Discussion and Summary

Research by scientists of the Agricultural Research Service, United States Department of Agriculture, has demonstrated that ethylene dibromide is effective as a fumigant against immature stages of the Caribbean fruit fly at the conditions tested. When grapefruit infested with eggs and larvae of this species were fumigated in cardboard shipping cartons in semi-trailer vans and in a conventional fumigation chamber according to the schedules used by the USDA Animal and Plant Health Inspection Service for fruit exposed to infestation by *Anastrepha* spp., no Caribbean fruit fly eggs or larvae survived. During the past shipping season there were some reports of grapefruit injury following fumigation with ethylene dibromide, apparently due to cooling fruit or inadequate ventilation after fumigation (4).

Officials of the Japanese Ministry of Agriculture and Forestry accepted data developed at our laboratory and approved use of semi-trailer vans as fumigation chambers for treatment of grapefruit being shipped to Japan. During the period from February 10, 1975 to May 5, 1975 the Florida citrus industry shipped 5,273,000 cartons of fumigated grapefruit to Japan. Industry data show that this fruit was valued at over $15 million.

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MINIMIZING HAZARDS FROM IN-TRUCK ETHYLENE DIBROMIDE FUMIGATION OF CARTON-PACKED CITRUS FRUIT[1]

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Abstract. **A program of in-truck fumigation of carton-packed citrus (almost entirely grapefruit) using ethylene dibromide (EDB) was necessitated by the discovery of Caribbean fruit fly (Anastrepha suspensa Loew) larvae in grapefruit exported to Japan in May, 1974. Experiments utilized an existing truck fumigation chamber; observations were also obtained from commercial loads which had been fumigated using the truck body as a fumigation chamber. Where epidermal injury (EDB burn) did occur, the injury was attributable to conditions before or after fumigation, not to the actual fumigation process. Precooling too soon after fumigation invited injury. The usual cause of injury was inadequate ventilation immediately after conclusion of fumigation. When fumigation injury occurred, it tended to be aggravated if diphenyl pads were used.**

Larvae of the Caribbean fruit fly, *Anastrepha suspensa* Loew (Caribfly), were found in a shipment of fruit to Japan in May, 1974. The Japanese Ministry of Agriculture embargoed Florida fruit until suitable Caribfly control measures could be agreed upon between them and the U.S. Depart-

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ment of Agriculture. Since grapefruit exports had amounted to ca. $20,000,000 that year, intensive efforts were started by both State and Federal agencies to produce a workable solution. All larval mortality studies, and many other aspects were conducted by the U.S. Department of Agriculture and are reported elsewhere (1). The agreed upon method involved fumigation of packed fruit, almost exclusively grapefruit, although a few oranges were also fumigated. Florida had extensive experience in fumigation of grove run fruit (3), but experience with fumigation of packed fruit had been limited to 5 years operation of 3 single-truck fumigation chambers in Gainesville. These were operated on an agreement between the State Departments of Agriculture for Florida and California. Neither funds nor time to build the additional 20 chambers necessary for fumigating a shipload of grapefruit at a time were available. The Florida Division of Plant Industry (DPI) therefore designed a system for using truck bodies as fumigation chambers.

About this time, reports were received of extensive fumigation injury to fruit fumigated for shipment to California. Reports from commercial operators indicated that this peel injury might be associated with: prior precooling, the presence of diphenyl pads, inadequate ventilation after fumigation, or some combination of these. Cooperative experiments were set up between DPI and the Agricultural Research and Education Center, Lake Alfred (AREC, LA) to find the cause of this damage, which occurred even though methods had not apparently varied since the previous year. The Florida Division of Fruit & Vegetable Inspection (DFVI) in Winter Haven carried out the residue analyses reported here.

Materials and Methods

Experiments on fumigation injury. The 1973-74 citrus season extended far longer than normal. It is unusual for Florida grapefruit to be shipped between mid-June and mid-September. In August, 1974, the last grapefruit from the Indian River district were shipped only 2 weeks before the first shipments of the 1974-75 season from the new South Florida growing district. Thus, the reported EDB injury to summer grapefruit was on very late or very early crops, both picked from trees in full flush of growth. The experiments were conducted on late (1973-74) grapefruit to obtain data for immediate application to the very early shipments of the new 1974-75 crop being fumigated in the Gainesville chambers for shipment to California.

Two experiments were involved. The first was, in part, an immediate response to a report that EDB injury was particularly prevalent where grapefruit were in contact with diphenyl pads. (This was particularly serious since diphenyl is the only fungicide currently permitted on exports to Japan).

Thirty 4/5 bu cartons were diverted from a commercial shipment on July 2, 1974. Fifteen cartons of grapefruit were placed in a 50°F (10°C) cold room at the University overnight. Next morning, this fruit was fumigated with a commercial truckload undergoing routine fumigation. The precooled grapefruit were at 62°F (16.7°C) and sweating profusely, non-precooled fruit were at 80°F (26.7°C). Air temp in the chamber was 83°F (28.3°C); fumigation was for 2 hr using 10 oz of EDB/1,000 ft^3 (10 g/m^3). After fumigation, 5 cartons of each lot (precooled and non-precooled) were removed to an airconditioned office and observed and tasted for a period of 2 weeks. The remaining 20 cartons were sent to AREC, LA for simulated ocean shipment. These 20 cartons were transferred to a pick-up truck immediately upon removal from the fumigation chamber and promptly covered with black polyethylene film. On arrival ca. 3 hr later at AREC, they were promptly transferred to 50°F (10°C) storage and again covered with a sheet of 1.5 mil polypropylene film. This was not sealed, but just draped over the cartons to give conditions simulating those in a ship's hold. Within hours, condensed moisture built up on the inside of the film. Cartons were left undisturbed for 30 days to simulate a sea voyage to Japan. All fruit were then removed for examination.

The second experiment was more elaborate. The experimental design (Table 1) was chosen to separate the effects on epidermal injury and decay of: diphenyl pads; prior precooling; immediate postfumigation refrigeration; postfumigation ventilation; and possible interactions between these factors. For this experiment, 108 packed cartons were diverted from a commercial shipment of *very* mature Indian River 'Marsh' seedless grapefruit, packed with diphenyl pads. These pads were removed from 54 cartons immediately on arrival at Gainesville on August 14. The cold storage at Lake Alfred was not available, so the 50°F (10°C) storage at the University of Florida, Fruit Crops Dept. was used for both precooling and simulated refrigerated transit. After 30 days "in transit," all 108 cartons were trucked to AREC, LA for examination. This 30 day "transit" period is longer than the normal voyage from Tampa to Tokyo. However, it approximates the total time in a ship's hold, including a period in harbor awaiting inspection and other delays such as have been common in the 1974-75 season. Statistical analysis of the resulting data was by analysis of variance (AOV) after arcsin transformation (4). AOV's had to be obtained by least squares because of the loss of one treatment due to excessive decay causing collapse of the cartons.

EDB residue analyses were done on fruit other than those in these two experiments, usually being taken from commercial shipments as noted.

In-truck fumigation units. In order to fumigate truckloads without constructing fumigation chambers, the unit shown in Fig. 1 was designed and a prototype model built by the Blizzard Fan and Blower Co., Miami. It has a 3 HP motor and a fan delivering 6,000 CFM at zero static pressure. Truck bodies were tested by sealing and pressurized with a small vacuum cleaner-type air pump, the pressure being measured on a manometer. When trucks failed to meet USDA Plant Pest Control specifications (5), they were checked for leaks by letting off a smoke bomb[2] inside while again applying air pressure. Where necessary, trucks were sealed with duct tape and caulking. Rear doors were a problem, and were sealed by caulking aluminum channel around the whole opening into which a 6 mil polyethylene sheet was sealed with a plastic strip forced into the aluminum channel. Air vent doors at the front and rear were covered with mesh screening so the trucks could have them open for postfumigation ventilation without risk of reinfestation while going down the road.

[2]No. 171356 Smoke bomb from Ben Meadows, Forestry and Engineering Supplies, Inc., P. O. Box 8377, Station F, Atlanta, Georgia 30306.

Table 1. Experimental design for second experiment. Numbers refer to treatments. There were 6 cartons per treatment, 108 cartons in all. (1252-112-1).

Non-fumigated controls	Fumigated[z]							
	Non Pre-cooled[y]				Pre-cooled[x]			
	Maximum ventilation[w]		Minimum ventilation[v]		Maximum ventilation[w]		Minimum ventilation[v]	
	Prompt cooling[u]	Delayed cooling[t]	Prompt cooling[u]	Delayed cooling[t]	Prompt cooling[u]	Delayed cooling[t]	Prompt cooling[u]	Delayed cooling[t]
				With diphenyl pads				
1	3	4	5	6	7	8	9	10
				Without diphenyl pads				
2	11	12	13	14	15	16	17	18

[z]Fumigated for 2 hr with 10 oz/1000 ft^3 (10 g/m^3) at ambient (ca. 90°F, 32.5°C) temp.

[y]Held at ambient temp prior to fumigation. Pulp temp 80°F (27°C).

[x]Held overnight in 50°F (10°C) storage. Pulp temp entering fumigation 61°F (16°C).

[w]Maximum ventilation: Left in open chamber with fan on for ca. 1/2 hr. Thereafter uncovered in open until next day.

[v]Minimum ventilation: Removed from fumigation immediately and covered with 6-mil polyethylene film until next day.

[u]Prompt cooling: Immediately transferred to 50°F after fumigation.

[t]Held under ambient (ca. 70-90°F) temp until next day. Then transferred to 50°F.

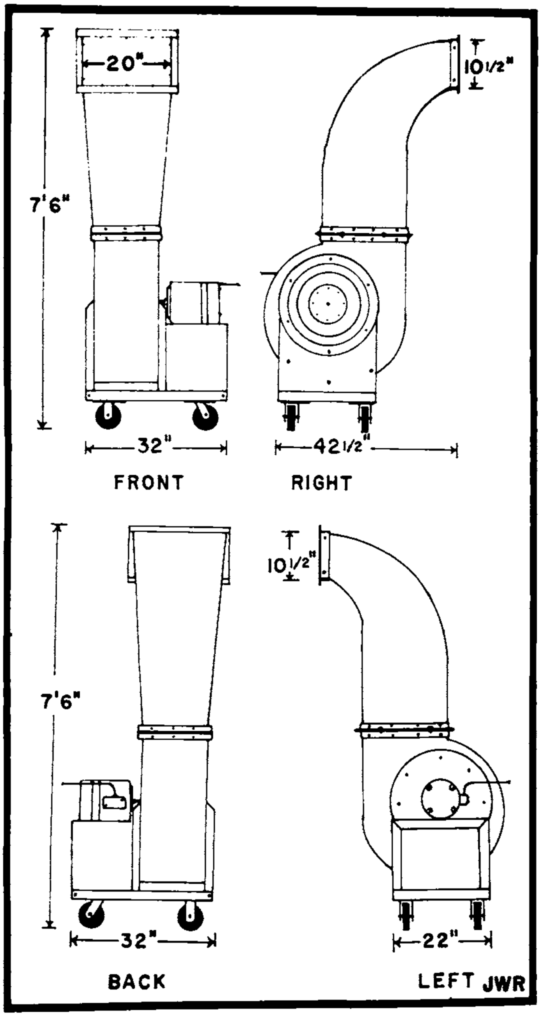

Fig. 1. Design of portable blower unit for in-truck fumigation. (The measured quantity of EDB was volatilized from an electric frying pan set near the fan intake).

Results and Discussion

Experiment No. 1. No injury was found in the 10 cartons removed to office conditions immediately after fumigation. All samples stored at AREC (but not all individual fruit) had some degree of epidermal burn. The injury was worst where the fruit contacted the diphenyl pads used for decay control. However, there tended to be clear undamaged areas where fruit were pressed tightly on either side of the diphenyl-impregnated paper. This was interpreted to mean that where EDB reached the diphenyl pad, enough EDB had been retained for long enough to cause injury. No peel injury was noted where fruit contacted the cartons. No clear cut difference was noted between the precooled and non-precooled lots either in terms of peel injury or decay.

Experiment No. 2. An attempt was made to classify peel injuries into EDB burn and chilling injury (CI). However, it was apparent that during the long simulated voyage, injured fruit had almost entirely succumbed to decay. Moreover, EDB burn and CI were not always clearly distinguishable.

Decay (Table 2) varied from less than 14% to over 60% among treatments. The six treatments having the most decay (a grouping significant at the .01 level) had all been subjected to restricted ventilation after fumigation. The five treatments with the most CI (not a statistically isolated group) were all promptly refrigerated after fumigation (Table 3).

Separation of the individual treatment factors showed the following relationships, (the level of significance is indicated in parentheses). Fumiga-

Table 2. Decay (all causes) at end of simulated 30-day voyage at 50°F (10°C).

1252-112-1

Fumigated	Pre-cooled	Well ventilated	Promptly stored	Diphenyl pads	Treatment No.	Average % decay[z]
-	-		-	+	2	13.5
-	-		-	-	1	16.2
+	-	+	-	+	4	18.2
+	+	+	-	+	8	22.0
+	+	-	+	+	9	22.4
+	-	+	+	+	3	23.4
+	-	+	-	-	12	26.3
+	-	+	+	-	11	26.5
+	-	-	+	+	5	28.1
+	+	+	-	-	16	31.7
+	+	+	+	-	15	33.1
+	+	+	+	+	7	37.4
+	+	-	+	-	17	39.4
+	-	-	-	+	6	46.4
+	-	-	+	-	13	48.3
+	+	-	-	+	10	59.6
+	-	-	-	-	14	60.6
+	+	-	-	-	18	[y]

[z]Mean separation among averages by Duncan's multiple range test, 1% level. F = 5.39**.

[y]Samples lost due to excessive decay (carton collapsed).

Table 3. Apparent chilling injury at end of simulated 30-day voyage at 50°F (10°C).

1252-112-1

Fumigated	Pre-cooled	Well ventilated	Promptly stored	Diphenyl pads	Treatment No.	Chilling injury[z] (as percentage of fruit seriously blemished).
+	+	-	+	-	17	0.8
+	-	+	-	-	12	0.8
+	-	-	+	-	13	1.3
+	+	-	-	+	10	1.7
-	-		-	+	2	2.1
-	-		-	-	1	2.4
+	-	+	-	+	4	2.6
+	+	+	-	-	16	3.2
+	+	+	-	+	8	3.2
+	+	-	+	+	9	4.6
+	-	-	-	-	14	7.4
+	-	-	-	+	6	9.9
+	-	-	+	+	5	11.5
+	+	+	+	-	15	12.2
+	-	+	+	-	11	14.6
+	+	+	+	+	7	17.7
+	-	+	+	-	3	23.1
+	+	-	-	-	18	[y]

[z]Mean separation among averages by Duncan's multiple range test, 1% level (F = 4.91).

[y]Samples lost due to excessive decay (carton collapsed).

tion increased decay (.01). Fumigation increased CI (.01). Diphenyl reduced decay significantly for fumigated grapefruit (.01), but not for non-fumigated fruit (ns). Diphenyl pads increased CI (.01). Precooling had no effect on decay (ns), but increased CI (.05). Restricting ventilation after fumigation increased both decay (.01) and CI (.01). Only one interaction was significant; minimum ventilation x prompt storage at 50°F (10°C) increased both decay (.01) and CI (.01).

The outstanding result is the very obvious injury to the fruit when ventilation immediately after fumigation is restricted. Apparently fumigation injury (followed by increased decay) occurs *after* the two hr fumigation when residual EDB is not thoroughly aired out of the cartons. To our surprise, prior precooling did not increase fumigation injury. The practice is not desirable, however, as the dosage of EDB should be raised for cold fruit (which was not done here) to ensure larval kill.

The findings on CI are more questionable. Until recently, CI was not expected in late season grapefruit held at 50°F. However recent work (2) has shown that with the advent of the spring growth flush, grapefruit still on the tree revert to a condition of CI sensitivity comparable to that in the fall. The same study also reported that delay between picking and cold storage decreases chilling injury. Thus the finding here that CI was greater in samples promptly stored than in those that were delayed 24 hr before storage is probably genuine. The apparent finding that fumigation and use of diphenyl increased CI may be merely due to confusion between similar forms of peel injury. It is also very possible that there is a synergistic effect with the cumulative strains of chilling, fumigation and diphenyl together augmenting CI.

Observations from commercial practice. In October, 1974, the Japanese inspection team observed the prototype in-truck fumigation unit and approved the principle. In a period of less than 3 months, starting in mid-February, 5,273,000 4/5-bu cartons of grapefruit were fumigated for export to Japan, initially utilizing the 3 existing truck chambers at Gainesville and 2 multiple in-truck fumigation stations servicing the Interior and Indian River districts, respectively. Later, another truck fumigation chamber was added at an Interior packinghouse, Orange-co of Florida, Inc. The greater part of this tonnage was fumigated in semi-trailer trucks which then proceeded promptly to the docks at Tampa or Port Everglades with front and rear vent doors open for postfumigation ventilation. Such loads were commonly palletized on slip-sheets, but were broken out for "break bulk" loading in the holds of the reefer vessels. Reports received of fumigation damage in such shipments were minimal and largely late in the season. It is possible that the damage reported was a synergistic compounding of late-season CI and EDB burn.

Some reports of serious fumigation injury were received from 2 sources: reports from USDA and Florida DFVI personnel who checked arrivals in Japan and from conferences with shippers who experienced decay claims. The great majority of reported damage occurred in loads fumigated in van containers in fumigation chambers. Such van containers were loaded on shipboard and not unloaded until reaching Japan. No particular problems were reported with van container loads in

Table 4. Residues of ethylene dibromide subsequent to fumigation

Fruit	Fumigation conditions[z]	Time to residue analysis	Sample	Residue	
				ppm	Expressed as
Oranges Valencia	Gainesville chamber with a truck load.	5 days	Composite Middle layer Outer layer	6.16 6.56 7.45	Inorganic bromide
Grapefruit Marsh	"	5 days	Composite Middle layer Outer layer	5.48 5.96 6.53	Inorganic bromide
Oranges Valencia	Fumigated in Texas for shipment to Florida, probably prior to loading.	At least 4 days	From truck at Florida cannery.	3.6 1.4 8.0 3.1	Inorganic bromide
Grapefruit Marsh	Gainesville chamber. Methyl bromide at 2-1/2 lb/1000 ft^3, aerated, then EDB at 10 oz/1000 ft^3, (with truck load).	4-1/4 days	1 carton, held in refrigerator over week-end.	10.0	Inorganic bromide
Grapefruit Marsh	Orange-co chamber[y], 2-1/2 oz/1000 ft^3.	6 days	Warm fruit	4.5	Total bromide
"	(Only samples in chamber).	6 days	Cold fruit	4.2	Total bromide
Grapefruit Marsh	In-truck fumigation unit.	6 days	From commercial load	5.2	Total bromide
Grapefruit Marsh	In-truck fumigation unit.	30 days	From commercial load	4.8	Total bromide
Grapefruit Marsh	Orange-co chamber[y].	30 days	From commercial load	5.3	Total bromide
Grapefruit Marsh	Orange-co chamber[y].	6 days	With commercial load (samples held in refrigerator).	13.82	Total bromide
Grapefruit Marsh	In-truck fumigation unit.	6 days	(Samples held in refrigerator), with commercial load.	6.39	Total bromide

[z]Unless otherwise stated, EDB at 10 oz/1000 ft^3 (= ca. 10 g/m^3).

[y]A new chamber at the Orange-co packinghouse, essentially similar to those at Gainesville.

which the fruit was fumigated in over-the-road trucks, ventilated thoroughly and then transferred to van containers for ocean shipment. These van containers lack the front and rear ventilation doors with which the over-the-road trucks are usually equipped. The lack of these ventilation doors impeded postfumigation ventilation while traveling down the highway. Also, when ventilating the truck fumigation chambers prior to pulling out the van containers, setting the fans on "ventilate" pulled all the air past the van container rather than through it. (These fan systems are being modified so as to circulate part of the air over the load while exhausting the rest.)

Thus, practical experience confirmed the findings in Experiment No. 2, that the major hazard was not during fumigation itself, but was due to inadequate ventilation (and possibly also too prompt refrigeration) after fumigation.

Residues. Table 4 reports a miscellany of residue data, some from commercial loads, some from experimental samples. Residues exceeded the permissible 10 ppm total bromide due to fumigation in only 2 out of 18 samplings, although most were analyzed very much sooner than the earliest possible retail marketing of fruit shipped to Japan. Nevertheless, such residue data indicate the importance of thorough postfumigation ventilation in order to minimize residues as well as to avoid the risk of peel injury.

Conclusion

The best way to avoid injury in fumigated loads is to provide maximum ventilation immediately after fumigation and to delay refrigeration for at least 24 hr. That failing to observe these precautions did not always result in damage, probably reflects physiological differences in fruit of differing maturity, growing districts, or cultural methods.

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