunker of 12000 tonnes was approximately 650 manhours during summer and 850 man-hours in winter. A little less labour is needed for emptying. The cost for filling, emptying, 1-year grain protection, liners, fuel and maintainance of one Bunker containing of 12,000 tonnes of grain as approximately US$20,000 or US$1.83/tonne (Table 2).

Table 2: Per item cost of filling, emptying, 1-year grain protection, liners and maintainance of one Bunker containing 12,000 tons of grain.

Type of Expenditure	US Dollars	US$ per tonne
Filling and emptying the Bunker	13,500	1.13
Fumigation, aeration, rodent control etc.	1,500	0.13
PVC sheet for covering the grain	4,500	0.36
Polyethylene for covering the floor	1,000	0.08
Maintenance of Bunker and machinery, fuel, oil etc.	1,500	0.13
TOTAL	22,000	1.83

CONCLUSIONS

1. Hermetic Bunkers and Platforms under PVC liner is a low cost grain storage facility (about US$8.5/tonne) and a fast way to increase storage capacity of a country or a company. This provides the possibility for a) securing the local production in a short time b) taking advance of low prices in the international grain market, that is important for importing countries c) increasing the grain stock d) successful protection of grain quality e) reduction of insecticides use, no need for liquid insecticides and MB.
2. The expenditure for building hermetic Bunkers and Platforms was about 7.15 and 25 times lower in comparison to the expenditure for building conventional flat shed, metal and concrete silos of the same capacity, respectively.
3. The labour needed to fill one Hermetic Bunker of 12,000 tonnes capacity was about 650-850 man-hours and for emptying a little less. The cost for filling, emptying, maintainance including liners and 1-year grain protection of one Bunker of 12,000 tonnes was approximately US$20,000 or US$1.83/tonne.
4. In hermetic Platforms, the reduction of O_2 up to 3-5% and the increase of CO_2 up to 10-12% may suppress the insect development without using insecticides. In hermetic Bunkers and Bins a successful fumigation using reduced doses of phosphine can be carried out, followed by aeration to remove phosphine residues.
5. The major problem in using hermetic Bunkers and Platforms for grain storage is the increased need of manual labour, the break in work during rainy days and the moisture migration towards the peak. The storage of grain with low moisture content (below 12.5%), the new possibility for aeration of grain in Bunkers, and the flattening of the structural configuration at the apex, reduce the mould losses at the peak.

6. The hermetic method of storage provides successful protection of grain against insects, rodent contamination, bird attack and losses caused by rain, reduces the need for using liquid insecticides or MB and it has ecological advantages.

REFERENCES

Banks, H.J. and Sticka, R. 1981: Phosphine fumigation of PVC-covered, earth-walled bulk grain storages: full scale trials using a surface application technique. *CSIRO (Aust.) Div. Entomol. Tech. Pap.*, 18: 1-45

Banks, H.J. 1984: Assessment of Sealant Systems for Treatment of Concrete Grain Storage Bins to Permit their Use with Fumigants or Controlled Atmospheres: Laboratory and Full Scale Tests. *CSIRO Division of Entomology*

McCabe, J.B. and Champ. B.R. 1981: Earth-covered Bunker Storage: Manual of Operations. *CSIRO Division of Entomology, Canberra, A.C.T.*

Navarro, S., Donahaye, E., Kashanchi, V. and Bulbul, O. 1984: Airtight storage of wheat in a PVC covered Bunker. *In:* B.E. Ribb, H.J. Banks, E.J. Bond, D.J. Calverley, E.G. Jay and S. Navarro (Editors), Controlled Atmosphere and Fumigation in Grain Storages. Elsevier, Amsterdam, pp. 601-614.

Navarro, S., Varnava, A. and Donahaye, E. 1993: Preservation of grain in hermetically sealed plastic liners with particular reference to storage of barley in Cyprus*. In:* S. Navarro and Donahaye, E. (Editors), Proceedings International Conference on Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, 1992. Caspit Press Ltd, Jerusalem, pp. 223-234.

Varnava, A., Navarro, S. and Donahaye, E, 1994: Long-term hermetic storage of barley in PVC-covered concrete platforms under Mediterranean conditions. *J. Postharvest Biology and Technology, Vol. 6: 177-186, Elsevier, 1995.*

Varnava, A. and Mouskos, C. 1996: 7-years results of hermetic storage of barley under PVC liners: Losses and justification for further implementation of this method for grain storage. *In:* Donahaye, E., Navarro, S. and Varnava, A. (Editors), Proceeding International Conference on Controlled Atmosphere and Fumigation in Stored Products, Nicosia, Cyprus, 1996, Printco Ltd, Nicosia, pp. 183-190.

Photo 1: A group of Bunkers of total 70 thousand tons capacity for hermetic storage of grain in Cyprus. An aeration system, controlled by a computer using data from a meteorological station, is installed in two of these Bunkers, to control the grain temperature and moisture migration, to increase the acceptable initial grain moisture content and to remove the phosphine residues after fumigation.

Photo 2: The historic "Cyprus Ctessifon semi-underground pits" built in 1956 and served as an international model for studying the possibility of using hermetic structures for grain storage.