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FUMIGATION OF FRESH FRUIT TO DESTROY THE ADULT JAPANESE BEETLE

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FUMIGATION OF FRESH FRUIT WITH CARBON DISULPHIDE AND ETHYLENE OXIDE [3]

Raspberries, blackberries, and blueberries are grown extensively in sections of New Jersey infested by the Japanese beetle (*Popillia japonica* Newm.). A certain proportion of the crop must be marketed at points outside the area now quarantined because of this beetle, but it is known that boxes and crates of fresh fruit harvested and shipped during the season when adult Japanese beetles are present are likely to be infested with this pest unless control methods are employed.

During the summer of 1928 such fruits were inspected and, if found to be free of beetles, were certified for shipment out of the

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[1] Transferred to the Division of Fruit Insect Investigations Aug. 1, 1934.

[2] The writers take this opportunity to acknowledge the assistance given by W. E. Fleming.

[3] By Max R. Osburn.

quarantined area. This was unsatisfactory because the fruit was injured by excessive handling, the inspection was slow and laborious, and there was the possibility of failure to discover all the beetles. It was therefore necessary to develop a practical method for eliminating the danger of transporting Japanese beetles with the fruit.

The Japanese beetle is often found resting or feeding on the fruit or the foliage of plants in the season when the crop is harvested, and it is impossible to pick the fruit at a time of day when beetles are not present. As the ordinary contact sprays and stomach poisons are ineffective for eliminating infestation in berry fields, some physical or chemical method had to be developed for destroying the beetles in the crates and boxes. Fumigation seemed to be the most practical procedure.

PRELIMINARY EXPERIMENTS

Preliminary tests were made in the summer of 1928 with carbon disulphide, benzene, ethyl acetate, trichloroethylene, ethylene dichloride, decahydronaphthalene, ethyl bromide, and geraniol. These materials were tested at different temperatures, both at room pressure and under partial vacuum, to determine their effectiveness in killing beetles and the effects of fumigation on the berries.

The results of these preliminary tests indicated that carbon disulphide at room pressure, used at the rate of 10 pounds to 1,000 cubic feet, was effective in destroying beetles when the treatment was prolonged for 2 hours at a temperature of 80° F., and that such treatment would not be detrimental to the fruit.

PROPERTIES OF CARBON DISULPHIDE

Carbon disulphide is a liquid with a specific gravity of 1.29 at the freezing temperature of water and with a boiling point of 46.2° C. (114.2° F.). It should be kept in an outhouse away from lights and fires. It is very volatile, evaporating rapidly when exposed to air. The vapor is highly inflammable; when mixed with air in the proper proportions it is explosive; and at 147° C. (296.6° F.) it ignites spontaneously. Pure carbon disulphide, according to Hinds (*4*),[4] is completely volatile, and does not impair the edibility of foodstuffs, even when poured directly upon them. All trace of the odor disappears quickly when the compound is exposed to air. The ordinary article, however, has a slightly yellowish tinge caused by its impurities, which also give it a rank, fetid, obnoxious odor. When the impure article is used, a slight residue may be left after the evaporation of the liquid.

The vapor of carbon disulphide, because of its density, will work downward. This point has an important bearing upon the application of the material as a fumigant. For the best results, means should be employed to give an even distribution of the gas.

THE FUMIGATION HOUSE USED FOR THE TESTS

The effectiveness of carbon disulphide as a commercial fumigant was determined in a fumigation house of 1,000 cubic feet capacity,

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[4] Italic numbers in parentheses refer to Literature Cited, p. 28.

10 feet long, 10 feet wide, and 10 feet high. It had a window in the rear and a door in front. It was gastight, being double-walled throughout, with two-ply roofing paper between the walls, and lined on the inside with galvanized-iron sheets, which were soldered together. The window and the door were made tight by means of rubber gaskets. A hot-water heating system of 24 gallons' capacity, thermostatically controlled, was used to maintain the desired temperature (fig. 1, *A*). A galvanized-iron pan, 24 inches square by 4 inches deep, containing 22 feet of half-inch copper tubing, through which hot water circulated, was used to vaporize the carbon disulphide (fig. 2, *A*). A fan (fig. 2, *B*) was provided for circulating the air in the house.

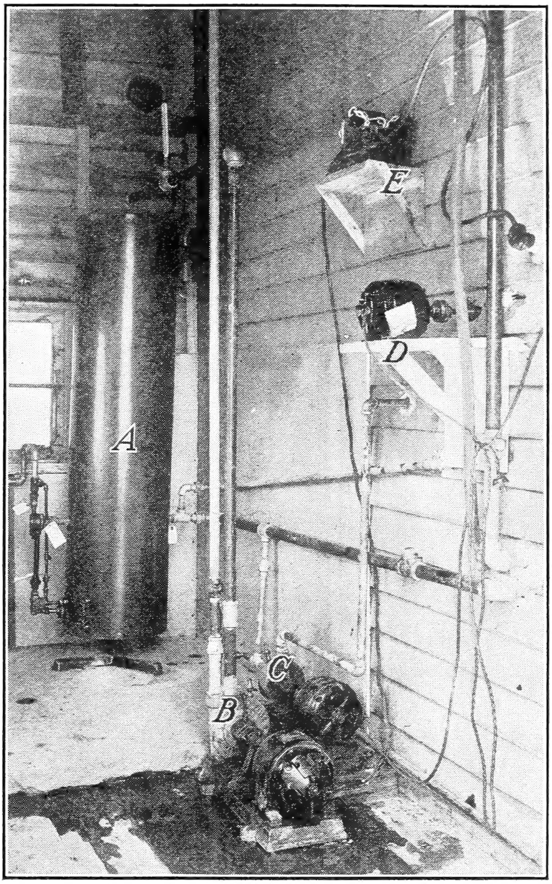

FIGURE 1.—Control room at the experimental fumigating plant: *A*, Hot-water heating system; *B*, hot-water circulation pump; *C*, circulation pump for evaporating coils; *D*, motor for ventilating fan; *E*, thermal control.

EFFECTIVENESS OF CARBON DISULPHIDE AS A FUMIGANT

In the summer of 1929, 165,000 adult Japanese beetles were treated with carbon disulphide in the fumigation house under different conditions to determine the best conditions for killing 100 percent of a given number. In one series of tests, in which 160,000 beetles were used, 2,000 individuals in cages were exposed directly to the gas in rectangular cages 24 inches long, 11 inches wide, and 14 inches high. The sides and tops of each cage were covered with wire screen and each cage was provided with a door. In another series of tests the beetles were treated in baskets of fruit. Immediately before treatment, several boxes in various parts of each layer of a crate were artificially infested with beetles and enclosed with mosquito netting to prevent the beetles from crawling out.

In both series the beetles were placed in the fumigation house as soon as the desired temperatures were reached. In each experiment the proper dosage of carbon disulphide was poured into the pan containing the copper coils, and the door of the house was closed and made tight. The carbon disulphide was volatilized rapidly by forcing water at a temperature between 140° and 180° F. through the copper coils, and the fan was started to circulate the carbon disulphide vapor. A period of 15 or 20 minutes was usually sufficient to vaporize the carbon disulphide. After the desired fumigation period had elapsed, the door and window were thrown open to ventilate the room. The treated beetles were then taken to the insectary, where they were examined at the end of 24 and 48 hours to determine the number that were normal, ill, or dead. The same number of untreated beetles was held in the same manner as a check.

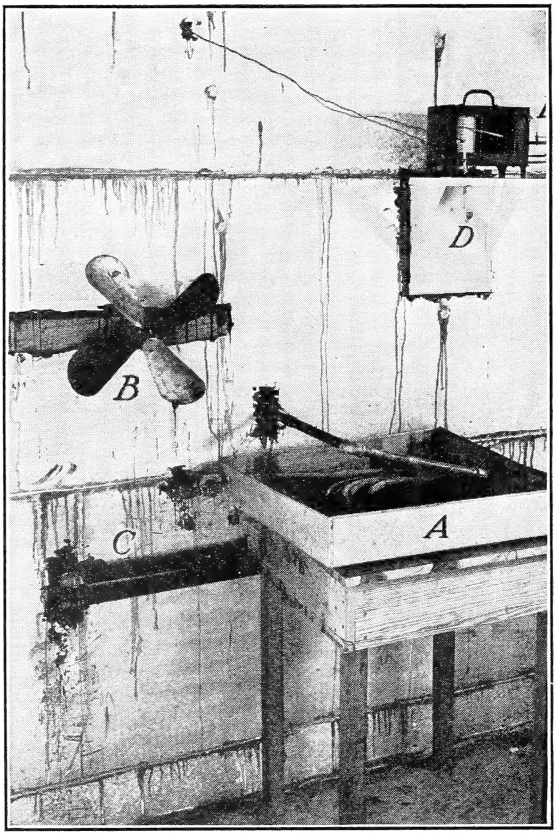

FIGURE 2.—Interior of fumigating chamber at the experimental plant: *A*, Evaporating pan; *B*, ventilating fan; *C*, hot-water heating pipes; *D*, thermotrol; *E*, thermograph.

In examining such a large number of insects it was found very difficult to pick out the few that still might be alive, especially since the species involved may feign death when disturbed. This difficulty was solved by placing the beetles in a shallow pan containing warm water, whereupon any that were alive could be distinguished by movements of their legs or mouth parts. Those that did not move were considered dead. There was no recovery of insects after a period of 48 hours. It was found that beetles were killed as readily in baskets of fruit as they were when exposed directly to the action of the vapor. A summary of the results obtained with various dosages of carbon disulphide is presented in figure 3.

TEMPERATURE IN FUMIGATION WITH CARBON DISULPHIDE

Temperature is an important factor in the insecticidal action of carbon disulphide. It was found that a concentration of 5 pounds of carbon disulphide to 1,000 cubic feet for a period of 2 hours killed 80 percent of the beetles at 80° F., 99 percent at 85°, 99 percent at

90°, and 100 percent at 95°. A concentration of 2½ pounds of the compound to 1,000 cubic feet for 2 hours was required to destroy all the beetles at 95°, 7½ pounds for 2 hours at 90°, and 10 pounds for 2 hours at 85° and 80°. Ten pounds for 2 hours at 75° killed only 96 percent.

No experiments were performed at temperatures of less than 75° F. because the fumigation house was not equipped for lowering the temperature and the work was done during the summer months when adult Japanese beetles were available.

It is apparent that for practical work it is not advisable to try fumigation with carbon disulphide when the temperature is below 80° F. and that the most effective and economical work can be done at higher temperatures.

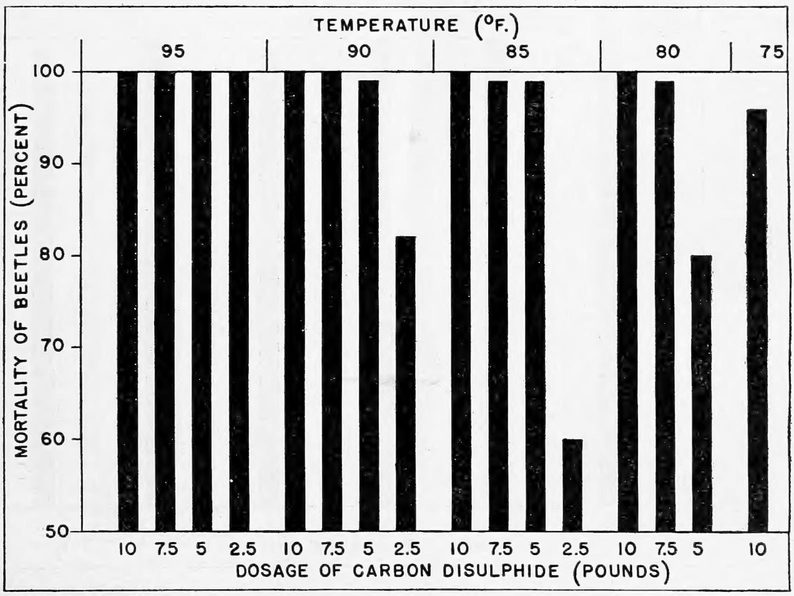

FIGURE 3.—Results of fumigating Japanese beetles with carbon disulphide vapor for 2 hours, at different temperatures and with different dosages per 1,000 cubic feet.

TIME OF EXPOSURE IN FUMIGATION WITH CARBON DISULPHIDE

It was found, as shown in figure 4, that a dosage of 10 pounds of carbon disulphide to 1,000 cubic feet was 100 percent effective when the treatment was prolonged to 2 hours, but that this dosage was only 99 percent effective with an exposure of 1 hour, unless the temperature was as high as 95° F. Since 15 minutes normally is required to vaporize the carbon disulphide and to obtain the desired concentration, the exposure should be not less than 2 hours, to assure complete destruction of the beetles.

PENETRATION OF CARBON DISULPHIDE INTO BASKETS OF FRUIT

The nature of the material to be fumigated has a bearing on the effectiveness of the treatment. Grain, flour, soil, or other compact materials must be exposed to the gas for longer periods than more porous or less compact materials. Fresh fruits, when packed for shipment, vary in their compactness according to their size and shape. There is, for instance, much more space for gas penetration between peaches than between blackberries when packed in baskets. This situation made it necessary to fumigate a number of kinds of fruits to determine the time, temperature, and dosage needed for each one.

Five thousand Japanese beetles were treated in baskets and crates of fruit during the season. The results showed that the presence of the fruit had very little influence on the effectiveness of the gas, a complete kill having been obtained both when the beetles were in the baskets of fruit and when they were exposed directly to the action of the vapor.

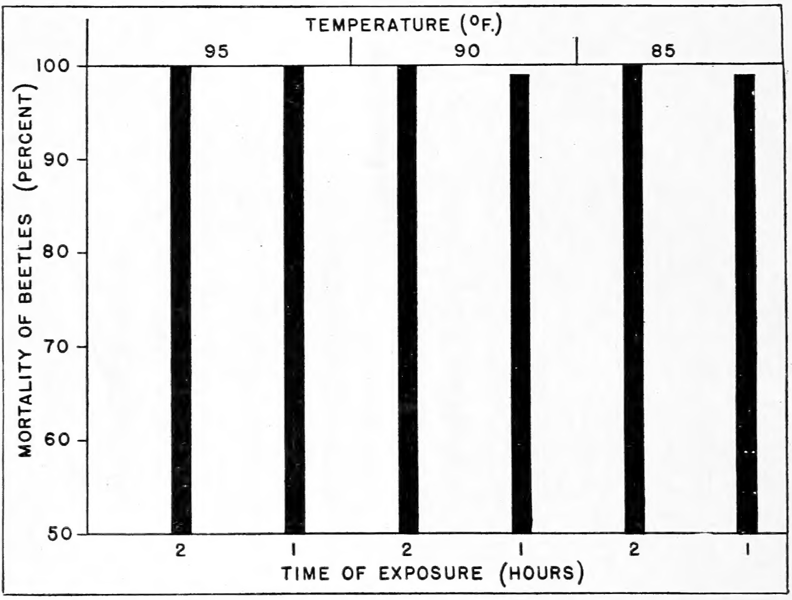

FIGURE 4.—Comparison of the effects of 1- and 2-hour fumigations at different temperatures. Dosages were 10 pounds of carbon disulphide per 1,000 cubic feet.

EFFECT OF CARBON DISULPHIDE ON FRUIT

In the summer of 1929, 12 varieties of fruit were treated with carbon disulphide at the rate of 10 pounds to 1,000 cubic feet for 2 hours at a temperature of 80° F. The varieties of fruit and the quantities treated are shown in table 1.

TABLE 1.—*Kinds and quantities of fruit treated with carbon disulphide, 1929*

Fruit	Variety	Quantity treated	Fruit	Variety	Quantity treated
Strawberries	Howard 17 (Premier).	194 quarts.	California plums		6 crates.
			Red currants		64 quarts.
	Big Tom	66 quarts.	Gooseberries		54 quarts.
Raspberries	Ranere (St. Regis).	1,050 pints.	Blueberries	Grover	16 quarts.
				Jersey	1 quart.
Blackberries		1,040 quarts.		Rubel	Do.
Peaches	Elberta	16 ⅝-bushel baskets.		1613C	Do.

These fruits, with the exception of the blueberries, were purchased in the open market and, when received, were packed into boxes and crates ready for shipment.

All fruits were treated in the original boxes and crates immediately after they were received at the laboratory. A record was made of the condition of each variety just before treatment. Upon completion of the treatment, all the fruit, except the blueberries, was taken from the fumigation chamber and, together with a representative control of untreated fruit of the same varieties, was held at outside temperatures. The fruit was tasted by various individuals immediately after treatment to determine whether enough carbon disulphide had been absorbed to be noticeable. In only a very few instances, and only when the person making the test knew that the fruit had been treated with carbon disulphide, was a slight taste of the compound reported.

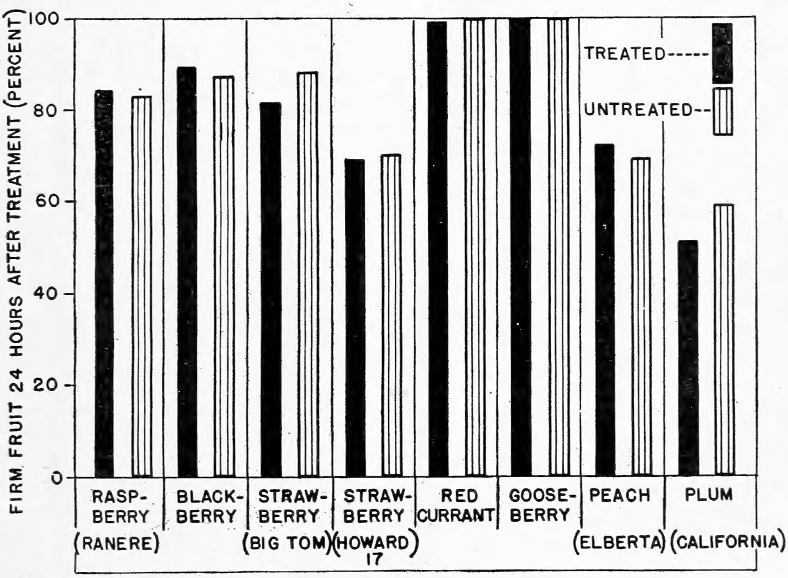

FIGURE 5.—Proportions of fruits that were firm 24 hours after treatment with 10 pounds of carbon disulphide per 1,000 cubic feet for 2 hours at 80° F. compared with the proportions of untreated fruits that were firm.

All the fruit was held for at least 24 hours after treatment and the effect of the treatment checked in several ways. In every case, with the exception of the blueberries, the treatment apparently had no detrimental effect on the appearance or edibility of the fruit. In addition, the treated raspberries seemed to retain their physical condition and bright color longer than the untreated berries.

Fruits such as blackberries, raspberries, or strawberries naturally are softer when ripe than gooseberries, currants, or blueberries. As a result, the keeping qualities of different fruits under normal conditions vary. A comparison, based on firmness, of the keeping qualities of fruits treated with carbon disulphide with those of untreated fruits is shown in figure 5.

Treated and untreated blueberries were held in an incubator at 86° F. for a period of 6 days, after which representative samples of berries were compared. In the case of three varieties, the treated berries were found to be slightly less firm than the untreated, as shown in figure 6.

ABSORPTION OF CARBON DISULPHIDE BY FRUIT

Samples of blackberries were tested immediately after they had been taken from the fumigation room. The proportion of carbon disulphide that had been absorbed was determined by the method used by Radcliffe (*6*). In no case did it exceed 2 milligrams to 1 kilogram of fruit (2 parts per million), and in all probability this quantity would be practically all dissipated before the fruit reached the ultimate consumer. Judging from taste, no more carbon disulphide is likely to be absorbed by the other fruits than by blackberries. The fruits treated as recommended for the destruction of the beetles were apparently normal in appearance, flavor, and keeping qualities when compared with untreated fruit.

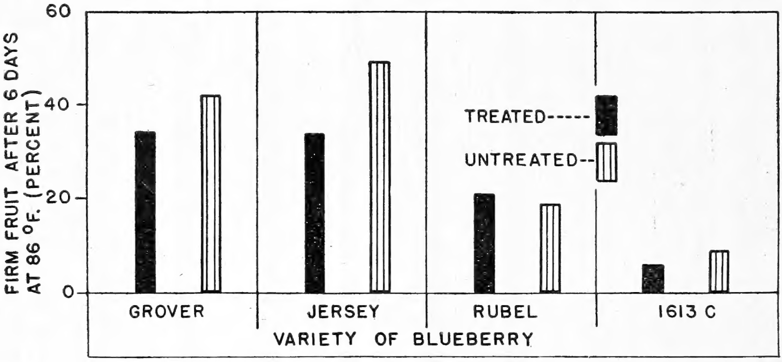

FIGURE 6.—Proportions of blueberries that were firm after treatment with 10 pounds of carbon disulphide per 1,000 cubic feet for 2 hours at 80° F. and subsequent storage for 6 days at 86°, cmpared with the proportions of untreated berries that were firm.

PREVIOUS EXPERIMENTS WITH ETHYLENE OXIDE

Since the development of a method for fumigating fresh fruit with carbon disulphide (*5*) to destroy the adult Japanese beetle, experiments have been under way to develop a fumigant for this purpose which would be equally effective as an insecticide and as noninjurious to the fruit, but which in addition would be less inflammable and explosive than carbon disulphide. The preliminary experiments with different compounds indicated that ethylene oxide, a chemical whose insecticidal properties were discovered by Cotton and Roark (*2*), might be substituted for carbon disulphide for this purpose.

Cotton and Roark showed that a dosage of 1 pound of ethylene oxide per 1,000 cubic feet of space for 20 hours proved to be 100 percent lethal to specimens of the webbing clothes moth, *Tineola bisselliella* Hum.; the black carpet beetle, *Attagenus piceus* Oliv.;

the furniture carpet beetle, *Anthrenus vorax* Csy.; the rice weevil, *Sitophilus oryzae* L.; the Indian-meal moth, *Plodia interpunctella* Hbn.; the saw-toothed grain beetle, *Oryzaephilus surinamensis* L.; the red-legged ham beetle, *Necrobia rufipes* DeG.; and the confused flour beetle, *Tribolium confusum* Duv.

Ethylene oxide, according to Back, Cotton, and Ellington (*1*), has been used as a fumigant with success in destroying infestations of the webbing clothes moth, the furniture carpet beetle, the confused flour beetle, the rice weevil, and the saw-toothed grain beetle.

PROPERTIES OF ETHYLENE OXIDE

The physical properties of ethylene oxide have been described recently by Back, Cotton, and Ellington (*1*), and by Roark and Nelson (*7*).

At ordinary temperatures it is a colorless gas; at low temperatures it is a mobile colorless liquid that boils at 10.5° C. (50.9° F.). The specific gravity of liquid ethylene oxide is 0.887 at 7°/4° C. (44.6°/39.2° F.). The empirical formula is C_2H_4O. The molecular weight is 44.031. The concentrations up to 3½ pounds per 1,000 cubic feet of space are nonexplosive and noninflammable. The ignition point is 434° C. (813.2° F.). Ethylene oxide has a faint but distinct etherlike odor, and the vapor is approximately 1.7 times as heavy as air. The vapor exhibits remarkable penetration into such compact materials as soil. The vapor of ethylene oxide, while not highly toxic to man, should not be inhaled extensively.

EFFECTIVENESS OF ETHYLENE OXIDE AS A FUMIGANT

The effect of ethylene oxide as a fumigant for fresh fruit was determined in the experimental fumigation house described in a previous section of this circular.

In the summer of 1930 some 16,000 adult Japanese beetles were fumigated, under various conditions, with ethylene oxide to determine the best conditions for killing 100 percent of them. In one series of tests the beetles were exposed directly to the vapor in rectangular cages 24 inches long, 11 inches wide, and 14 inches high. The sides and tops of these cages were covered with wire screen and each was provided with a door. In another series of tests the beetles were treated while contained in baskets of fruit. Immediately before treatment, several boxes placed in various parts of each layer of a crate of fruit were artificially infested with beetles.

In the various experiments the insects were placed in the fumigation house as soon as the desired temperature was reached. In each experiment the proper dosage of ethylene oxide was measured as a liquid and poured into shallow pans that rested on a table. The window and door of the house were closed and made tight. The fan was started to circulate the ethylene oxide vapor, which evolves rapidly at ordinary fumigation temperatures. After the desired time had elapsed, the door and window were thrown open to ventilate the room. The treated insects were taken to the insectary, where they were examined, at the end of 24 and 48 hours, to determine the number that were alive or dead.

TEMPERATURE, EXPOSURE, AND DOSAGE IN ETHYLENE OXIDE FUMIGATION

It was found that when adult Japanese beetles were exposed for 2 hours to the vapor of 1 pound of ethylene oxide to 1,000 cubic feet of space, 90 percent of them were killed at a temperature of 65° F., 96 percent at 70°, and 100 percent at 75°. One pound for 1 hour killed 54 percent at 75° and 93 percent at 80°. When ethylene oxide was used at the rate of 2 pounds per 1,000 cubic feet, 96 percent of the beetles were destroyed at the end of 1 hour at a temperature of 75° and all of the beetles were destroyed when the temperature was 80° or the period of exposure was 2 hours.

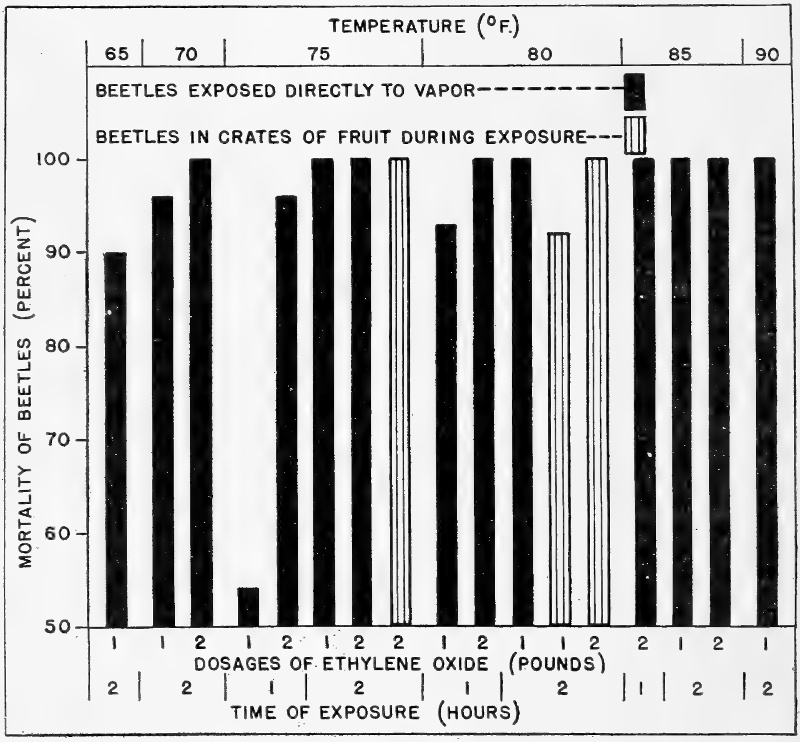

FIGURE 7.—Results of fumigation of adult Japanese beetles with ethylene oxide for different periods, at different temperatures, and with different dosages per 1,000 cubic feet.

Experiments in which beetles were fumigated in boxes of fresh fruit showed that it was necessary to use 2 pounds of ethylene oxide per 1,000 cubic feet of space for a period of 2 hours at 75° F., to obtain a 100-percent mortality.

A summary of the various tests is presented in figure 7.

EFFECT OF ETHYLENE OXIDE ON CERTAIN SMALL FRUITS

In the summer of 1930, raspberries, blackberries, and blueberries were fumigated with ethylene oxide at the rate of 2 pounds to 1,000 cubic feet of space for 2 hours at temperatures of 75° and 80°

F., respectively. All fruits were treated immediately after they were received at the laboratory. The varieties of fruit and the quantities treated are shown in table 2.

TABLE 2.—*Kinds and quantities of fruit treated with ethylene oxide, 1930*

Fruit	Variety	Quantity treated
Blueberries	Rubel Grover	32 quarts. Do.
Raspberries		936 pints.
Blackberries		1,600 quarts.

Upon completion of the treatment, the raspberries and blackberries were taken from the fumigation chamber and held at outside temperatures, together with representative quantities of untreated fruit of the same varieties, for at least 48 hours to determine the effect of the treatments. The blueberries were held in an incubator at 86° F. for a period of 6 days. A comparison, based on the firmness of the fruit, indicated that raspberries and blackberries were apparently uninjured by the treatment, as shown in figure 8. The treated blueberries were slightly less firm than the untreated ones, as shown in figure 9, but otherwise they seemed equal to the untreated. The presence of retained ethylene oxide was not evident from either the odor or the taste of the fumigated fruit.

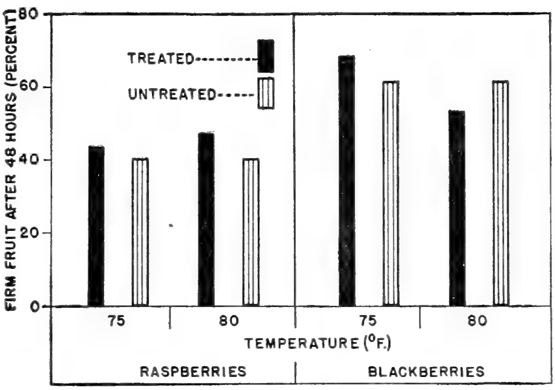

FIGURE 8.—Proportions of fruits that were firm after treatment with 2 pounds of ethylene oxide per 1,000 cubic feet for 2 hours at 75° and 80° F., and subsequent storage for 48 hours at outside temperatures, compared with the proportions of untreated fruits that were firm.

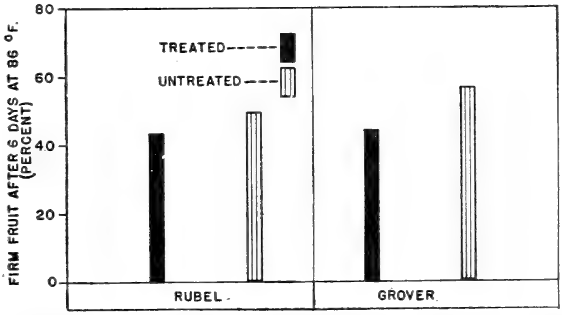

FIGURE 9.—Proportions of blueberries that were firm after treatment with 2 pounds of ethylene oxide per 1,000 cubic feet for 2 hours at 75° F., and subsequent storage for 6 days at 86°, compared with the proportions of untreated berries that were firm.

EFFECT OF ETHYLENE OXIDE ON WET GREEN BANANAS

Conditions at the port of Philadelphia make it necessary to fumigate railway fruit cars containing wet, green bananas. In view of the possibility of using ethylene oxide as the fumigant for this work, 30 hands of wet green bananas were exposed to 2 pounds of ethylene oxide per 1,000 cubic feet of space at 75° F. for 2 hours. When the fruit was examined 48 hours later it was found that this treatment caused such extensive damage that it would not be advisable to use ethylene oxide as the fumigating material.

OPERATION OF COMMERCIAL FUMIGATION HOUSES

A frame building equipped to use carbon disulphide, costing approximately $2,000, was erected on the outskirts of Hammonton, N. J. It is 30 feet long, 20 feet wide, and 10 feet high, has a capacity of 6,000 cubic feet, and can hold 1½ carloads of berries. The building is double-walled throughout, and its walls and ceiling are lined with matched ceiling boards covered with insulating wall board. They also are lined with a layer of three-ply tarred roofing paper, folded to fit into the corners, and with all joints overlapping 3 or 4 inches. All cracks, seams, joints, and nail heads are coated with pitch to make the building practically gastight. The floor is made of boards running in one direction over boards running at right angles to them, with tarred roofing paper between. The joint between the floor and the walls is sealed with pitch.

A door 6 feet high by 5 feet wide, opening outward, was placed at each end of the building to facilitate the loading of the fruit and the ventilation of the building after treatment. The doors operate like refrigerator doors and close tightly against rubber gaskets on the doorframe.

The house is equipped with a special apparatus consisting of 60 feet of ⅝-inch seamless copper tubing coiled in a 16-ounce copper pan 5 inches deep and 6 feet in diameter. The pan is hung a few inches below the ceiling, and the copper tubing is connected with pipes that lead through the side of the building to a hot-water system driven by an electric motor (figs. 10 and 11). The fumigant is injected into the pan through a pipe in the roof, equipped with a valve that may be closed immediately after the fumigant is poured into the pan (fig. 12).

There is a fan at each end of the building, one near the ceiling and the other near the floor, to insure circulation of air. The fan shafts pass through the walls to motors outside of the room and are equipped with stuffing boxes.

There is no heating system in the house to raise the temperature of the room, nor is one necessary if treatments are made when the temperature is 80° F. or higher. Blackberries are fumigated at times when temperatures are usually high.

This plant was in operation by August 1, 1929, and one fumigation was performed daily for 21 days. In that time a total of 9,980 crates of Evergreen (Black Diamond) blackberries were treated. The largest number of crates fumigated at one time was 913. From August 9 to 20 a total of 191 dead adult Japanese beetles were collected after treatments.

In 1932 a commercial fumigation house was erected at New Lisbon, N. J. The construction of this house differs from that of the one described above in that the walls are made of cinder block, covered on the outside with stucco. The interior of the house, with the exception of the concrete floor, is coated with pitch to make the chamber practically gastight. It has a capacity of 2,563 cubic feet and can hold one-half carload of berries.

This plant was in operation during the summer of 1932 and in that time 1,544 crates of blueberries, 251 crates of blackberries, and 127 crates of raspberries were fumigated.

RECOMMENDATIONS FOR THE USE OF CARBON DISULPHIDE

The fresh fruits considered in these experiments can be fumigated in crates with carbon disulphide in a satisfactory manner for the destruction of Japanese beetles.

Fumigation house.—The house in which fumigation is to be done must be gastight to prevent reduction of concentration in the carbon disulphide vapor by seepage through walls, seams, or cracks. Great care should be taken and proper materials should be used in the construction of a gastight room. An ordinary, well-matched ceiling or floor is far from tight. All felt materials are extremely porous and are unsatisfactory for use as packing around doors and other openings. Heavy wrapping paper or two-ply roofing paper of certain brands is very nearly gastight and may be used between layers of boards in the construction of a fumigation house.

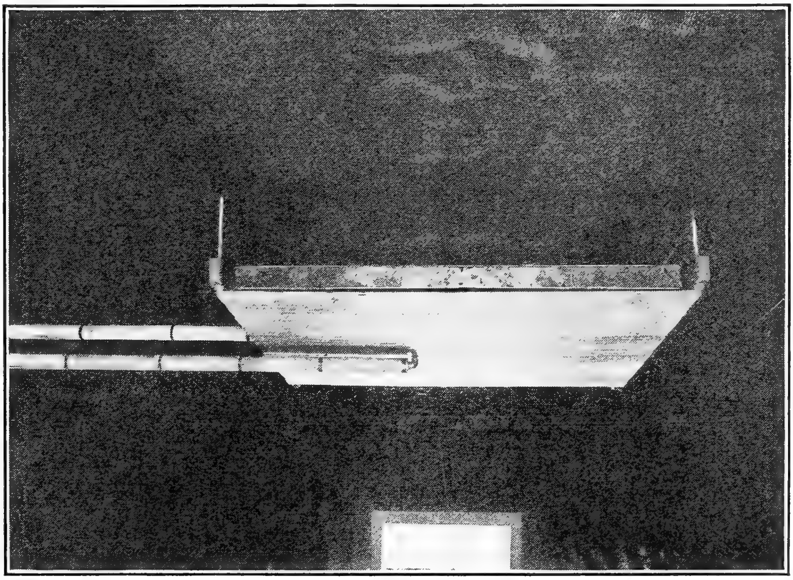

FIGURE 10.—Evaporating pan suspended from ceiling, showing hot-water pipes leading to heating coil. The carbon disulphide is poured into the pan through a pipe in the roof of the building.

The house must contain equipment for the rapid evaporation of carbon disulphide. The system used in the experimental fumigation house described earlier in this circular is satisfactory for a small plant. The apparatus consisted of a copper coil placed in a shallow copper or galvanized pan, which held the carbon disulphide while it was being vaporized. The copper coil was attached to a hot-water supply, and water at 140° to 180° F. was circulated through the coils. The size of the evaporation system needed depends on the size of the house and on the quantity of carbon disulphide to be used. Information on the amount of coil surface and length of copper tubing required for vaporizing different quantities of carbon disulphide is given by Weigel, Young, and Swenson (*9*). There must be a sufficient number of fans to insure complete circulation of the gas in the room.

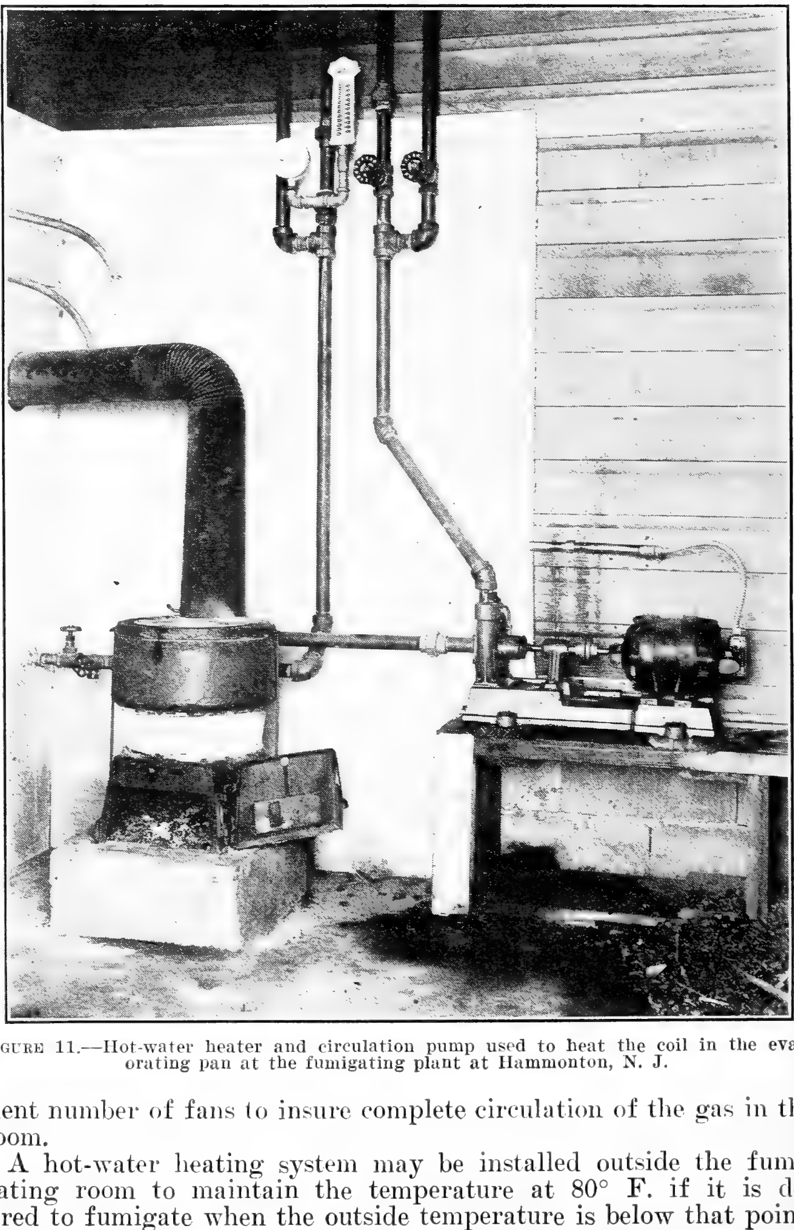

FIGURE 11.—Hot-water heater and circulation pump used to heat the coil in the evaporating pan at the fumigating plant at Hammonton, N. J.

A hot-water heating system may be installed outside the fumigating room to maintain the temperature at 80° F. if it is desired to fumigate when the outside temperature is below that point. The hot water may be circulated by an electric motor and automatically controlled by an electric thermostat, which will maintain a constant temperature in the room during treatment.

Caution.—The vapor of carbon disulphide is highly inflammable. Great care should be taken in isolating from the fumigation chamber all fires, electric motors, and other sources from which a spark or fire might originate, and anything that would cause a temperature higher than the 180° F. in the evaporating coils. All holes made for the passage of pipes or wires through the walls of the house must be tightly sealed. Electric motors for driving the fans and circulating the hot water must be outside of the fumigation room, and the hot water that circulates through the pipes in the evaporating pan or the heating unit should never be above 180°. The vapor of carbon disulphide, while not highly toxic to man, should not be inhaled extensively.

FIGURE 12.—Pouring carbon disulphide into the evaporating pan at the fumigating plant at Hammonton, N. J.

Dosage.—Carbon disulphide should be used at the rate of 10 pounds to 1,000 cubic feet of space. It should be volatilized rapidly, so that the full concentration may be obtained in about 15 minutes.

Temperature.—The temperature during treatment should be 80° F. Higher temperatures should be avoided because of their detrimental effect on the fruit. Lower temperatures should be avoided if all the beetles are to be killed.

Exposure.—The fruit must be exposed for 2 hours. It should not be exposed for more than 2 hours.

Loading the fumigating chamber.—As many crates or boxes of fruits as can be placed in the house with at least ½-inch air spaces between them, may be fumigated at one time. When crates are stacked one on top of another, narrow strips of wood should be used to separate the upper from the lower and provide for better and more rapid penetration of the gas.

RECOMMENDATIONS FOR THE USE OF ETHYLENE OXIDE

Blackberries and raspberries can be fumigated in crates with ethylene oxide in a satisfactory manner for the destruction of Japanese beetles. Ethylene oxide slightly injures blueberries by removing the bloom from the fruit, but may be used if the absence of the bloom is not of commercial importance.

Fumigation house.—The house must be constructed so as to be gas-tight. Ethylene oxide evolves rapidly at the temperature recommended for fumigation, so it is not necessary that the house be equipped for rapid evaporation of the fumigant.

A hot-water heating system may be installed, as recommended for the use of carbon disulphide, to maintain a temperature of 75° F.

There must be a sufficient number of fans to insure circulation of the gas.

Caution.—The vapor of ethylene oxide, while not highly toxic to man, should not be inhaled extensively. The concentrated vapors of ethylene oxide are inflammable, but the concentration herein recommended is nonexplosive and noninflammable.

Dosage.—Ethylene oxide should be used at the rate of 2 pounds to 1,000 cubic feet of space. It will volatilize rapidly when exposed to the temperature recommended for fumigation.

Temperature.—The temperature during treatment should be 75° F.

Exposure.—The fruit must be exposed for 2 hours.

Loading the fumigating chamber.—See recommendation under carbon disulphide fumigation.

FUMIGATION OF GREEN BANANAS BY THE USE OF HYDROCYANIC ACID[5]

Large quantities of bananas are imported from the Tropics into the city of Philadelphia, Pa. The green fruit is shipped by boat to Philadelphia and transferred to refrigerator cars, in which it is distributed to localities throughout the Eastern States. Since Philadelphia is situated in the area heavily infested with the Japanese beetle (*Popillia japonica* Newm.), cars loaded in this city while the beetles are abundant are subject to infestation. Quarantine regulations, therefore, require that when the presence of the insects is noted in the vicinity of the wharves, no cars destined for points outside the

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[5] By J. William Lipp.

area under quarantine for the beetle may be moved unless assurance can be given that no infestation exists in them. The period during which this ruling is in force is approximately July 1 to August 15, the exact date being designated by the quarantine inspectors.

DISCUSSION OF METHODS USED PRIOR TO 1930

It had been hoped that the temperature produced in the cars as a result of icing would kill all the beetles that might be present, but it was found that they were merely rendered inactive. Attempts to prevent infestation were made by screening the passage between the fruit boat and the cars, but this method was unsuccessful. Since the desired results were not obtained by physical methods, it was decided to try chemical methods, and in this connection the use of a fumigant seemed the most logical of all insecticidal measures.

Although the usual way to obtain the answer to the problem would have been to test the effect of a number of materials upon the beetle, the need of a fumigant was urgent and it was decided to utilize the results obtained from experiments conducted in the Bureau of Entomology in 1926,[6] which indicated that hydrocyanic acid is very toxic to the adult beetle. With this work as a basis the following recommendations were suggested:

Three pounds of calcium cyanide (50 percent cyanogen (CN) content) per refrigerator car, for 2 hours, the temperature inside the car to be not less than 80° F. at the time of treatment.

Tests were conducted with caged beetles in refrigerator cars under the conditions recommended. As all the beetles were killed in these tests, the tentative recommendations were adopted. Research on this problem was continued, however, and in view of subsequent results the fumigation period was decreased to 1½ hours. In carrying out the fumigation 1 pound of the chemical was dropped into a flat container in each ice compartment (fig. 13) and the remainder was spread on the floor in the middle of the car. The hatches and side doors were then closed for the required length of time, after which the residues were removed and the doors sealed. The cars were then iced, the covers of the ice compartments were fastened open, and the openings were covered with screening to prevent reinfestation. The car was not ventilated at the wharf, as ventilation is accomplished by the passage of the air through the car during transit by way of the screened openings of the ice compartment.

This method was found to be very satisfactory in the case of ventilated cargoes. Where refrigerated cargoes were concerned, however, some injury was reported to have resulted from the treatment. It was supposed that the dropping of the fumigant into the bunkers caused the scattering of the smaller particles of the powder and that these particles of the cyanide dust had reacted with the moisture that had condensed on the surface of the cold fruit. This injury was eliminated by spreading one-half of the required quantity of calcium cyanide in each of two paper-lined wooden trays (3 by 6 feet) outside the car, and then placing these on top of the fruit (fig. 14). The trays were introduced at the start and removed at the end of the fumigation period through the center doors in the

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[6] Unpublished data of W. E. Fleming.

side of the car. By this revised procedure the fumigation of the cars was conducted for several seasons with very satisfactory results.

TESTS WITH COMMERCIAL PRODUCTS

The appearance on the market of several compounds that produce hydrocyanic acid gas suggested the desirability of finding out how effective these materials were against the beetle and whether or not they might be used as alternative fumigants. Accordingly, in 1930, a series of comparative tests was begun with five materials designated by number as follows:

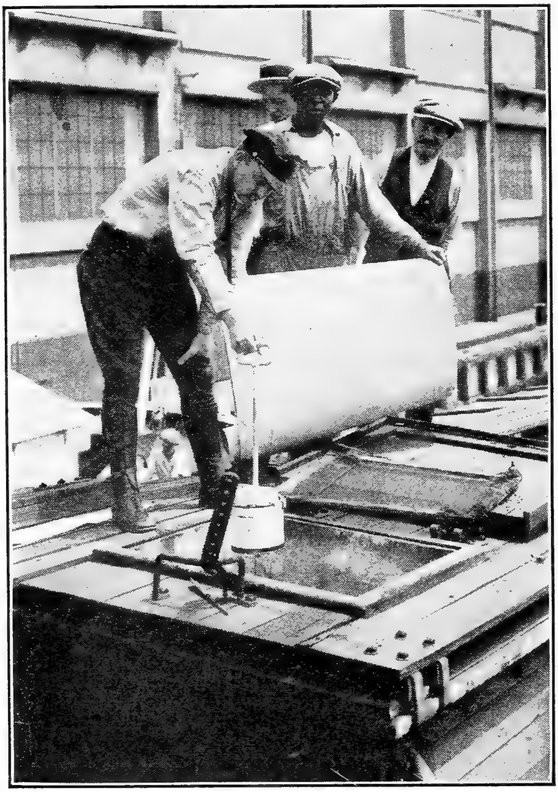

FIGURE 13.—Method of applying powdered calcium cyanide through the hatch into a container in the ice compartment.

No. 1. A crude calcium cyanide, made by treating calcium cyanamide with carbon and alkaline salts, and containing between 40 and 50 percent of calcium cyanide, in addition to impurities.

No. 2. A commercial calcium cyanide, made by treating lime with liquid hydrocyanic acid. This material contains approximately 88 percent of calcium cyanide, calculated from the 50 percent cyanogen content guaranteed by the manufacturers. (This was the product indicated in the recommendations, previously mentioned, for refrigerator-car fumigation.)

No. 3. A commercial preparation containing hydrocyanic acid, plus chloropicrin as a warning gas, absorbed on granular infusorial earth. This material is sold on the basis of net hydrocyanic acid content, a so-called " 1-pound can " meaning 1 pound of hydrocyanic acid, the weight of the inert material being disregarded.

No. 4. A commercial preparation containing hydrocyanic acid absorbed in disks of wood-paper pulp. This material is also sold on the basis of the hydrocyanic acid content, rather than the total weight of the contents of the can.

No. 5. Commercial sodium cyanide (96–98 percent NaCN). In all tests run with this material it was added to water and sulphuric acid in the usual ratio of 1 part sodium cyanide to 1½ parts of sulphuric acid and 2 parts of water.

Japanese beetle larvae were used as an index of toxicity, as they were procurable over a long period. All tests were performed in the fumigating house described in detail on page 2. The larvae, confined in wire cages, were placed in the house prior to the introduction of the fumigants. Compounds nos. 1 to 4 were spread out upon paper placed on the floor, while compound no. 5 was used according to the regular "pot method." At the conclusion of each test the larvae were removed for observation, the residues from the fumigating materials were discarded, and the house was aired thoroughly for 2 days before the next test.

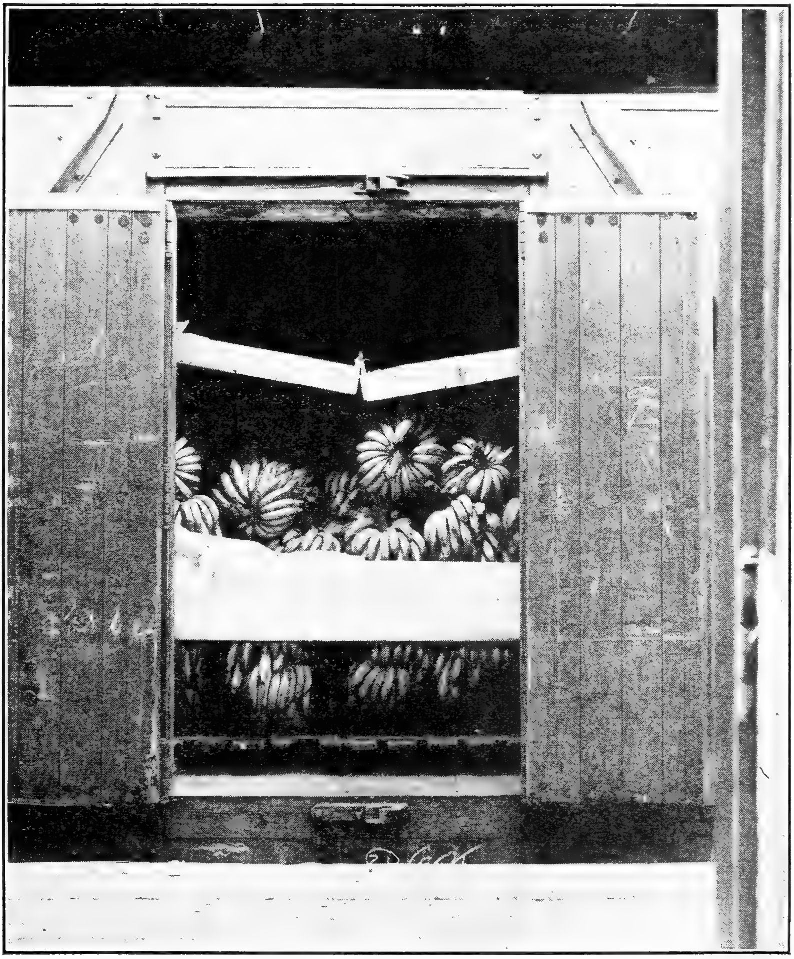

FIGURE 14.—Side view of car showing trays containing calcium cyanide on the bunches of bananas.

For making preliminary comparisons the writer decided to use as standard conditions a volume of 1,000 cubic feet (the volume of the fumigating house), a temperature of 80° F., and an exposure of 2 hours. Under these conditions a complete larval mortality was obtained with 3 ounces of compound no. 1, and with 1 ounce of compound no. 2 or no. 5.

Tests with compounds nos. 3 and 4 could not be run as indicated above because these materials are ordinarily unobtainable in packages smaller than 1 pound, although for experimental purposes "4-ounce cans" were supplied by the manufacturers. As indicated before, these "4-ounce cans" meant a net weight of 4 ounces of hydrocyanic acid, and it is obvious that the contents of these cans could not be divided into 1-ounce portions with any degree of accuracy. Consequently, an experiment was run with 4 ounces of each of compounds nos. 1 to 4[7] to determine the relative toxicity by the length of time required for each to effect a complete kill. The experiment was repeated, 1 pound instead of 4 ounces of each compound being used. The results of these experiments are shown in table 3 and graphically in figures 15 and 16.

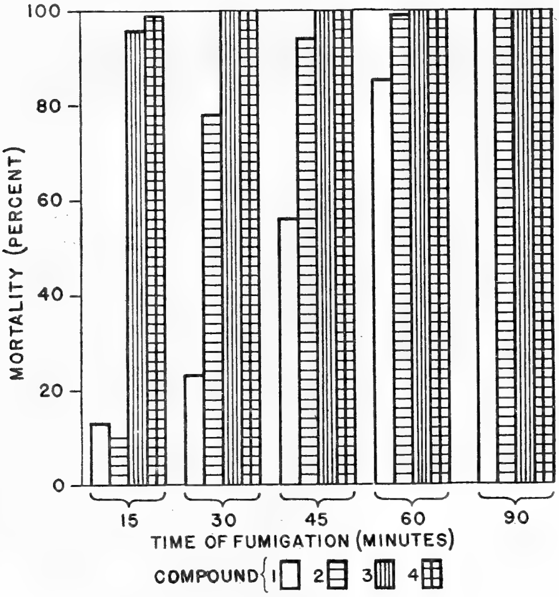

FIGURE 15.—Mortality of Japanese beetle larvae after exposure to compounds nos. 1 to 4 (4 ounces per 1,000 cubic feet) at 80° F.

TABLE 3.—*Mortality of Japanese beetle larvae from different periods of exposure to 4 ounces and 16 ounces of fumigating material per 1,000 cubic feet at 80° F.*

Quantity of material (ounces)	Time of fumigation	Mortality of larvae			
		Compound no. 1	Compound no. 2	Compound no. 3	Compound no. 4
	Minutes	*Percent*	*Percent*	*Percent*	*Percent*
4	15	13	10	96	99
4	30	23	78	100	100
4	45	56	94	100	100
4	60	85	99	100	100
4	90	100	100	100	100
16	15	33	17	100	100
16	30	95	95	100	100
16	45	100	100	100	100

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[7] No further tests were run with sodium cyanide (compound no. 5), as in refrigerator cars the use of this material with the necessary cumbersome equipment seemed impractical.

Tests were also run with 4 ounces each of compounds nos. 3 and 4 per 1,000 cubic feet at 75° and 70° F. Both compounds gave a complete larval mortality with an exposure of 45 minutes.

While all four of the materials being tested produce hydrocyanic acid, two important factors help to account for the varying results obtained with them, viz, the amount of hydrocyanic acid derivable from each material and the rapidity with which the gas is released from each.

The theoretical production of hydrocyanic acid from 1 pound of 100-percent pure calcium cyanide is 266.2 grams (0.587 pound). Therefore, from 1 pound of compound no. 1, assuming a 45-percent calcium cyanide content (based on the manufacturer's claim of 40–50 percent) the theoretical production would be 119.8 grams (0.264 pound) of hydrocyanic acid. From 1 pound of compound no. 2, assuming an 88-percent calcium cyanide content (50-percent cyanogen), the theoretical production would be 234.3 grams (0.517 pound) of hydrocyanic acid. With compounds nos. 3 and 4, however, the theoretical production of hydrocyanic acid from a "1-pound can" should be 453.6 grams (1 pound), since, as indicated above, the weight designation on the cans indicated the net weight of the hydrocyanic acid.

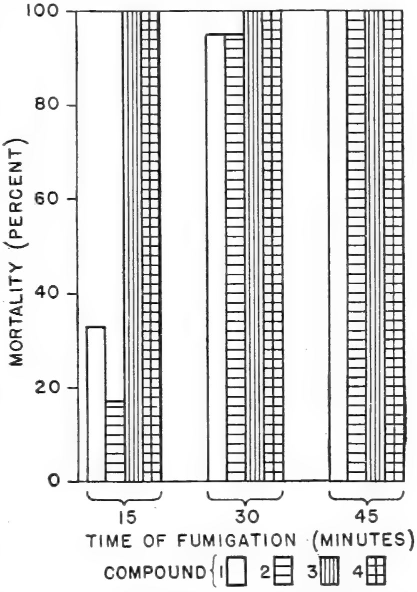

FIGURE 16.—Mortality of Japanese beetle larvae after exposure to compounds nos. 1 to 4 (16 ounces per 1,000 cubic feet) at 80° F.

From compounds 1 and 2 the gas is released by the action of atmospheric moisture, whereas from compounds 3 and 4 it is released by volatilization. The difference in the rapidity of the release of the gas by these two methods is very evident if data in table 3 are compared. One pound of crude calcium cyanide (compound no. 1) should theoretically produce 0.264 pound of hydrocyanic acid, as shown in the preceding paragraph, while a "4-ounce can" of compound no. 4 should produce 0.25 pound. While the theoretical production of hydrocyanic acid in these two cases is practically identical, it will be seen that with a 15-minute exposure in the first case only 33 percent of the larvae were killed, while in the second 99 percent were killed. It is evident that in the second case the hydrocyanic acid volatilized rapidly and that during the period of exposure the larvae were subjected to a higher concentration than that to which the larvae were subjected in the first case. That this explanation is not merely theoretical can be seen by comparing the mortalities which 4 ounces and 1 pound of compound no. 1 produced in the same length of time. In 45 minutes, for example, the 4-ounce dosage killed 56 percent of the larvae while the 1-pound dosage killed 100 percent. Since the compound and the method of liberation were the same in both cases, the higher kill with the larger quantity must have been due to the larger quantity of hydrocyanic acid gas in the air.

TESTS WITH LIQUID HYDROCYANIC ACID

As previously indicated, compounds nos. 3 and 4 are sold on a basis of the net weight of hydrocyanic acid per can, and the contents cannot be divided accurately into smaller quantities. In view of this condition it was not possible to determine the value of smaller quantities of either of these materials. However, since the active killing agent in all the compounds tested is hydrocyanic acid gas, tests were begun with liquid hydrocyanic acid.

For experimental work a storage cylinder containing the liquid was brought into the fumigating house. By the proper manipulation of valves the liquid was permitted to flow into a measuring glass. The valves in the cylinder were then closed, and the measured quantity of liquid hydrocyanic acid was released into a flat metal pan, from which it volatilized quickly.

Tests were run with different amounts of chemical and for different periods of time, using Japanese beetle grubs as indicators of toxicity. The results are given in table 4.

TABLE 4.—*Mortality of Japanese beetle larvae from different periods of exposure to varying quantities of liquid hydrocyanic acid per 1,000 cubic feet*

Quantity of hydrocyanic acid (ounces)	Time of fumigation	Temperature	Larvae found		
			Normal	Sick	Dead
	Minutes	° *F.*	*Percent*	*Percent*	*Percent*
4	120	75–77	0	0	100
4	90	75–77	0	0	100
4	60	75–77	0	0	100
4	30	75–77	0	0	100
2	120	75–78	0	0	100
2	90	75–78	0	0	100
1	120	76–78	0	33. 8	66. 2
1	90	76–78	4. 6	60. 7	34. 7

In this table several significant points can be noted. Some normal grubs were found in the tests with 1 ounce for 90 minutes, whereas with 1 ounce for 120 minutes no normal but some sick grubs were found. With 2 ounces a complete kill was obtained with exposures of 90 and 120 minutes. With 4 ounces a complete kill resulted from exposures of 30 minutes or longer. Reference to table 3 shows that these results confirm those with compounds nos. 3 and 4, although the tests with those materials were conducted at 80° F.

REACTION OF ADULT BEETLES TO LIQUID HYDROCYANIC ACID

As soon as adult beetles were available, a series of three tests were conducted in the fumigating house with liquid hydrocyanic acid. In each test 1,000 beetles were exposed to 2 ounces of the chemical per 1,000 cubic feet of space, for 2 hours, at temperatures of 76°, 71° and 66–71° F., respectively. In the third test the initial temperature of 66° was obtained by placing several large cakes of ice in the fumigating house. By the end of the 2-hour exposure, however, the temperature had risen to 71°. In all tests a complete kill was obtained.

On June 30, 1932, approximately 2,000 beetles, confined in cages, were taken from Moorestown, N. J., to Philadelphia. One thousand were distributed throughout a refrigerator car immediately after it had been loaded with bananas. The remaining beetles were allowed to remain outside the car during the period of treatment. A total of 6 ounces of liquid hydrocyanic acid was applied to the car (capacity 2,600 cubic feet), 3 ounces through the ice compartment at each end of the car. The covers of these compartments were then closed for 2 hours, after which the apparatus (discussed below) and the beetles were removed. The car was then iced, the covers were fastened open, and the tops of the ice compartments were screened to prevent infestation.

This car was shipped within a few hours, and 5 days later representatives of the Bureau of Entomology and of the fruit company examined the fruit in the warehouse of a Cleveland, Ohio, dealer, to whom the fruit had been consigned. No injury attributable to the treatment was detected.

The beetles that had been removed from the car at the end of the fumigating period, along with those which had been left untreated, were taken to Moorestown, where they were kept under observation for 48 hours. At the end of this period the untreated beetles showed a survival of 94 percent, while none of the treated beetles survived. As a result of these tests with the adult beetle, recommendations were made to the quarantine authorities for the use of 6 ounces of hydrocyanic acid per refrigerator car for 2 hours, the temperature inside the car to be not less than 75° F. at the time of treatment. These recommendations were in turn issued by the quarantine authorities as an alternative treatment.

METHOD OF APPLICATION OF LIQUID HYDROCYANIC ACID TO REFRIGERATOR CARS

In one test the liquid was applied through the side doors of the car. The doors were closed almost completely, just enough space being left to permit inserting a long tube by means of which the chemical was sprayed into the car. The storage cylinder was placed outside the car on a set of scales. After the combined weight of the cylinder and liquid was read, hydrocyanic acid was pumped into the car until the reading on the scales indicated that the required quantity had been used. During the process the odor of the chemical was very pronounced outside the car.

The method which seemed the most practical consisted of applying the liquid from the top of the car, through the openings of the ice compartments. On the ice rack in each compartment a small cup, capable of holding 3 ounces of hydrocyanic acid, was placed in a shallow pan. A long cord was tied to the handle of the cup. By means of a long delivery tube the cup was filled from a small portable drum, and the liquid emptied into the pan by pulling the cord. The compartment covers were then closed for 2 hours, after which they were opened and the operator removed the pans and cups.

COMPARISONS OF THE USE OF CALCIUM CYANIDE AND LIQUID HYDROCYANIC ACID

During one treating season (1932) liquid hydrocyanic acid was used to fumigate a total of 111 cars at a cost of $0.37 per car (6 ounces of hydrocyanic acid at $1 per pound). The calcium cyanide costs $3.45 per car (3 pounds of calcium cyanide at $1.15 per pound). In this way a saving was made of approximately $340 on materials for treating the 111 cars with the hydrocyanic acid. In addition, no fruit injury due to the treatment was reported at any time during the treating season.

The introduction of the hydrocyanic acid from the top of the cars is much simpler than the introduction of calcium cyanide through the side doors. In the former method the cups and pans can be placed in the ice compartments while the interiors of the cars are being loaded with fruit. As soon as the cars have been loaded the side doors may be closed and sealed. The operator can then go along the tops of the cars, applying the fumigant, followed by an assistant to lower the covers of the ice compartment. At the conclusion of the treatment the operator can remove the apparatus from the ice compartments. This eliminates the necessity of opening and closing the heavy side doors of the car, as is the case both when introducing the trays containing the calcium cyanide and when removing the residues.

Certain local conditions may, of course, govern the choice of chemical. It is obvious, for example, that although the use of hydrocyanic acid would probably be more satisfactory for the dealer with a large number of cars to fumigate, the dealer with only a few cars to fumigate would be more inclined to purchase a few cans of calcium cyanide.

ABSORPTION OF HYDROCYANIC ACID BY BANANAS

In connection with this work there naturally arose the question of whether or not the bananas would absorb any appreciable quantity of fumigant. Griffin and others (*3*) had found that ripe bananas absorbed as much as 440 parts per million when fumigated at the rate of 40 ounces of sodium cyanide per 1,000 cubic feet. The theoretical production of hydrocyanic acid from this quantity of material is approximately 22 ounces, which is much greater than the quantity needed in refrigerator-car fumigation.

In order to determine the amount of hydrocyanic acid absorbed by green bananas, analyses[8] were made in 1927 of green fruit treated for 2 hours with 3 pounds of calcium cyanide per car. The hydrocyanic acid in the fruit was determined by the method of Viehoever and Johns (*8*). Only very small quantities were found. In 1931 many analyses[9] were made of green fruit which had been subjected to a fumigation of 1 hour with 1½ pounds of hydrocyanic acid absorbed in disks of wood-paper pulp per car. The method of analysis mentioned above was used. Separate analyses were made of skin and pulp, samples having been taken from the same bunches both 2 hours after fumigation and after they had remained in a cold

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[8] This work was done by K. B. Rogers and H. W. Coward, former members of the laboratory staff.

[9] This work was done by C. W. Mell, a former member of the laboratory staff.

cellar for 5 days. Results of a typical set of analyses are indicated in table 5.

TABLE 5.—*Amounts of hydrocyanic acid, expressed as parts per million of fruit, found in skin and pulp of bananas fumigated in a refrigerator car for 1 hour with $1^1/_2$ pounds of hydrocyanic acid absorbed in wood-paper pulp*

Sample no.	Samples taken within 2 hours of fumigation		Samples taken 5 days after fruit had been placed in cold cellar		Sample no.	Samples taken within 2 hours of fumigation		Samples taken 5 days after fruit had been placed in cold cellar	
	Skin	Pulp	Skin	Pulp		Skin	Pulp	Skin	Pulp
1	10	2	0	0	5	10	1	0	1
2	5	2	0	0	6	1	1	0	0
3	4	4	1	0	7	7	1	0	0
4	5	3	1	0	8	5	1	0	0

It can be seen from table 5 that 10 parts of hydrocyanic acid per million was the greatest quantity found in any of the determinations. Furthermore, 5 days after fumigation the hydrocyanic acid had disappeared almost completely.

INJURY TO FRUIT

From the time bananas are picked and leave the plantations they are subject to injury from bruising and scarring. Improperly packed fruit, for example, may be tossed about on the boats or in the cars. Fruit injured in this manner while green usually gives little evidence of the injury until it has ripened, at which time the skin darkens and the flesh just beneath becomes soft.

Injury from hydrocyanic acid is very different, and there are many factors which govern its occurrence and severity. It rarely occurs with ventilated fruit. Even when 1½ pounds of liquid hydrocyanic acid was sprayed into the fruit compartment of the car, no injury was detected. The situation is quite different with refrigerated fruit, which becomes covered with condensed atmospheric moisture as soon as it is brought from the hold of the ship to the outside air. When calcium cyanide was dumped into the ice compartments, as in the original fumigation procedure, particles of the dust were caught by the moisture and reacted with it. Certain of the fruit company officials, however, claimed that the injury which occurred was due to lime rather than the hydrocyanic acid, since similar injury could be produced by dusting fruit with hydrated lime.

With the use of liquid hydrocyanic acid the possibility of lime injury is eliminated. In this case any injury which results is undoubtedly caused by the absorption of the gas by the moisture on the fruit. Very high concentrations or prolonged exposures cause severe injury. Figure 17 shows the differences in injury caused by exposures of one-half hour and 4 hours to a concentration of 5 pounds of hydrocyanic acid per 1,000 cubic feet, the pictures having been taken 5 days after the fumigation.

Cyanide injury often starts as a slight discoloration at the point of a bruise or a scar, but, unlike the latter, it spreads until a considerable area is discolored. Figure 18 shows two stages in the progression of cyanide injury, 3 days having elapsed between the taking of the pictures. Another feature which characterizes cyanide injury is the fact that the flesh beneath the injured skin is usually hard and pithy. In the case of a banana severely injured (fig. 17, *B*) by a heavy dosage of hydrocyanic acid the fruit does not ripen and remains hard long after untreated fruit has become overripe.

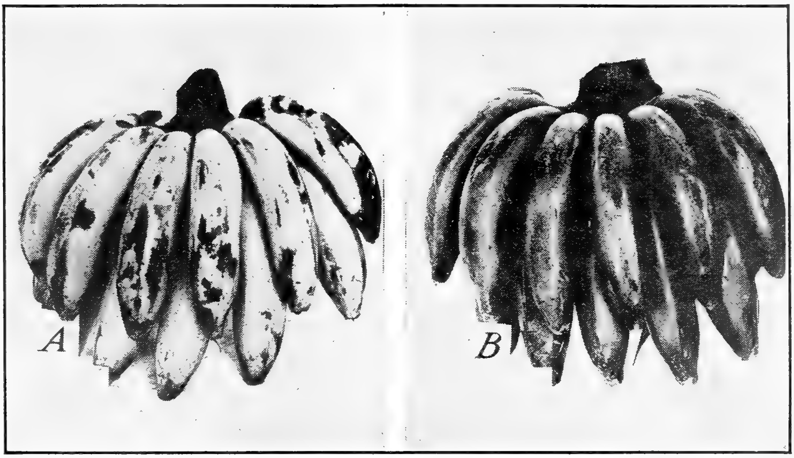

FIGURE 17.—Bananas injured by fumigation with hydrocyanic acid (5 pounds per 1,000 cubic feet): *A*, Hand exposed to fumigant for one-half hour; *B*, hand exposed to fumigant for 4 hours. Photographs taken 5 days after fumigation.

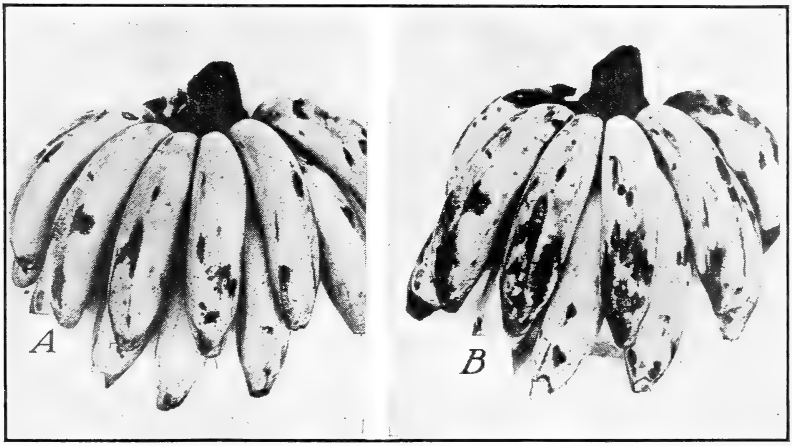

FIGURE 18.—Progressive stages in injury to bananas caused by fumigation with hydrocyanic acid (5 pounds per 1,000 cubic feet for one-half hour): *A*, Hand showing slight injury; *B*, the same hand, 3 days later, showing how the injury has spread.

It must be remembered that all the fruit under discussion was subjected to a dosage of 5 pounds of hydrocyanic acid per 1,000 cubic feet. The difference between this concentration and 6 ounces per refrigerator car is apparent, and it has been previously pointed out that 111 cars were treated in one season with this latter dosage without any complaints about fruit injury having been made.

RECOMMENDATIONS FOR REFRIGERATOR-CAR FUMIGATION

Infestations of the Japanese beetle can be destroyed by either of the following fumigation procedures.

(1) Application of 3 pounds of calcium cyanide (50-percent cyanogen) per refrigerator car for a period of 1½ hours, the temperature inside the car to be not less than 80° F. at the time of treatment.

(2) Application of 6 ounces of liquid hydrocyanic acid per car for 2 hours, the temperature inside the car to be not less than 75° F. at the time of treatment.

PRECAUTIONS TO BE OBSERVED

Hydrocyanic acid gas, whether evolved as a result of the action of moisture on calcium cyanide, or as a result of the volatilization of liquid hydrocyanic acid, is highly toxic to human beings. For this reason no one working with either of the two recommended materials should fail to use a gas mask, either when applying the treatment, or when removing the residues or apparatus used in connection with them, at the end of the treatment. Although the gas has a characteristic odor, the knowledge of its presence is not a complete safeguard, and no one should assume that the amount present in the air is not sufficient to be harmful.

SUMMARY

The shipment of fresh fruit, such as raspberries, blackberries, and blueberries, which are harvested at the time that adult Japanese beetles are present, is not permitted to points outside the quarantined area, unless methods are used to eliminate the danger of transporting beetles with the fruit. As fumigation seemed to be the most practical procedure with this problem, preliminary tests were begun in 1928, which indicated that carbon disulphide is very effective in destroying the beetles. Fumigating the fruit in an airtight room, using 10 pounds of chemical per 1,000 cubic feet for 2 hours with a temperature of 80° F., gives a complete kill of the beetles, both in baskets of fruit and when exposed directly to the action of the vapor.

Blueberries treated with this dosage were found to be slightly inferior to untreated fruit. All the treated fruit of the other varieties was normal in appearance, flavor, and keeping qualities when compared with untreated fruit.

Samples of blackberries were analyzed immediately after they had been taken from the fumigating room. In no case did the amount of carbon disulphide absorbed exceed 2 parts per million of fruit.

Experiments with ethylene oxide indicated that a complete kill of beetles resulted from a 2-hour exposure to 2 pounds of chemical per 1,000 cubic feet at 75° F. Blackberries exposed to this treatment were apparently uninjured, while treated blueberries were slightly inferior to untreated ones.

A description of the fumigating house used, a discussion of the operation of commercial fumigating houses, and details of fumigating under commercial conditions, are included.

Large quantities of bananas are imported from the Tropics into the city of Philadelphia, Pa. Refrigerator cars loaded in this city while Japanese beetles are abundant are subject to infestation, and no cars destined for points outside the quarantine area can be moved unless assurance can be given that no infestation exists in them. Attempts to screen the passage between the fruit boat and the cars proved unsuccessful. Severe injury occurred to bananas exposed to 2 pounds of ethylene oxide under the conditions indicated above.

Tests have shown that all beetles can be killed with an exposure to 3 pounds of calcium cyanide (50-percent cyanogen) per refrigerator car of 2,600 cubic feet capacity, for 1½ or 2 hours, with an initial temperature of 80° F. inside the car. The powdered chemical is spread in paper-lined wooden trays, which are placed on top of the fruit.

Tests with a number of compounds which produce hydrocyanic acid gas indicated that toxicity to Japanese beetle grubs is dependent on the amount of hydrocyanic acid gas produced and the rapidity of its evolution, under similar conditions of exposure and temperature. The compounds showing the highest degree of toxicity were those containing liquid hydrocyanic acid absorbed in diatomaceous earth or in wood-paper pulp.

Tests with liquid hydrocyanic acid showed that both grubs and adult beetles can be killed by a 2-hour exposure to 6 ounces of the chemical per refrigerator car, the temperature inside the car being 75° F. at the start of the treatment. The liquid is introduced from a portable drum into containers placed on the rack in the ice compartment at each end of the car.

The costs for calcium cyanide and hydrocyanic acid are approximately $3.45 and $0.37 per car, respectively.

The amount of hydrocyanic acid absorbed by the bananas is not more than 10 parts per million, practically all of which has disappeared 5 days after fumigation.

Bananas were injured by dosages of 5 pounds of hydrocyanic acid per 1,000 cubic feet. However, no injury to fruit when fumigated with the recommended amount (6 ounces per car) has been reported.

Precautions to be observed while handling cyanide compounds are included.

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