HAWAII AGRICULTURAL EXPERIMENT STATION
of the
UNIVERSITY OF HAWAII

CIRCULAR NO. 14

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HONOLULU, T. H.
September 1939

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The authorization for entry of Hawaiian fruits and vegetables into the mainland of the United States permits sterilization by heating the fruit or vegetable until the approximate center reaches 110° F. and holding this temperature for a period of 8 hours in a treating medium saturated with water. No specifications as to the exact methods and equipment for obtaining these conditions are given.

The use of heat for the single purpose of destroying insect life is a well-known practice and does not generally involve difficulty when the only consideration is the effect on the insect. Applications of high temperatures to plant material, however, introduce complications with respect to ability of the host plant to withstand exposure which is lethal to the insect. This point was clearly demonstrated in the development of the high-temperature sterilization treatment for Florida citrus fruits during the Mediterranean fruitfly campaign in that state. Early experiments indicated conclusively that, with application of dry heat, the required temperature (110° F.) could not be maintained for 8 hours without injury to the fruit. To prevent such injury, and yet obtain satisfactory larval mortality, it was necessary to maintain a very high humidity throughout the period of treatment. In commercial application, live steam was applied in such a way as not to discharge directly on the fruit but with as nearly as possible uniform distribution. The air ranged in temperature from 110° to 112° F. and was fully saturated with moisture obtained from the steam and water spray nozzles located in the air conditioning and circulating system.

This particular process of sterilizing plant material for insect destruction has remained basically unchanged since its development in 1929. By its use the Florida citrus industry was enabled

to ship out of a quarantined area and successfully market more than 180,000,000 pounds of citrus fruits. Grapefruit, oranges, tangerines, satsumas, and avocados were all subjected to the same process and moved commercially. It was early noticed that, in some instances, fruits other than grapefruit did not completely tolerate the sterilization process and injury could not be entirely avoided.

Subsequent experimental work in Florida and California indicated that certain fruits and vegetables did not permit the process, others were perfectly tolerant, and still others were on the borderline. In the last-mentioned cases, varietal differences were noted, and sometimes variations in tolerance within the variety were evident.

Recent work in Hawaii in connection with Solo papayas treated in accordance with quarantine requirements has disclosed this same intravarietal variation in resistance to injury, and has led to the efforts and experimental results described below.

Results of First Four Trial Shipments to the Coast

After several trial treatments of papayas by the sterilization method, apparently without injury to the fruits, experimental shipments to the coast began. Four such shipments were made between November 23 and December 30, 1938; all were consigned to a laboratory in California where the fruits were opened and examined for general appearance, flavor, texture, and soundness. They were reported as having arrived in good condition with fine flavor and very little decay.

Results of Fifth Shipment

Following the same procedure as for previous lots, a fifth shipment was made on January 13, 1939. The coast laboratory reported that all fruits were injured, some seriously. The only apparent difference between the first four successful shipments and the fifth unsuccessful shipment was in time of harvest of the fruits, the former after a period of light rainfall and the latter after a period of heavy rainfall. Thus it was apparent that the success of sterilization treatment at 110° F. for 8 hours, with air at 100 percent relative humidity, might depend on the condition of the fruits. There being no practical way of controlling this

condition as determined by climate, the solution was dependent on modifying the sterilization treatment so as to prevent injury to fruits harvested under less desirable conditions.

Plan of Further Experimental Treatments

Since the only apparent difference between successful and unsuccessful shipments was that the fruits for the latter were harvested after a period of heavy rainfall, it was suspected that the rainy period caused an increase in the moisture content of the fruits with a resulting decrease in tolerance to the sterilization process. A consequent assumption was that if the higher water content of the fruits could be decreased before the sterilization period, injury would be less likely.

Papayas were harvested from the Kailua and Ewa districts of Oahu under known conditions in quantities sufficient for comprehensive tests.

Maturity

The ripening process in the papaya is continuous and, once begun, has no definite stages, but for practical purposes the fruits were divided into three stages of maturity: (a) Mature-green, (b) firm-ripe, and (c) ripe. Mature-green fruits are those in which the dark-green color is beginning to fade and there is a slight blush of yellow near the blossom end. Firm-ripe includes all fruits which range from mature-green to about two-thirds full yellow. Ripe fruits are classified as all riper than firm-ripe but not overripe. These color standards vary somewhat with the location and with the season of the year so that it is necessary in most instances to cut a few fruits to determine the correlation of the color with the maturity.

Selection and Handling

In the experiments conducted to date, only fruits of the Solo variety were selected. These came from the complete flower or type IV trees, as the pyriform papaya has proved to be more acceptable to the market than the round female Solo. Only fruits free of blemishes and of the best quality were selected. These, on harvesting, were placed in field boxes containing excelsior and brought to the sterilization room. They were then transferred to boxes with slatted bottoms for the heat treatment.

Relative Humidity During Treatment

For the purposes of these experiments, the heat treatment was broken down into three phases: (a) conditioning, (b) approach, and (c) sterilization. The conditioning period was an interval at the beginning of the treatment, the purpose of which was to reduce the moisture content of the fruits. The approach was the period during which the fruits were brought to the required temperature. The sterilization phase was an 8-hour period during which the temperature of the fruits was maintained at 110° F. by means of air fully saturated with water.

Handling After Treatment

After each treatment, the fruits were immediately removed from the sterilization room and allowed to cool at room temperature or, in some cases, at 50° F. After periods of about 48 hours for papayas held at room temperature and about 10 days for those held at 50° F., the fruits were examined to determine the physiological effects of the treatment, including external appearance, flavor, aroma, color, and texture.

Results

The general effect upon external appearance of high-temperature sterilization was a marked acceleration of color development. The flavor, aroma, color, and texture of treated, uninjured fruits were equal to or better than those of untreated fruits. Injured fruits had a cooked flavor and an unpleasant and disagreeable odor. The injured portions of the flesh and the funiculi had changed from golden orange to bright lemon-yellow. Several days after treatment, injury in some cases apparently accentuated a blackening of the vascular bundles. In the riper fruits the injured flesh became soft and translucent. In less ripe fruits, the injured portions did not ripen and remained as a hard shell about the fruit cavities.

The following table shows typical results of a few experiments which are representative of many. Twenty-four fruits at each stage of maturity were treated under each set of conditions.

TABLE 1.—Effects of high-temperature sterilization under various conditions on Solo papayas

Relative humidity of treating medium			Extent of injury		
Conditioning period—6 hours at 100° F.	Approach period—2 to 2½ hours at 110° F.	Sterilization period—8 hours at 110° F.	Ripe fruit	Firm-ripe fruit	Mature-green fruit
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
60	80	100	38	8	0
60	60	100	25	0	0
100	100	100	100	100	100

It is apparent from table 1 that less injury occurred when air with a low relative humidity was used during the conditioning and approach periods. Sterilization with air at 100 percent relative humidity during the entire treatment injured all fruits harvested at this season. At other periods of the year, the fruits may not all be injured.

With fruits subjected to a conditioning period of 6 hours at 100° F. and 60 percent relative humidity and an approach period of 2 hours at 110° F. and 80 percent relative humidity before the required sterilization, injury was reduced from 100 percent to 37.5 percent for ripe, 8.3 percent for firm-ripe, and none for mature-green fruits. When the approach period was also held at 60 percent relative humidity instead of being increased to 80, the injury was further reduced to 25 percent in the ripe fruits and none in the firm-ripe and mature-green fruits.

CONCLUSIONS

1. The use of air fully saturated with water throughout the entire high-temperature treatment of Solo papayas resulted in maximum percentage of injury.

2. A conditioning period of 6 hours with air at 100° F. and 60 percent relative humidity followed by a period of approximately 2½ hours with air at 60 percent relative humidity and 110° F. gave minimum injury. After the conditioning and approach intervals, the sterilization was carried out according to requirements.

3. In general, ripe fruits were less tolerant than firm-ripe or mature-green fruits during the high temperature treatment.

Recommendations

The following recommendations are based on the results and observations of experimental work to date. Experience has shown that even though these recommendations are followed, some injury may occur. The extent of such injury, however, is well within the limits of commercial practice.

1. Only highest-quality, type IV Solo fruits should be selected for heat sterilization. Bruised, misshapen, scarred, and insect or fungus-injured fruits should be discarded. To avoid bruising, care must be practiced in all handling. The field boxes should be padded.

2. Fruits should be graded as to maturity before treatment and ripe fruits disposed of locally.

3. Before sterilization, the fruits should be subjected to a conditioning period of 6 hours during which the air is maintained at 100° F. and 60 percent relative humidity. The fruit temperature should be raised to 110° F. (this approach period requires from 2 to 2½ hours) before the humidity is increased to saturation and then held at this temperature for 8 hours, during which final stage the relative humidity of the air must be maintained at 100 percent.

4. Immediately upon termination of the treatment, the fruits should be removed from the sterilization chamber and arranged in such a manner that they will be aerated and allowed to cool as quickly as possible to atmospheric temperature. Under no circumstances should they be packed while warm.

5. After cooling, the fruits, if they are to be shipped commercially, should be graded to allow for different rates of ripening during treatment, and any bruised or cut fruits should be discarded. They should then be packed in an approved manner in a suitable container for shipment.

6. After packing, the fruits should be cooled to and maintained at 50° F. Fruits treated as recommended may be safely held for at least 10 days at this temperature.