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Scientific Notes

Current Research of Alternatives to Methyl Bromide and its Reduction in Japanese Plant Quarantine

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Abstract: Total amounts of methyl bromide consumption used for Japanese plant quarantine in 1997 was 2,070 t with 1,255 t for timbers (60.6%), 579 t for cereal grains (27.9%), 221 t for fresh fruit and vegetables (10.7%) and 16 t for cut flowers and live plants (0.8%). Current alternative technologies for reduction of methyl bromide use are as follows; **Stored grains**: carbon dioxide was introduced into a quarantine treatment with 4 schedules at three different temperatures. Use of hydrogen phosphide from a cylinder-based formulation or phosphine generator could be effectively for the pupal stage of *Sitophilus* spp. and applicable to other grain pests with shorter exposure time. Hydrogen phosphide + carbon dioxide showed an adverse effect on mortality than hydrogen phosphide alone. *S. granarius*, *C. rodesianus*, *E. cautella*, etc. were killed at low temperature of -18℃ for 5 hours without damage of wheat, maize and soy bean. **Fresh fruit and vegetables**: combined treatment of cold storage + methyl bromide was introduced into a quarantine treatment for export apples to the USA. The lepidopterous egg stages were killed by cold storage as the first step and the larval stages were also killed by subsequent methyl bromide fumigation as the second step of the treatment. Mango, papaya, bitter cucumber, etc. infested with *B. dorsalis* species complex and *B. cucurbitae* and sweet potato infested with *C. formicarius*, *E. postfasciatus* and *O. anastomosalis* from Okinawa was shipped to mainland after vapor heat treatment at 43-48 ℃. Hydrogen phosphide may be a possible fumigant for apples and grapes as a 100% mortality of *T. urticae* and no chemical damage on those fruit were confirmed at $2g/m^3$ for 16-24 hours. **Cut flowers**: mixture gas fumigation of methyl bromide ($14g/m^3$), hydrogen phosphide ($3g/m^3$) and carbon dioxide (5%) for 4 hours at 15℃ or for 3 hours at 20℃ was established a quarantine treatment for imported cut flowers with attaining 100% mortality of several pests without damage on several cultivars of chrysanthemum and orchid. All stages of *T. urticae*, *T. palmi*, *M. persicae*, etc. were killed or sterilized at 400 Gy of electron beam irradiation without damage on 17 species of cut flowers. **Timbers**: sulfuryle fluoride showed high efficacy on forest insect pests at only high temperature of 25℃ or above. Lower effect was observed on the larval and pupal stages of the pests at $2g/m^3$ of hydrogen phosphide for 24 hours at 15℃. Mixture gas of sulfuryle fluoride ($50g/m^3$) and hydrogen phosphide ($2g/m^3$) for 24 and 48 hours at 15 ℃ showed high mortality of the pests which were not killed by sulfuryle fluoride alone. Alternative fumigants and these fumigant mixtures have disadvantages of relatively longer exposure time with rather more specified narrow range of pests. Physical treatments also need longer exposure time, costly facilities and higher operation cost.

Key words: ozone-depleting substance, Montreal Protocol, alternatives to methyl bromide, quarantine treatment, methyl bromide, carbon dioxide, hydrogen phosphide, sulfuryl fluoride, methyl isothiocyanate, fumigant mixture, vapor heat, cold treatment, electron beam irradiation, stored grain, fruit and vegetable, cut flower, timber, quarantine pests

Introduction

Methyl bromide (MB) is a colorless, odorless, non-flammable fumigant with a boiling point of 3.6℃, a specific gravity in air of 3.3 and only slightly soluble in water. In particular, it is quite penetrative, usually effective at low concentrations and leaves residues which have generally been found acceptable. Its action is usually fast and it airs rapidly enough from treated systems to cause relatively little disruption to commerce or crop production (MONRO, 1969). MB has been used for controlling a wide range of pests including insects, mites, nematodes, soil-born pathogens as a versatile and convenient fumigant for 60 years. It has sufficient phytotoxicity to control many weeds and their seeds in soils. It is also used for disinfesting durable and perishable commodities of pests and for disinfesting buildings (MBTOC, 1998).

On the other hand, MB was decided as an ozone-depleting substance at the 4th Meeting of the Parties in Copenhagen in 1992. Since then, advanced control measures and schedules for reduction of MB use with exemptions of quarantine and pre-shipment purposes were agreed rapidly at the 7th Meeting in 1995 and the 9th Meeting in 1997.

Because of the controls that have been imposed on MB, both globally and nationally, a number of agricultural research institutions and private sector organizations have engaged in work to develop and implement economically viable and environmentally sound alternatives to MB. Japan has also engaged in the development of alternatives to MB and its reduction in plant quarantine because of protection of the Ozone-Layer.

Current Methyl Bromide Controls

The control measures and schedules of MB were substantially agreed at 7th Meeting of the Parties in Vienna in 1995 consist of: for developed countries, the production and consumption of MB from 2001, 2005 and 2010 should not exceed annually 75%, 50% and 0% of the level in 1991, respectively and for developing countries, its calculated level of consumption from 2002 should not exceed the average for the period of 1995-1998. These levels shall not include the amounts used for quarantine and pre-shipment purposes (KAWAKAMI, 1997a, b). The current control measures agreed by the Parties in Montreal in September 1997 consist of: a 100% phase out by 2005 for developed countries and that by 2015 for developing countries with still remaining of exemptions of quarantine and pre-shipment treatments (MBTOC, 1998). At the 17th Meeting of the Open-ended Working Group of the Parties held in Geneva in 1998, a proposal was made on the MB used for quarantine and pre-shipment treatments (UNEP, 1998a). The purpose of the proposal was to reduce the unnecessary use of MB and also to obtain further clarification on the definitions since the International Plant Protection Convention (IPPC) definitions of quarantine pests had recently been changed. A draft has been forwarded to the 10th Meeting of the Parties in the compendium of draft decisions (UNEP, 1998b).

Methyl Bromide Consumption

Of the 1996 global production of MB of 71,425 t, approximately 2,759 t (3.9%) was used as a feedstock for chemical synthesis with the remaining 68,666 t produced for agricultural purposes. The 1996 global consumption figure for agricultural uses reported to the Meeting of the Parties to the Montreal Protocol including that for quarantine and pre-shipment uses, was estimated as 64,910 t with approximately 76% of this being for soil treatment, 15% for fumigation of durable commodities and structures, and 9% for perishable commodities. The quarantine and pre-shipment treatment use currently accounts for 22% or 15,000 t of MB consumption and is increasing globally at about 2% annually, although it has decreased in some countries (MBTOC, 1998).

Annual consumption volume of MB by use sector in 1991-1997 in Japan is shown in Table 1. The increase of the consumption in preplanting sector in 1993 and 1994 was due to the dead stock of the big purchase by the farmers who were concerned of insufficient supply of MB from 1995. The consumption in 1997 was 7,908 t with 5,470 t for preplanting (69.2%), 2,030 t for quarantine and pre-shipment (25.7%) and 408 t for other (5.2%). MB use (7,908 t) in Japan in 1996 may take account of approximately 11.1% of 71,425 t of global use (MBTOC,1998). The consumption in Japan has decreased gradually in all sectors. In particular, big reduction is found in the sales of preplanting and quarantine & pre-shipment sector as much as 2,312 t and 673 t, respectively when comparing to the consumption between in 1994 and 1997.

Table 1. Methyl bromide sales volume by use sector in Japan (tons).

Use sector	1991	1992	1993	1994	1995	1996	1997
Preplanting	6,269	6,594	7,241	7,782	5,742	5,559	5,470
Quarantine	2,848	2,646	2,712	2,703	2,448	2,198	2,030
Pre-shipment	-	-	-	-	-	-	-
Other	219	121	204	426	523	431	408
Total	9,336	9,361	10,157	10,911	8,713	8,188	7,908

Data source: Plant Protection Division, Ministry of Agriculture, Forestry and Fisheries (1998).

MB consumption for quarantine and pre-shipment in 1997 in Japan is shown in Table 2. Total amounts of MB consumption was 2,070 t with 1,255 t for timbers (60.6%), 579 t for cereal grains (27.9%), 221 t for fresh fruit and vegetables (10.7%) and 16 t for cut flowers and live plants (0.8%), respectively. A 10 t was used for wooden packing products infested with quarantine pests for Australia, New Zealand, USA and China. There were few examples of pre-shipment treatment except for export rice fumigated with a small amount of MB in the foodstuff support program of Japanese government.

Table 2. Methyl bromide use for plant quarantine in Japan (1997).

Commodity	Methyl bromide use (tons)	Rate (%)
Timbers	1,255	66.6
Cereal grains	579	27.9
Fruit, vegetables	221	10.7
Other	16	0.8
Total	2,070	100.0

Data source: Yokohama Plant Protection Station, Ministry of Agriculture, Forestry and Fisheries (1998).

Note: The quantity of methyl bromide in 1997 includes a part of methyl bromide produced in 1996.

Current Research of Alternatives to Methyl Bromide in Japan

Japan has focused on developments and alternatives to MB for its reduction. The disinfestation technologies introduced into quarantine treatments and the current research are as follows;

Stored Grains

Carbon dioxide(CO_2): CO_2 fumigation in warehouse and silo was introduced into a quarantine treatment for stored grain pests (*Sitophilus granarius*, *Sitophilus zeamais*, *Sitophilus oryzae*, *Triborium confusum*, *Lasioderna serricorne*, *Rhizopertha dominica*, *Ephestia kuehniella*, *Plodia interpunctella* and *Ephestia cautella*) with four schedules at 20-25 ℃, 25 ℃ or above and 30 ℃ or above on the bases of dose-response tests and large scale mortality tests (Table 3). *S. granarius* pupa was the most resistant to CO_2 fumigation, while all stages of the grain moths were least susceptible. A complete mortality was obtained in different concentrations of CO_2 with ranging from 40-80% for *Sitophilus* spp. and more than 50% for other pests (SOMA *et al.*, 1995; KISHINO *et al.*, 1996). Large scale mortality tests were conducted with initial concentrations of 74% of CO_2 for 14 days at 25℃ in 1,886 m^3 steel silo containing 1,422 t of wheat and that of 80% of CO_2 for 7 days at 33℃ in 2,698 m^3 silo containing 2,100 t of wheat.

Table 3. Carbon dioxide fumigation schedules for stored grains.

Pests	CO_2 concentration	Exposure period	Temperature
Granary weevil	40-80 %	35 day	20-25℃
		21	25 or above
Rice weevil	40-80	21	20-25
Small rice weevil		14	25-30
Red flour beetle	more than 50	10	30 or above
Cigarette beetle		14	20-25
Lesser grain borer		10	25 or above
Mediterranean flour moth Indian meal moth Almond moth	more than 50	7 5	20-25 25 or above

Liquid CO_2 was introduced into the silo from bottom injection site through a vaporizer. The gas expelled extra air from upper exhaust vent. Both valves were closed, and then air circulation system was operated (Fig. 1). The result showed (a) *S. zeamais* pupa was killed completely without damage of wheat, (b) same temperatures were maintained throughout fumigation, (c) initial concentration of 74% and 80% of CO_2 decreased gradually and reached to 59% and 50% at the end of fumigation, (d) the pressure in silo decreased rapidly in a few days after introducing CO_2 and vacuum state was maintained throughout fumigation, and (e) approximately 28% of initial dose of CO_2 was lost during fumigation due to absorption by wheat (KAWAKAMI, 1995a; KAWAKAMI *et al.*, 1996a).

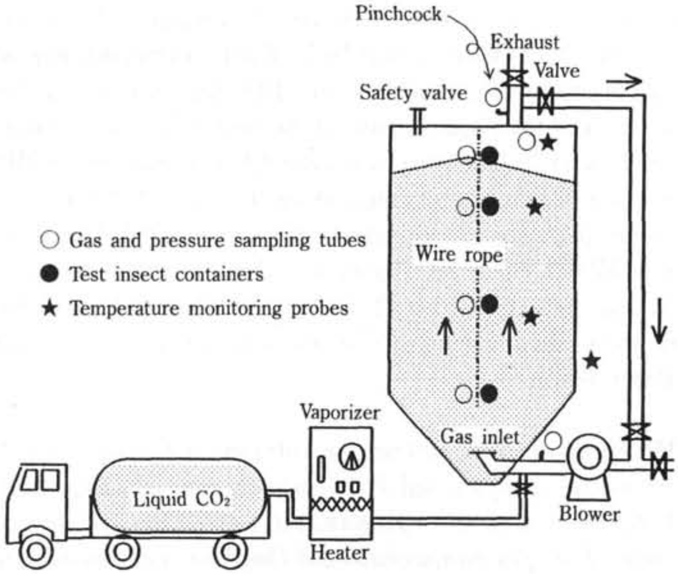

Fig. 1. The experimental silo and accessory equipment.

Hydrogen phosphide (PH_3): Aluminum phosphide has disadvantages of little effect on the pupal stage of *Sitophilus* spp. with taking longer than other methods because of the slower release of active gas, especially under low temperature (below 5℃) and also because of the tendency to exhibit insecticidal effect at longer exposure time. Current research in small scale tests showed that *S. granarius* pupa was killed at 0.5g/m^3 of phosphine from a cylinder-based formulation or a phosphine generator for 10 days at 20℃ and complete mortalities against *S. zeamais* and *S. oryzae* pupae and other pests such as *T. confusum*, *R. dominica*, *E. kuehniella* were obtained for 14 days and 2 days, respectively (GOTO *et al.*, 1996).

PH_3 + CO_2 : Mortality effects on pupal stages of *S. granarius*, *S. zeamais* and *S. oryzae* were compared to PH_3 (0.3 and 0.6g/m^3) alone and mixture gas of PH_3 (0.3 and 0.5g/m^3) and CO_2 (0, 30, 40 and 50%) to study the shortage of exposure time of PH_3 fumigation. The mixture gas fumigation showed an adverse effect of lower mortality than that of PH_3 alone (GOTO *et al.*, 1966).

Cold Treatment (CT): All stages of *S. granarius*, *Callosobruchus rodesianus*, *E. cautella* and *E. kuehniella* were killed completely at −18℃ for 5 hours and no damage was observed on wheat, maize, soy bean and small red bean (DOHINO *et al.*, 1999). This technology could be applied for small amounts of commodities by postal packages and carry on baggage. It could be also applied for cargoes in the commercial cold storage at temperatures of ranging from 0-5℃ although it takes much longer exposure time.

Fresh fruit and vegetables

MB+CT: Combined treatment of CT and MB against *Carposina niponensis*, *Conogethes punctiferalis* was introduced into as a disinfestation for apples export to the USA. The

Adoxyphyes orana fasciata, *Tetranychus viennensis*, *T. kanzawai*, *T. urticae* associated with apples were also completely killed by the standard. The *C. niponensis* egg, which is the most resistant of all stages of two species of the pests to MB fumigation, is completely killed by cold storage as the first step and the diapause larva of the pest, which is the most resistant to low temperature of all larval stages of the two pests is also killed by subsequent MB fumigation with lower doses as the second step of the treatment (KAWAKAMI *et al.*, 1994).

The treatment schedules were that Standard 1: CT (at 0.5 ± 0.5℃ for 40 days or more, fruit in plastic field bins) + MB (at 38g/m^3 for 2 hours at 15℃ or above with 40% or less loading, fruit packed in export cartons) and Standard 2: CT (at 0.5 ± 0.5℃ for 40 days or more, fruit in plastic field bins) + MB (at 48g/m^3 for 2 hours at 10℃ or above with 50% or less loading, fruit in plastic field bins) (KAWAKAMI, 1994).

Vapor heat (VH): Mango, papaya, bell pepper, bitter cucumber, netted melon infested with *Bactrocera dorsalis* species complex and *B. cucurbitae* from Okinawa had been shipped to mainland after VH treatment at 43-46℃ (KAWAKAMI, 1996). Recently, sweet potato infested with *Cylas formicarius*, *Euscepes postfasciatus* and *Omphisa anastomosalis* was also shipped from Okinawa to mainland after treatment at 47-48℃ for 3 hours and 10 minutes (SHIMABUKURO *et al.*, 1997). Mortality tests against scales and mites on the surface of fruit are studying on.

PH_3 : Apples, grapes and Satsuma mandarins were fumigated at 3g/m^3 of PH_3 for 24 hours at 15℃. No chemical injury was observed on apples ('Ohrin', 'Kinsei' and 'Fuji' varieties) and grapes ('Kyoho' variety), while small brown spots on 'Sekaiichi' apple variety and spots, brownish or blackish brown discoloration and sensory disorder of Satsuma mandarins were observed, respectively (SOMA *et al.*, 1997a, b; AKAGAWA *et al.*, 1997). *T. urticae* egg, which is the most resistant stage was killed at 2g/m^3 for 16-24 hours at 15℃ (SOMA *et al.*, 1997b). PH_3 may indicate a possible fumigant for fresh fruit. Further test needs on efficacy against some lepidopterous species.

PH_3 + MB: Mixture gas of PH_3 (3g/m^3) and MB (14g/m^3) showed no damage of Satsuma mandarins for 3 hours at 20℃ (AKAGAWA *et al.*, 1997), while severe damages were observed on 'Kyoho' grape with softening or rot and sensory disorders of berries, dropping berries from the cap stem (SOMA *et al.*, 1997b).

Methyl isothiocyanate (MITC): Severe damages were observed on apples with brown colored skin and pulp and on Satsuma mandarines with discoloration of skin at 4-8g/m^3 for 24 hours at 15℃ (SOMA *et al.*, 1997a; AKAGAWA *et al.*, 1997). MITC could not be applied for fresh fruit.

Cut Flowers

MB+PH_3 +CO_2 : All stages of pests (*T. kanzawai*, *T. urticae*, *Thrips palmi*, *Trialeurodes vaporariorum*, *Myzus persicae*, *Aphis gossypii*, *Planococcus kraunhiae* and *Plutella xylostella*) on cut flowers were completely killed by mixture gas with MB (14g/m^3), PH_3 (3g/m^3) and CO_2

(5%) for 3 and 4 hours at 15 and 20 ℃ without injuries on six cultivars of chrysanthemum and 4 cultivars of orchid, which were more sensitive to the fumigation than other species of cut flowers. A slight injury was confirmed on both cut flowers when fumigated at 20℃ for 3 hours. The injury, however, could be acceptable in commercial trading (KAWAKAMI, 1995b; KAWAKAMI *et al.*, 1996b). The mixture gas fumigation was introduced into a quarantine treatment (Table 4) and MB use in the schedule was reduced to 2/3 compared to the dose of conventional schedule of MB alone (at 48g/m^3 for 3 hours)(KAWAKAMI, 1995b).

Table 4. Fumigation schedules for pests on cut floweres by mixture gas of methyl bromide, hydrogen phosphide and carbon dioxide.

Pests	Doses		Exposure time	Temperature
Mites, Thrips,	Methyl bromide	14 g/m^3	4 hr	15-20 ℃
Whiteflies, Aphids,	Hydrogen phosphide	3 g/m^3	3	20 or above
Mealybugs, etc.	Carbon dioxide	5 %		

Diagram of fumigation procedure in commercial warehouse is shown in Fig. 2. First, CO_2 is introduced into warehouse from bottom injection site through a vaporizer. Heavier specific gravity of CO_2 expels extra air from upper exhaust vent. Following introduction of CO_2, humidified PH_3 and vaporized MB are lead to a special gas mixing apparatus through mass flow controllers and introduced into warehouse. PH_3 is humidified prior to being lead to the mixing apparatus for avoiding flammability and air-PH_3 mixture in injection duct must be expelled by vacuum pump and replaced with nitrogen gas before and after introduction of PH_3. Electrical and other machinery in fumigation chamber must be taken to seal or cover for avoiding PH_3 corrosion (KAWAKAMI *et al.*, 1996b). The newest tests showed that the same efficacy was obtained on *T. urticae* egg when fumigated either mixture gas with MB, PH_3 and CO_2 or that with MB and PH_3 (MIZOBUCHI *et al.*, 1997).

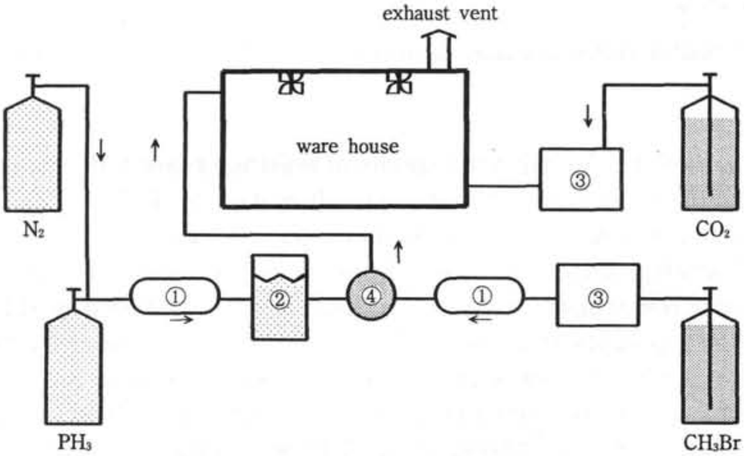

Fig. 2. Diagram of fumigation procedure in commercial warehouse by mixture gas with carbon dioxide, phosphine and methyl bromide. ① mass flow controller ② humidifier ③ vaporizer ④ gas mixing apparatus

Electron beam irradiation (EBI): All stages of pests tested (*T. urticae*, *Pseudococcus comstocki*, *Liriomyza trifolii*, *T. palmi*, *T. tabaci*, *Spodoptera litura*, *Myzus persicae*) were killed or sterilized at 400 Gy (Table 5). No injury was observed on 17 species of cut flowers such as carnation, chrysanthemum, lily, dendrobium, freesia, antherium, etc. (HAYASHI *et al.*, 1998; DOHINO *et al.*, 1998). There are, however, a few quarantine problems that the sterile aphids still have ability to plant virus transmission, and that the EBI has insufficient penetration to high-density packages of cut flowers (DOHINO *et al.*, unpublished data).

Table 5. Susceptibility of pests on cut flowers to electron beam irradiation.

Pests	Stage	100 Gy	200 Gy	400 Gy	600 Gy
Two-spotted spider mite	egg	-	-	○	○
(*Tetranychus urticae*)	larva, nymph	-	-	○	○
	adult	-	×	○	○
Comstock mealybug	egg	-	○	◎	◎
(*Pseudococcus comstocki*)	larva	-	○	○	○
	adult	-	×	○	○
American serpentine leaf miner	egg	◎	◎	-	-
(*Liriomyza trifoli*)	larva	◎	◎	-	-
	pupa	◎	◎	-	-
Thrips	egg	◎	◎	◎	-
(*Thrips palmi*)	larva	○	○	○	-
(*T. tabaci*)	adult	×	×	○	-
Tobacco cutworm	egg	◎	◎	◎	-
(*Spodoptera litura*)	larva	◎	◎	◎	-
Green peach aphid	nymph, adult	-	○	○	○
(*Myzus persicae*)					

◎ ; Dead or inhibition of adult emergence, ○ ; Sterilized, × ; No effect

Timbers

Sulfuryl fluoride(SF): All stages of 7 species of wood borers and bark beetles (*Semanotus japonicus*, *Callidiellium rufipenne*, *Monochamus alternatus*, *Cryphallus fulvus*, *Ips cembrae* and *Sirahoshizo* sp.) were fumigated with SF at 5-7 doses for 24 hours (larval, pupal and adult stages) and 48 hours (egg stage) at 15℃ to evaluate the susceptibility to SF. The egg stage was more resistant than other stages. *C. fulvus* egg was the most resistant stage (LD_{50}: 52.0g/m^3; LD_{95}: 86.5g/m^3) in egg stages of all species. It was estimated that a practical dose of SF for attaining 100% mortality of *C. fulvus* egg would be required for as much as 130g/m^3 or above when the fumigation was conducted for 48 hours at 15℃ (SOMA *et al.*, 1996).

As for ambrosia beetles (*Xyleborus pfeili*, *Xyleborus validus*, *Xylosandrus germanus*, *Platypus calamus* and *Platypus quercivorus*), *X. pfeili*, *X. validus* and *X. germanus* adults, *P. calamus* and *P. quercivorus* larvae and adults were completely killed at 15g/m^3 or below for 24 hours at 15℃. Low mortality ratios were obtained on *X. pfeili* egg (19.0% at 80g/m^3), *X. validus* and *X. germanus* larvae (11.1% at 40g/m^3) for 24 hours at 15℃, respectively, while the mortality for *X. pfeili* were 11.1% at 40g/m^3 and 23.1% at 50g/m^3 for eggs, 98% at 50g/m^3 for larvae, and 100% at 20g/m^3 for adults, respectively for 48 hours at 15℃. It is, therefore, very difficult for *X. pfeili* egg to be estimated applied dose for attaining 100% mortality at 15℃ (MIZOBUCHI *et al.*, 1996). However, SF fumigation for 24 hours at 25℃ showed that all life stages of 13 species were killed completely at 10-50g/m^3, while a complete mortality for *X. pfeili* egg was not obtained at a dose of as much as 100g/m^3 (SOMA *et al.*, 1997). SF fumigation for forest insect pests except for *X. pfeili* could be applied for imported timbers at limited seasons of summer and early autumn in Japan.

PH_3 : *S. japonica*, *C. rufipenne*, *M. alternatus*, *P. perlatus*, *C. fulvus*, *X. pfeili*, *P. quercivorus* and *P. calamus* were fumigated at 1.0 and 2.0g/m^3 of PH_3 for 24 and 48 hours at 15 and 25℃. *S. japonica* and *P. perlatus* eggs were killed completely at 2g/m^3 for 48 hours at 15℃, but larvae and pupae of all species were not killed at 2g/m^3 for 48 hours at 15℃. All stages of *C. fulvus* and *X. pfeili* except for *C. fulvus* larvae were killed at 2g/m^3 for 48 hours at 25℃. It is, therefore, difficult for PH_3 fumigation alone to introduce into a quarantine treatment (OOGITA *et al.*, 1997).

SF+PH_3 : Many species of pests, which were not killed by SF fumigation alone, were completely killed by mixture gas fumigation of SF (50g/m^3) and PH_3 (2.0g/m^3) for 24 hours at 15℃. *X. pfeili* egg , howerver, was not killed under such conditions (SOMA *et al.*, 1998). Mixture gas fumigation of SF and PH_3 may be a possible disinfestation method.

SF+MB: Nine species of pests were fumigated with low dose of MB (5, 10 and 15g/m^3) for 24 hours at 15℃. All stages of the pest except for *M. alternatus* larvae and pupae, *X. pfeili* larvae and *Shirahoshizo rufescens* pupae were completely killed at 15g/m^3. Almost of the forest insect pests could be killed by mixture gas fumigation of MB and SF or PH_3 (OOGITA *et al.*, 1998).

Controversial Points for Alternatives to Methyl Bromide

Quarantine treatment is applied as a practical means to prevent dissemination or spread of injurious quarantine pests across international and intrenational boundaries. As far as the quarantine pests are concerned, it is an essential requirement for the treatment that the effect should always be completed to the maximum extent attainable. In this respect, quarantine treatment differs distinctively from the common control practices in the field in which the aim can be met as long as the pest population is suppressed down and kept below a certain level to avoid economic losses to the crops.

We have made a challenge to find out new alternatives to MB. MB treatment takes rather short time to ensure complete mortalities of various species of quarantine pests. Contrarily, alternative fumigants such as CO_2, PH_3, and SF and these fumigant mixtures have disadvantages of relatively longer exposure time with rather more specified narrow range of pests. In addition, they need higher airtight facilities, higher operation cost and authorization of the local government regulations and registration. Physical treatments also need longer exposure time, costly facilities, higher energy and higher operation cost.

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和 文 摘 要

日本の植物検疫における臭化メチル代替及び削減技術開発の現状

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1997年に植物検疫で消費された臭化メチルは2,070トンであった。このうち，木材で1,255トン（全体の60.6%），穀類で579トン（同27.9%），青果物で221トン（同10.7%）及び切り花で16トン（同0.8%）が使用された。臭化メチル代替法及び削減法の検疫への導入及び開発の現状は以下のとおりである。**穀類**：二酸化炭素くん蒸法が穀類害虫を対象に検疫処理（3温度区4処理基準）に導入された。ボンベに充填された又はリン化アルミニウム錠剤を高速投薬装置で発生させたリン化水素を用いる方法は，リン化アルミニウム剤くん蒸よりも*Sitophilus* spp. の蛹に効果があり，その他の害虫に対しても短い期間で効果が得られた。リン化水素＋二酸化炭素の混合ガスくん蒸は，リン化水素単独くん蒸に比較して殺虫効果が低かった。低温（−18℃）処理では，グラナリアコクゾウムシ（*S. granarius*），ローデシアマメゾウムシ（*C. rodesianus*），スジコナマダラメイガ（*E. cautella*）などが5時間の処理で完全殺虫され，小麦，トウモロコシ，大豆に障害は認められなかった。**果実及び野菜**：低温＋臭化メチルくん蒸の組合せ処理が対米輸出りんごの検疫処理法として導入された。この方法は，最初の低温処理でチョウ目害虫の卵態を殺虫し，続く臭化メチルくん蒸で幼虫態を殺虫するものである。ミカンコミバエ種群（*B. dorsalis* species complex），ウリミバエ（*B. cucurbitae*）が寄生するマンゴウ，パパイヤ，ニガウリなど及びアリモドキゾウムシ（*C. formicarius*），イモゾウムシ（*E. postfasciatus*），サツマイモノメイガ（*O. anastomosalis*）が寄生するサツマイモは，蒸熱処理（43〜48℃）後に沖縄から本州への移動が認められている。りんご及びぶどうのリン化水素くん蒸（$2g/m^3$，16-24時間）において，ナミハダニ（*T. urticae*）が完全に殺虫され，果実にも障害が認められなかった。**切り花**：三種混合ガスくん蒸（臭化メチル$14g/m^3$，リン化水素$3g/m^3$，二酸化炭素5%，20℃，3時間）では，数種の切り花害虫が完全に殺虫され，また，数品種のキク及びラン切り花に障害が認められなかった。電子線照射処理では，ナミハダニ（*T. urticae*），アザミウマ（*T. palmi*），モモアカアブラムシ（*M. persicae*）などが400Gで不妊化あるいは殺虫され，17種の切り花にも障害が認められなかった。**木材**：フッ化スルフリルくん蒸では25℃以上の温度で10数種木材害虫に対し高い殺虫効果が認められた。リン化水素くん蒸（$2g/m^3$，15℃，24時間）は幼虫及び蛹に対する殺虫効果が低かった。フッ化スルフリル（$50g/m^3$）＋リン化水素（$2g/m^3$）の混合ガスくん蒸（15℃，24及び48時間）では，フッ化スルフリル単独くん蒸で殺虫されなかった害虫が高い率で殺虫された。代替くん蒸剤及びこれらの混合使用は，適用範囲が狭いうえ処理時間も長く，くん蒸作業が繁雑になること，物理的処理は長時間の処理が必要であるうえ施設の建設費やランニングコストが高くなるなど問題を抱えている。