Phytotoxic Responses of Citrus Fruit to Fumigation with Ethylene Dibromide

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ABSTRACT

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Commercially packed California citrus fruit fumigated with ethylene dibromide (EDB) at 24 or 32 g/m^3 of storage space for 2 hr at 20 C (30% [v/v] load factor) developed a high incidence of unacceptable rind injury during postfumigation storage (5 C for 3 wk then 20 C for 1 wk). Order of susceptibility to injury by EDB at 32 g/m^3 was navel oranges > Valencia oranges > lemons. With EDB at 12 and 16 g/m^3 the susceptibility order was Valencias > lemons > navel oranges. Rind injury increased with temperature of fumigation (10 < 20 < 30 C). Rind injury decreased (15 > 30 > 58%) with an increase in the load factor (v/v) in the fumigation chamber. Ripe yellow lemons were injured more by EDB fumigation than were less-ripe, silver lemons. More fruit decayed during storage after fumigation at a 15% load factor than at load factors of 30 or 58%. Increasing the EDB dosage from 12 to 32 g/m^3 (30% load factor) did not increase fruit decay.

Additional key words: *Ceratitis capitata*, grapefruit, quarantine, tangelos.

The introduction of various species of tephritid fruit flies into California is a continual threat. The oriental fruit fly, *Dacus dorsalis* Hendel; the melon fly, *D. cucurbitae* Coquillett; and the Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann) are in the Hawaiian Islands. The Medfly also is in Central America. The Mexican fruit fly, *Anastrepha ludens* (Loew), is endemic to Mexico and often crosses over into the Rio Grande Valley in Texas. The Caribbean fruit fly, *A. suspensa* (Loew), is in several Caribbean countries and has been established in Florida since 1965 (33). The Queensland fruit fly, *D. tryoni* (Froggatt), is well established in parts of Australia. Over 18 infestations of the Medfly or the oriental, melon, and (more recently) the Caribbean and Mexican fruit flies, have occurred in California since 1955 (8,13; J. C. Manning, 1977, *unpublished*). Two simultaneous Medfly outbreaks in 1980, one of which became the large 1980–1982 infestation in northern California, resulted in quarantine treatments being required for all California citrus fruit shipped to the important Japanese market. Domestic quarantine treatments also were considered for shipments to select areas in the United States, where the climate would be suitable for Medfly survival.

The only quarantine treatments that have been approved for eradication of fruit flies from citrus fruit (2) are fumigation with ethylene dibromide (EDB) (banned for use on citrus fruit for domestic use but not for export since 1 September 1984 [27]), or cold treatment. Vapor heat treatment is also approved, but only for the Mexican fruit fly (2). During the 1980–1982 Medfly outbreaks in California, EDB fumigation was used almost exclusively because it is quick, and fumigation chambers could be built easily. Fruit also could be fumigated after being loaded on ships (19). Even so, the necessity for EDB fumigation disrupted the marketing of citrus fruit. On the other hand, cold treatments were not an option because approved facilities to treat the large volume of citrus and other fruits and vegetables produced in California were not available, and the cost of building the necessary facilities was prohibitive. Cold treatments also require fruit to be held for long periods before it can be certified as treated for quarantine purposes, which is a disadvantage. For example, required cold exposure of citrus at 0.55 C is 11, 13, 14, or 18 days, respectively, for the Medfly and for Caribbean, Queensland, or Mexican fruit flies (2). At warmer allowable temperatures (up to 2.2 C), exposure times are proportionately longer. Grapefruit and lemons may be damaged (chilling injury) if held for long periods at low temperatures (16,22). However, approved cold treatments may be practical during shipments to distant markets if the journey is long enough for the fruit to be treated during transit.

Fruit fly species vary in susceptibility to dosages of EDB as well as to cold treatments. For instance, Balock (4) found that an initial EDB dosage of 4 g/m^3 was sufficient to kill the melon fly, but 8 g/m^3 was necessary for eradicating the Mediterranean and oriental fruit flies. In Florida, Burditt and von Windeguth (5) found that EDB at 12 g/m^3 effectively eliminated the Caribbean fruit fly infestations in Florida grapefruit treated in semitrailers. These authors (6) estimated, from dosage-mortality curve calculations, that EDB at 6.5–8.0 g/m^3 would be required for quarantine security if the vans of fruit were fumigated in large chambers. Bussel and Kamburov (9) in Israel determined that EDB at 12 g/m^3 was necessary to kill all stages of the Medfly in artificially inoculated oranges and lemons, but that 16 g/m^3 was needed with grapefruit. Rigney and Wild (26) determined that EDB at 24 g/m^3 was necessary for eradication of Queensland fruit flies in infested citrus in Australia. All tests (4–6,26) were for 2 hr exposure periods, and were at 16–26 C, but mostly at 20 C.

Citrus has been commercially fumigated with EDB in Florida, Israel, and Australia and much has been written regarding EDB injury to fruit produced in those areas (1,5–7,9–11,15,24). However, none of the fruit flies mentioned above have become permanently established in California and little is known about EDB fumigation of commercially washed, waxed, and packed citrus grown in various parts of this state.

The tests reported here were conducted cooperatively with the California citrus industry to determine the effect of EDB fumigation on phytotoxic responses and decay of fruit of the common citrus cultivars. Although federal regulations forbid EDB fumigation of fruits and vegetables for domestic consumption, we

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report this work because other countries (including important markets for citrus fruit) still accept treated fruit, domestic fumigation of fruit for foreign consumption is still permitted, and EDB fumigation is approved for emergency use against future fruit fly outbreaks.

MATERIALS AND METHODS

Fruit. Test lots were obtained from commercial packinghouses after the fruit was washed, waxed, graded, sized, and packed. The fruit had been treated with sodium o-phenylphenate (SOPP), added in the foam wash and/or in the waxes, and either thiabendazole (TBZ) or benomyl was incorporated in the waxes. Biphenyl, a volatile fungistat, was impregnated into kraft paper sheets, two of which were added to each box during packing. Biphenyl was used with oranges, lemons, and grapefruit, but not Minneola tangelos. Waxes used were representative of, but did not include, all waxes used by citrus packers in the California-Arizona area. Fruit was packed in standard two-piece fiberboard telescoping boxes which hold approximately 18 kg of fruit. Box size was approximately $41.5 \times 26.5 \times 26$ cm (inside dimensions), with 16 2.5-cm-diameter ventilation holes per box, except that tangelo boxes were 19 rather than 26 cm high.

Fruit were obtained at 22 packinghouses, seven in the Ventura coastal area, 13 in the San Joaquin Valley, and two in the southern interior (Upland-Riverside) citrus producing area. Lemons (cultivar Eureka) (from coastal and southern California) and navel oranges (from the San Joaquin Valley) were tested from January through May, Minneola tangelos (San Joaquin Valley) in April, grapefruit (southern California) in May, and Valencia oranges (San Joaquin Valley) in July and August 1981. A total of 631 boxes of lemons, 423 of navel oranges, 238 of Valencia oranges, 256 of Minneola tangelos and eight of grapefruit were treated. A normal fruit sample consisted of 32 boxes distributed as eight boxes among each of four variables. Lemons averaged 5.4 or 5.7 cm in diameter (165 or 140 fruit per box), oranges were 6.6 or 7.2 cm in diameter (113 or 88 fruit, respectively, per box), Minneola tangelos were approximately 6.5 cm in diameter (120 fruit per box), and grapefruit averaged 9.5 cm in diameter (40 fruit per box).

Fumigation. Fruit was taken directly from packinghouses to the USDA facilities in Fresno either on the day or the day after it was packed, held overnight (16–20 hr) to bring fruit to the fumigation temperature(s) (10, 20, or 30 C), and fumigated the following morning.

Boxes were stacked in the fumigation chambers on a raised, slotted pallet. In tests using a 30% (v/v) load factor, there were seven boxes per layer, three layers high, with three boxes in a fourth layer. Ventilation holes in all boxes were exposed directly to chamber air, with the exception of three boxes in the middle layer in which vent holes faced matching holes in adjacent boxes.

Citrus was fumigated at normal (ambient) atmospheric pressure in 3.15 m^3 gas-tight, temperature-controlled, wood chambers with interior surfaces painted and sealed with three to four coats of an approved epoxy paint. The chambers exceeded the positive-pressure requirements for gas tightness (2).

Calculated amounts of liquid EDB for desired dosages were dispensed into heated (>132 C) vessels in the chambers and volatilized. Each chamber was equipped with a spark-free air circulation fan (600 CFM), which was operated continuously throughout the 2-hr exposure period. Concentrations of EDB gas in the chamber atmospheres were determined at various sampling times during fumigation by using the gas chromatographic procedures developed by Hartsell (31). Standard EDB fumigation was at 20 ± 2 C for 2 hr after the liquid EDB had vaporized and reached its peak concentration. The treatments were followed by a 1-hr aeration period with vents open and fans on, after which the chamber doors were opened for an additional 1 hr of aeration. For most tests, the standard load factor in the chambers was $30 \pm 3\%$ v/v (24 boxes occupying 0.89 m^3), but load factors of 15% (12 boxes) and 58% (46 boxes) also were tested.

Each set of 24 boxes of fruit fumigated at the 30% load factor was comprised of three groups of eight boxes; each group was from one of three different packinghouses. Nonfumigated (control) fruit was held in a fumigation chamber to simulate all conditions of temperature and handling except exposure to EDB.

The EDB dosages chosen were representative of the range of dosages required for control of various tephritid fruit flies (2) and also included a dosage likely to injure fruit, so that we could determine upper dosage limits for EDB fumigation of commercially packed fruit.

After fumigation, the various lots of fruit were stored in controlled-temperature storerooms at 5 ± 1 C for 3 wk, followed by 1 wk at 20 ± 2 C, to approximate marketing and transit conditions.

Inspection. The fumigated fruit samples were inspected weekly during the postfumigation simulated marketing period. Two of the eight boxes that received each test treatment were inspected each week and then discarded. In a few tests that had fewer boxes per variable, the fruits were inspected only once after 4 wk of storage.

Each fruit in the boxes was rated for phytotoxicity caused by EDB, or any injury similar to EDB injury, by trained inspectors from Sunkist Growers, and by the first and second authors. Fruits were classified as either healthy or having slight, moderate, or severe injury. Healthy fruit had no EDB-type symptoms. Slightly injured fruit had a few relatively light EDB-type symptoms that covered less than one-fifth of the surface and probably would not be objectionable to a consumer. Fruit classed as moderate had EDB-type injury covering no more than half the fruit surface and probably would not be acceptable to a consumer. Severely injured fruit had well defined, heavily developed EDB-type damage over a large portion of the fruit surface, making it completely unacceptable to the consumer. The numbers of fruit that decayed also were counted and the causal fungi were identified.

Most of the Valencia oranges that were sampled developed mild to severe stem-end rind breakdown (SERB), which is a common physiological disorder that is not present when citrus fruits are packed but develops during storage. Symptoms are similar to EDB injury and were not easily differentiated from EDB injury during inspections. When SERB was present, the amount of injury that developed on control fruit was subtracted from the total EDB-SERB injury on fumigated fruit. Data shown in this report are adjusted to eliminate SERB injury.

RESULTS AND DISCUSSION

Sorption. Averaged time-concentration curves for EDB sorption by chamber surfaces, citrus boxes, and fruit, fumigated with EDB at 32 g/m^3, are shown in Fig. 1. When filled boxes were fumigated for 2 hr, approximately 16% of the initial EDB remained in the chamber atmosphere. Fumigation of an empty chamber showed that 34% of the EDB was sorbed by chamber surfaces; if boxes were included, 33% was sorbed by the empty fiberboard boxes; and if fruit was included, 17% was sorbed by the fruit. Sorption by the fruit was approximately the same, in the two tests that we conducted, whether the commodity was navel oranges or lemons. EDB sorbed by the boxes and chamber reduces the amount of EDB available for control of insects or that may injure fruit. EDB sorbed by boxes and fruit is later desorbed into storerooms or transit vehicles and therefore must be monitored to assure worker safety.

EDB concentrations in chamber atmospheres also varied with the load factor (Fig. 2). Initial atmospheric concentrations of EDB were not as high in the chambers with larger loads as in those with smaller loads. One-half hour after fumigation began (peak EDB concentration) approximately 48% of the initial EDB dosage remained in chambers with 15% loads, while 33 and 17% remained in chambers with 30 and 58% loads, respectively. After 2 hr, approximately 28% EDB remained in chambers with 15% loads, while 16 and 8% remained when the loads were 30 and 58%, respectively.

Average EDB concentrations in chambers during fumigation with EDB at 12, 16, and 32 g/m^3, 30% load capacity, are shown in Fig. 3. EDB was rapidly sorbed from the atmospheres, dropping by approximately 66% of the initial concentration in the first 30 min, 78% in the first hour, and 85% after 2 hr. The percentages of EDB sorbed from the atmospheres containing EDB at 12, 16, and 32

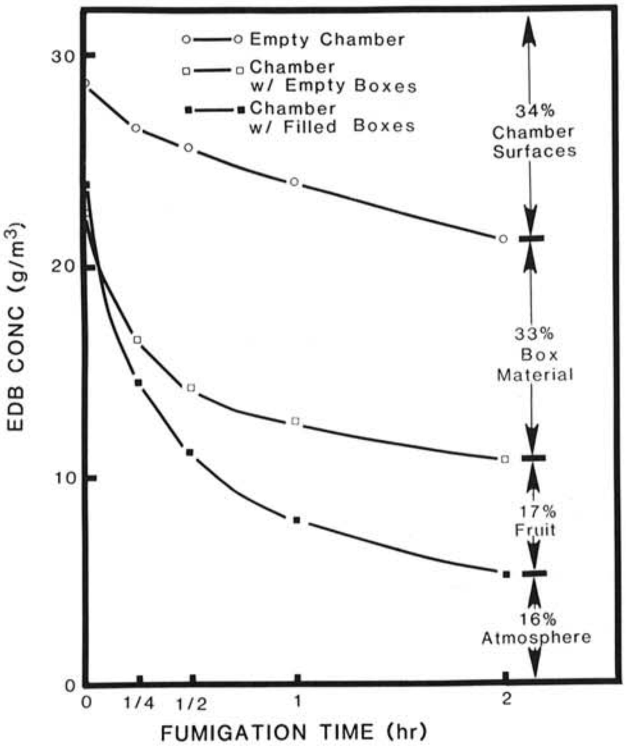

Fig. 1. Ethylene dibromide (EDB) content of atmospheres in similar 3.15-m^3 wooden chambers either empty, loaded with 24 empty citrus boxes, or loaded with 24 fruit-filled citrus boxes (load factor 30 ± 3%, v/v). Means of two tests, one each of lemons and navel oranges, fumigated with EDB at 32 g/m^3 and maintained at 20 ± 2 C for 2 hr.

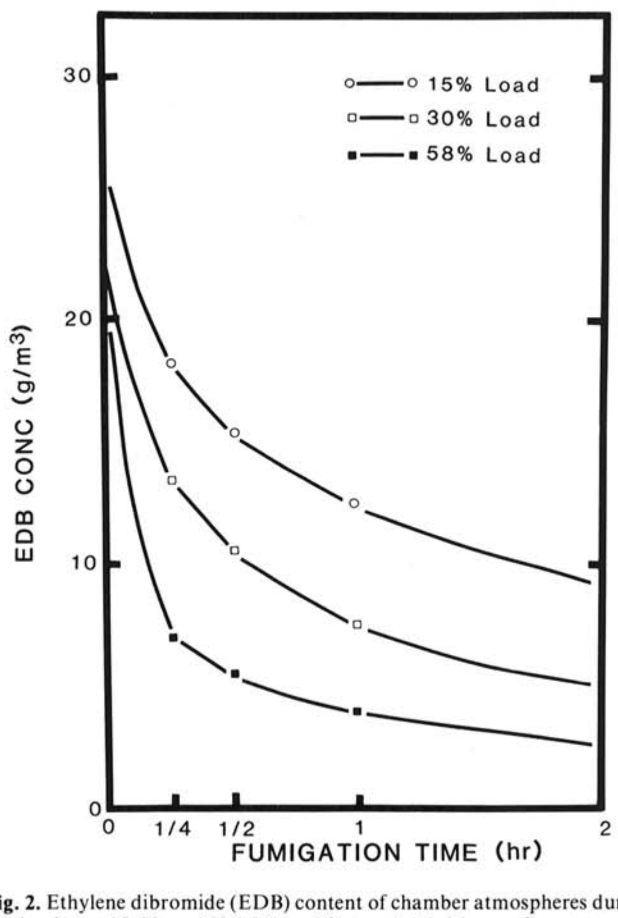

Fig. 2. Ethylene dibromide (EDB) content of chamber atmospheres during fumigation at 15, 30, and 58 ± 3% load factors (v/v). Means of two tests, one each of lemons and navel oranges, fumigated with EDB at 32 g/m^3 at 20 ± 2 C for 2 hr, in 3.15-m^3 wood chambers.

g/m^3 was markedly consistent at all three dosages. However, there was more EDB available throughout the fumigation at the higher dosages than at lower dosages (Fig. 3).

EDB concentrations in atmospheres inside citrus boxes are shown in Fig. 4. Boxes stacked with ventilation holes directly exposed to the chamber atmosphere had only slightly more EDB inside than boxes stacked with ventilation holes covered by other boxes. After 2 hr of fumigation, EDB concentrations inside the

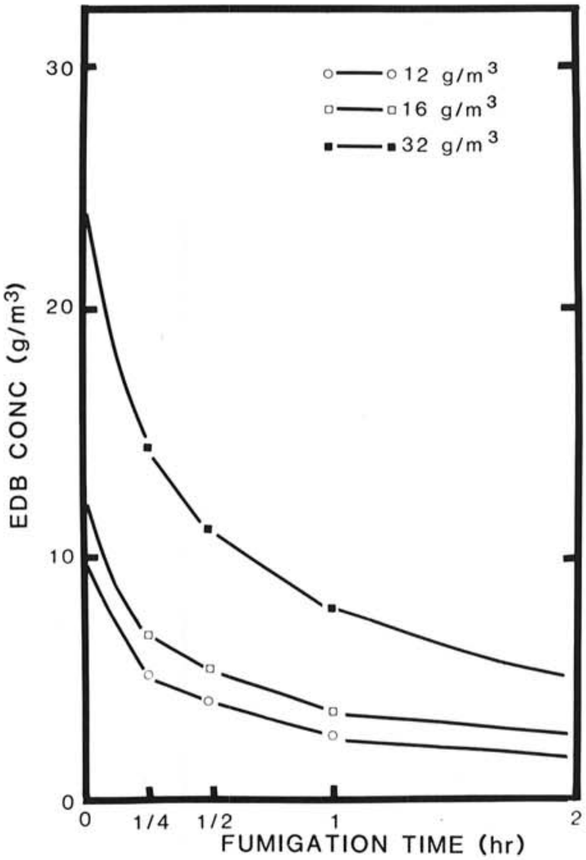

Fig. 3. Ethylene dibromide (EDB) levels in fumigation chamber atmospheres during treatment with EDB at 12, 16, and 32 g/m^3. Means of two tests, one each of lemons and navel oranges, 20 ± 2 C, 30 ± 3% load factor (v/v), for 2 hr in 3.15-m^3 wood chambers.

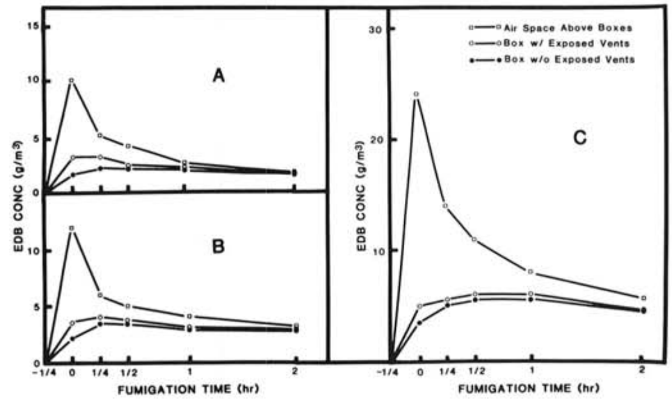

Fig. 4. Ethylene dibromide (EDB) levels in citrus boxes and fumigation chamber atmospheres during treatment with EDB at **A,** 12; **B,** 16; and **C,** 32 g/m^3. Means of two tests, one each of lemons and navel oranges, 20 ± 2 C, 30 ± 3% load factor (v/v) for 2 hr, in 3.15-m^3 wood chambers. Boxes with exposed ventilation holes were in the bottom layer (side and bottom vents exposed). Boxes without exposed vents were in the second layer and had all side, top, and bottom vents facing similar vents in adjacent boxes.

boxes differed only slightly from EDB concentrations in the air outside the boxes (Fig. 4A–C). Consequently, box location was not further considered when evaluating fruit injury or decay.

Phytotoxicity. *Symptoms.* Symptoms of EDB injury sometimes developed as early as 5 days after fumigation on fruit stored at 5 C, but the injury usually developed more slowly, requiring 10–14 days or longer. Symptoms intensified, and more fruit was affected as time in storage increased. Severity occasionally abated slightly when fruits were moved to 20 C after 4 wk. Examples of this reduction were observed in Valencia oranges (Fig. 5) and lemons (Figs. 6 and 7).

Two types of EDB injury were observed on all citrus cultivars in these tests. One form of injury was a surface pitting on the peel, which started as 1- to 3-mm-sized, light-tan discolored spots or freckles on the peel surface. The spots often became dark tan or brown and the peel below the spots became depressed, forming shallow pits. These pits often became enlarged, involving oil glands and surrounding tissue. The other form of injury was a general discoloration of large areas on the peel surface of several centimeters or more. Those discolored areas usually intensified in color and texture, becoming dark brown, tough, leathery, and slightly depressed. This latter injury was perhaps slightly more common on oranges and Minneola tangelos than on lemons or grapefruit. These symptoms are similar to the EDB injury reported by Lindgren and Sinclair (20) in California and Grierson and Haywood (15) in Florida.

Response to EDB dosage. The response of fruit to EDB is affected by dosage, load factor, exposure time, fumigation temperature, and sorption characteristics of the shipping boxes and of the fumitorium. EDB injury is also influenced by the storage temperature of the fruit after fumigation. Lindgren and Sinclair (20) found that fruit stored at 12 C did not develop injury as quickly as that stored at room temperatures, although some fruit developed severe injury after 5–6 wk at room temperature. In our tests with various EDB dosages, we kept factors affecting sorption as close to commercial conditions and as uniform as possible from test to test so that differences in fruit responses could be attributed only to EDB dosages and fruit differences.

Citrus fruits were noticeably injured in about half of our tests when they were fumigated with EDB at 12 g/m^3, 30% load factor, for 2 hr at 20 ± 2 C, and then placed in postfumigation storage at 5 ± 1 C. Slightly more fruit were injured with EDB at 16 g/m^3 than at 12 g/m^3 (Fig. 5). With EDB at 24 and 32 g/m^3, nearly all fruit was injured, much of it severely. The injury that occurred to Minneola tangelo and grapefruit with EDB at 8 and 12 g/m^3 was usually slight or moderate, with only occasional severe injury. Increasing the load factor (see below) reduced injury to minor levels. Injury was so consistent and severe following exposure to EDB at 24 and

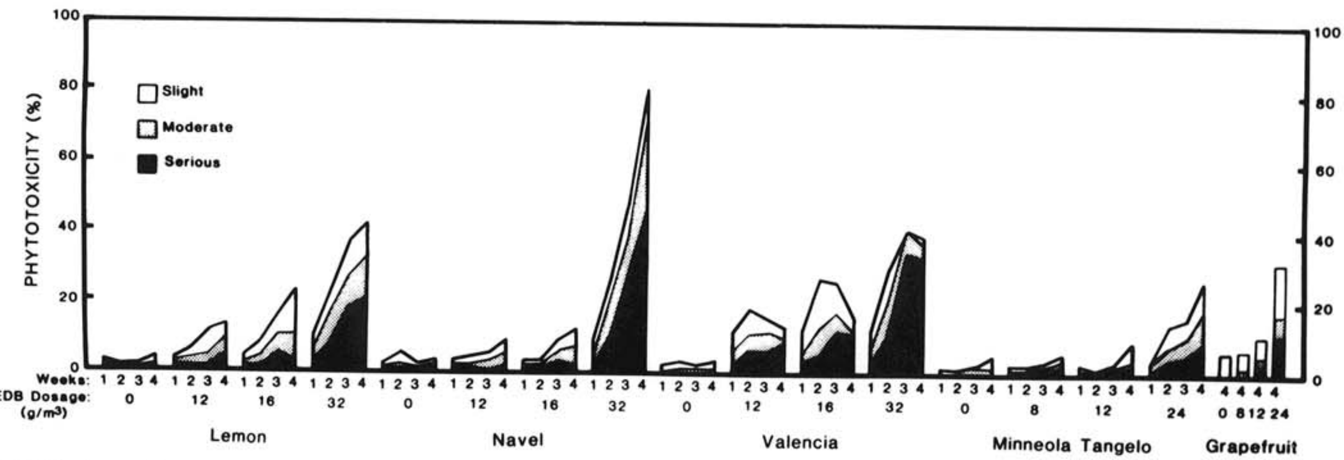

Fig. 5. Rind injury (phytotoxicity) of citrus fruit at weekly intervals during storage following fumigation with several dosages of ethylene dibromide (EDB) at 20 ± 2 C, 30 ± 3% load factor (v/v), for 2 hr. Postfumigation storage for 3 wk at 5 C and plus 1 wk at 20 C. See text for definitions of slight, moderate and serious ratings. Each data point on the graph is an average of: lemons—10 tests (fruit samples), 3,100 fruit in 20 boxes; navel oranges—five tests, 1,030 fruit in 10 boxes; Valencia oranges—three tests, 628 fruit in six boxes; Minneola tangelos—two tests, 720 fruits in six boxes; grapefruit—one test, 80 fruit in two boxes. Sample sizes of 2,500, 1,100, 625, 400, and 100 provide reliability of ±2, 3, 4, 5, and 10%, respectively, at $P = 0.05$ (3).

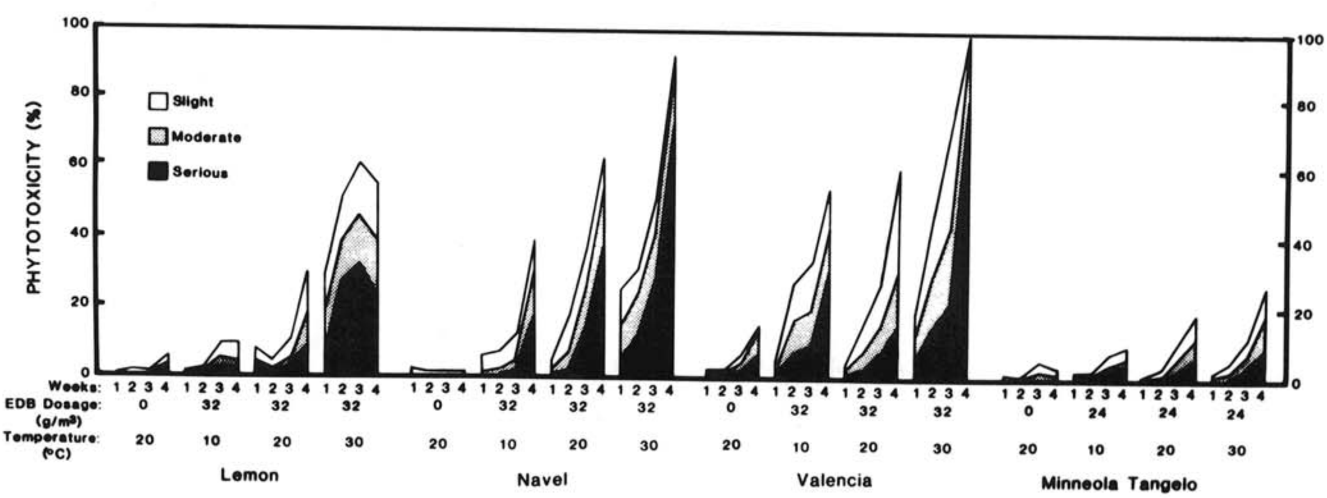

Fig. 6. Rind injury (phytotoxicity) of citrus fruit fumigated at 10, 20, and 30 C with ethylene dibromide (EDB) at 24 or 32 g/m^3, 30 ± 3% load factor (v/v). Postfumigation storage, rating systems, and statistical reliability are as in Fig. 5. Each data point on the graph is an average of: lemons—three tests, 840 fruit in six boxes; navel oranges—two tests, 452 fruit in four boxes; Valencia oranges—two tests, 452 fruit in four boxes; and Minneola tangelos—one test, 630 fruit in seven boxes.

32 g/m^3 that these treatments could not be used safely, suggesting that rates no more than 16 g/m^3 should be used. Our results supplement earlier findings by Lindgren and Sinclair (20,21) and Eaks and Ludi (14), which suggest that the appearance of nonwaxed orchard-run, or waxed but not packed, fruit would not be impaired by commercial fumigation with EDB at 16 g/m^3.

Different samples of fruit varied in the incidence and severity of injury, which may be due to differences in fruit from different areas or grown with different cultural practices, or to variation in maturity among fruits, the hold time after harvest, or the presence of TBZ in some waxes but not in others. TBZ has been reported (10) to reduce severity and incidence of EDB injury. TBZ was used on many of the fruit samples that we tested, while benomyl was used on the remainder. TBZ and benomyl are used interchangeably in waxes depending upon fungicide resistance problems (18) and fungicide residues allowed by different foreign markets. Factors such as maturity (14,25,29,30), time of storage before fumigation (12,14), and root stock (25) may also be involved.

Fumigation temperature. The most important environmental factor influencing the action of fumigants on insects is temperature. Physical and chemical properties of fumigants, and complex metabolic responses of commodities and insects are altered by temperature (23). At low temperatures (about 5 C), absorption of the fumigant on exposed surfaces of boxes, the commodity and the fumigation chamber reduces the effective concentration of fumigant available to kill the insect, and also affects potential for injury to the commodity (23). At higher temperatures there is less adsorption onto surfaces, and proportionally more fumigant is available to kill insects. More EDB is required at low temperature than at high temperature to provide the same insect mortality.

Citrus fruit fumigated with EDB at 24 or 32 g/m^3 (30% load) were usually injured more severely when fumigated at 20 C than at 10 C (Fig. 6), but differences in percentages of fruits injured were not statistically significant. Even more fruits were injured and the injury was more severe when fumigation was done at 30 C, rather than at the lower temperatures.

Temperatures of citrus fruit vary seasonally and may be as low as 5–10 C in an orchard in winter or as high as 25–30 C in summer. At packinghouses, pulp temperatures are modified considerably, but still vary according to the season. Most fruit is cooled to preserve quality during storage. Before fruit is loaded into transit vehicles it is usually cooled to recommended shipping temperatures because most vehicles cannot properly cool warm fruit after it is loaded. Therefore, fruit at packinghouses may be at various temperatures, ranging from field temperatures to storage and shipping temperatures. It is obvious that batches of fruit at different temperatures should not be mixed in a fumigation chamber because some fruit may be injured by EDB if the temperature is too high, and insects may not be killed if temperatures are too low. Preconditioning all the fruit to a selected fumigation temperature would eliminate this problem.

Load factor. Injury to lemons and navel oranges decreased as the load factor increased (Fig. 8). More fruit were injured and the injury was more severe in the 15% than in the 30% load. The least injury occurred with the 58% load. Because we used a high EDB dosage (32 g/m^3) to compare the effects of load factor, injury was very severe. The importance of matching load levels with EDB dosages is readily seen. The high sorptive capacity of citrus fruit and fiberboard boxes (Fig. 1) can significantly alter the concentration of EDB in the fumitorium atmosphere. EDB concentrations must be maintained at levels sufficient to kill target insects, yet not injure fruit. Lindgren and Sinclair (20,28) showed the relationship between load (navel oranges in wood picking boxes) and EDB concentration in the gas phase during fumigation with EDB at 8 g/m^3, a dosage that did not injure fruit in their tests.

Maturity. Yellow, tree-ripe lemons were more severely injured at all three EDB dosages tested than were "silver" lemons (Fig. 7). These samples of fruit at different maturities were obtained at the same packinghouse on the same day, were the same size, received identical wax and fungicide treatments, and were fumigated together in the same chambers. The "silvers" were picked green, then stored or "conditioned" at the packinghouse for several weeks at 12–15 C until the silver color developed, while the "yellows" attained their color on the tree and were not stored. The yellow lemons were injured more at the low, usually nonphytotoxic, rate (12 g/m^3) than were the silver lemons. Both samples were injured considerably by EDB at 16 and 32 g/m^3, but more "yellows" were injured severely. Eaks and Ludi (14) observed that freshly harvested lemons appeared to be more sensitive to EDB fumigation than fruit previously stored. Possibly, the "silver" lemons had less injury than the "yellow" fruit because the "silvers" were stored (cured) for several weeks and the "yellows" for only a few days. Coggiola and Huelin (12) reported EDB loss from fumigated oranges increased with time of storage before fumigation. If there is a relationship between EDB residues in fruit and injury, as reported by Chalutz et al (11), the effect of prefumigation storage time may be confused with the effect of maturity. Rigney and Blanch (25) also found that maturity and root stock were important factors in determining susceptibility of early season citrus to injury.

Fruit variability and wax effect. The severity of injury that developed on fruit following EDB fumigation varied considerably among samples. Some samples were injured only slightly while others were severely injured by EDB and/or biphenyl. Also some of the control samples developed light-tan, discolored areas

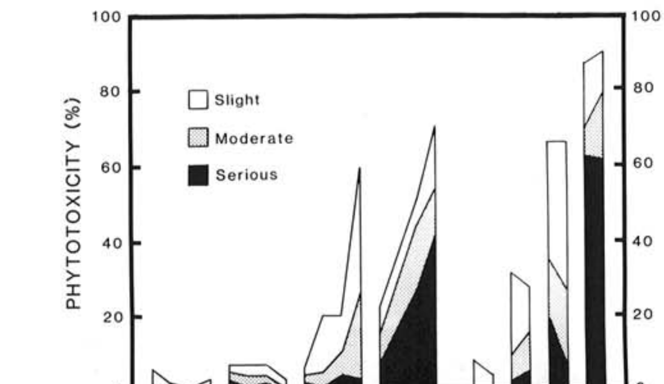

Fig. 7. Rind injury (phytotoxicity) of "silver" and "yellow" lemons developing during storage after fumigation with ethylene dibromide at 0, 12, 16, and 32 g/m^3 at 20 ± 2 C for 2 hr. Postfumigation storage, rating systems, and statistical requirements are as in Fig. 5. Each data point on the graph is an average of 330 fruit in two boxes, one test.

Fig. 8. Rind injury (phytotoxicity) of lemons and navel oranges following fumigation in fumigation chambers at 0, 15, 30, and 58 ± 3% load factors v/v with ethylene dibromide (EDB) at 32 g/m^3 at 20 ± 2 C for 2 hr. Each data point on the graph is an average of: lemons—three tests, 940 fruit in six boxes; and navel oranges—two tests, 452 fruit in four boxes. Postfumigation storage, rating systems, and statistical requirements are as in Fig. 5.

suggestive of early stages of EDB injury. This injury could not be easily differentiated from early EDB injury before pitting developed, and was probably caused by biphenyl. Some of the test-to-test variability among samples of fruit might be attributed to the fungicide TBZ, which was used on some fruit samples but not on others. TBZ has been reported to reduce EDB injury (10) and TBZ and benomyl to reduce chilling injury (32) in citrus. Others also have noted variable phytotoxic responses of citrus to fumigation with EDB (9,20).

Some waxes used on citrus appeared to have a predisposing influence on fruit susceptibility to EDB injury. However, because of the random selection of fruit from various packinghouses, the random use of different waxes, with and without TBZ, and the variable response of different fruit samples to EDB injury, it was not possible to accurately rate individual waxes for compatibility with EDB. Eaks and Ludi (14) reported that application of a wax on washed fruit protected it from EDB injury. Before fruit are fumigated in commercial situations, the wax formulators should be consulted to be sure that their waxes are compatible with EDB.

Fruit waxed with the three solvent-based and most of the nine water-based waxes were not excessively injured by EDB, at fumigation conditions of 20 C temperature, 30% load factor, and dosages of EDB at 8, 12, or 16 g/m^3. Further tests would be needed to precisely evaluate specific waxes for compatibility with EDB.

Biphenyl. Several tests to determine whether biphenyl had a stimulatory or inhibitory effect on EDB injury to citrus were inconclusive. Biphenyl is used to suppress sporulation of the blue and green molds, *Penicillium italicum* and *P. digitatum*, and reduces fruit soilage and decay (17), but occasionally causes a mild to serious rind discoloration (22). In about half of our tests, there was more peel injury to EDB-fumigated fruit when biphenyl sheets were included in the boxes, but in the other tests there was more injury in boxes without the biphenyl. Norman et al (24) found that EDB injury to Florida grapefruit was aggravated if biphenyl-impregnated pads were used, and injury usually occurred where the fruit contacted the biphenyl sheet, which we also observed. McCornack (22) also reported that biphenyl increased rind injury caused by chilling.

Decay. Percentages of fruit that had decayed after 4 wk of postfumigation storage are shown in Table 1. EDB at dosages up to 32 g/m^3 did not significantly increase decay in the 22 fruit samples tested at 20 C, 30% load factor. Fumigation temperature also did not consistently influence subsequent decay, although there was a trend toward more decay in fruit fumigated at the higher temperatures. Load volume during fumigation at specified EDB dosages had a pronounced effect on postfumigation decay and there was significantly ($P = 0.05$) more decay in fruit fumigated at the 15% than at the 30 or 58% load levels. There also was more decay in fruit treated at the 30% than at the 58% load level or in untreated fruit, but the differences were not significant. Biphenyl reduced decay whether fruit was fumigated or not. Norman et al (24) found that biphenyl significantly reduced decay of fumigated Florida grapefruit, but not of nonfumigated fruit. Biphenyl is generally used in California and Arizona for sporulation and spoilage control, but it also reduces losses from Penicillium decay of citrus (17).

EDB did not selectively increase decay caused by any particular fungus. Most of the decay in our tests was due to two *Penicillium*

TABLE 1. Decay of citrus fruit after 3 wk of storage at 5 C followed by 1 wk at 20 C as influenced by ethylene dibromide (EDB) fumigation dosage, temperature, load factor, and presence or absence of biphenyl-treated pads

EDB dosage (g/m^3)	Fumigation temperature (C)	Load factor (%, v/v)	Biphenyl presence (±)	Decay (%)				
				Lemon	Navel	Valencia	Tangelo/ grapefruit	Avg.
0	20	30	+	2.6 a[m,n]	1.9 a[o]	0.8 a[p]	5.2 a[q]	2.5 a[r]
8–12[s]	20	30	+	4.9 a	2.6 a	0.1 a	3.8 a	3.4 a
12–16	20	30	+	2.4 a	2.2 a	0.6 a	5.8 a	2.6 a
24–32	20	30	+	3.7 a	3.2 a	0.0 a	11.3 a	4.1 a
0	20	30	+	4.6 a[p]	5.8 a[p]	0.4 a[p]	6.5[t]	3.9 a[u]
24–32[v]	10	30	+	5.2 a	8.1 a	1.5 a	7.1	5.2 a
24–32	20	30	+	6.9 a	8.4 a	2.7 a	7.0	6.1 a
24–32	30	30	+	4.8 a	10.5 a	1.6 a	9.0	6.0 a
0	20	30	+	1.1 a[p]	3.1 a[p]		2.7[t]	2.2 a[o]
16–32[w]	20	15	+	1.8 a	35.6 b		6.7	16.9 b
16–32	20	30	+	1.4 a	5.2 a		4.2	3.4 a
16–32	20	58	+	1.1 a	3.2 a		2.0	2.1 a
0	20	30	−	4.1 b[p] 4.0 a[p]	14.5 bc[p]			7.5 bc[n]
0	20	30	+	1.1 a 2.9 a	7.2 a			3.7 a
12–32–16[x]	20	30	−	3.4 ab 8.6 b	17.3 c			9.8 c
12–32–16	20	30	+	1.7 ab 4.8 a	12.0 b			6.2 ab
Comparison of group means[y]							LSD ($P = 0.05$) =	2.84
− Biphenyl ± EDB								8.7[z]
+ Biphenyl ± EDB								5.0

[m]Means followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple range test.
[n]Nine tests.
[o]Seven tests.
[p]Three tests.
[q]Two tangelo tests and one grapefruit test.
[r]Average of 22 tests.
[s]Minneola tangelos and grapefruit treated with EDB at 8, 12, and 24 g/m^3; lemons and navel and Valencia oranges were treated at 12, 16, and 32 g/m^3.
[t]One test.
[u]Average of 10 tests.
[v]Minneola tangelos treated with EDB at 24 g/m^3; lemons and navel and Valencia oranges were treated at 32 g/m^3.
[w]Minneola tangelos treated with EDB at 16 g/m^3; lemons and navel oranges were treated at 32 g/m^3.
[x]EDB dosages were 12 and 32 g/m^3 for the two groups of lemons, respectively, and 16 g/m^3 for the navel oranges.
[y]The "−" indicates "without biphenyl treatment," the "+" indicates "with biphenyl treatment." The "±" indicates that both EDB-treated and EDB-nontreated groups were merged to obtain the biphenyl treatments group means.
[z]Group means differ at $P = 0.11$.

spp. Occasional fruit were affected by black rot (caused by *Alternaria citri*), brown rot (caused by *Phytophthora* spp.), or sour rot (caused by *Geotrichum candidum*).

Cultivar differences. We did not directly compare various citrus cultivars for sensitivity to EDB rind injury or to decay in our tests. Our fruit samples were obtained at many packinghouses in different growing areas, at different times, and wax and fungicide applications were not the same on all cultivar samples. It is possible that the presence or absence of TBZ (10), or use of certain waxes, could have had more influence on phytotoxicity than cultivar differences. Fruit maturity (25) and holding time in storage before fumigation (12) also may have influenced injury.

However, we found more rind injury to navel oranges, fumigated at the 32 g/m^3 EDB dose, at 20 C and 30% load factor, after 3 and 4 wk of storage, than similarly treated lemons and Valencia oranges (Figs. 5 and 6). At lower EDB dosages (12 and 16 g/m^3) navel oranges were injured less than lemons or Valencias. At 30 C Valencia and navel orange rind was injured severely at the 32 g/m^3 EDB dosage while lemon rind was injured only two thirds as much (Fig. 5). At all three load volumes tested, navel oranges were injured more severely with EDB at 32 g/m^3 than were lemons (Fig. 8). Grapefruit and Minneola tangelos were not injured as severely as lemons and oranges. However, the former were treated with EDB at 24 rather than 32 g/m^3 and at 12 rather than 16 g/m^3. The Minneola tangelos were not packed with biphenyl inserts in the boxes, which may have had some effect on their lesser EDB injury (24).

Lindgren and Sinclair (20) in tests with unwashed, nonwaxed, orchard-run citrus fumigated in open wood boxes at 27 C found that the navel oranges "in most instances" were injured more by EDB, ethylene chlorobromide, and methyl bromide than were Valencia oranges, grapefruit, or lemons. In their tests, citrus fruits were injured only slightly by EDB at 16 g/m^3, but were severely injured at 32 and 48 g/m^3. Eaks and Ludi (14), also in California, found button deterioration on Valencia and navel oranges but not on lemons with no other fruit injury at high EDB dosages (24 and 32 g/m^3). In Israel, Chalutz et al (11) found that susceptibility to peel injury from EDB fumigation was greatest in Marsh grapefruit, followed by Shamouti and Valencia oranges.

Cultivar differences in EDB-influenced sensitivity to decay were not apparent in our tests (Table 1).

CONCLUSION

Dosages of EDB required for quarantine treatment of citrus fruit for the Medfly and the Caribbean and Mexican fruit flies vary from 8 g/m^3 at 21 C or above, with a 25% or less fruit load in the fumigation chamber, to 16 g/m^3 at 10–15 C and a 50–80% load factor (2). Our tests showed citrus fruits were often noticeably but not severely injured when fumigated with EDB at a 12 g/m^3, 30% load factor. More fruit were injured, more severely, and more often by fumigation with EDB at 16 g/m^3. The dosages of EDB required for quarantine treatments for fruit flies approach the dosages at which EDB causes serious fruit phytotoxicity. Only by careful attention to detail during fumigation will unacceptable fruit injury in commercial shipments be prevented. Sorption characteristics of EDB may vary depending upon: materials used to construct chambers; type, size, and venting of fiberboard or wood boxes; the cultivar being fumigated; temperature during fumigation; moisture content of the commodity; load factor; air circulation rates; and patterns in the chamber and through the load during fumigation and during aeration following fumigation (23,29). Therefore, citrus fruit fumigated in chambers or boxes with sorption characteristics different from those used in our tests will not have the same response as the fruit in our tests.

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