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Hot-Air Quarantine Treatment for Apples Infested with Apple Maggot

Trisha R. Blessington and Dr. Guy J. Hallman

Subtropical Agricultural Research Center, Crop Quality and Fruit Insects Unit, 2301 International Blvd., USDA-ARS, Weslaco, TX 78596

ABSTRACT

Red 'Delicious' apples, *Malus domestica*, were infested with apple maggot, *Rhagoletis pomonella* (Walsh), third instar larvae and subjected to forced hot air at 46°C (air speed 0.3-0.4 $m^3 \cdot s^{-1}$). One hundred percent mortality was found for a treatment for 240 minutes in the dry hot air chamber. The average core temperature was 41.0°C and the maximum core temperature was 45.9°C. The average surface temperature was 43.9°C and the maximum surface temperature was 45.6°C.

RESUMEN

Se infestaron manzanas *Malus domestica* cultivar Red 'Delicious' con larvas del tercer instar de gusano de la manzana, *Rhagoletis pomonella* (Walsh), y se sometieron a tratamientos de aire caliente forzado a 46°C (velocidad del aire de 0.3 - 0.4 $m^3 \cdot s^{-1}$). Se encontró un cien por ciento de mortalidad con el tratamiento de 240 minutos en la cámara de aire caliente seco. La temperatura promedio en el corazón fue 41.0°C y alcanzó un valor máximo de 45.9°C. La temperatura promedio en la superficie fue 43.9°C y alcanzó un valor máximo de 45.6°C.

Additional index words: methyl bromide, commodity treatment, hot air chamber

The red 'Delicious' apple, *Malus domestica*, is a host of the apple maggot, *Rhagoletis pomonella* (Walsh). The apple maggot is native to temperate North America east of the Rocky Mountains and also attacks native hawthorns, *Crataegus* spp. (Prokopy and Mason, 1996). It has also moved to the west of the Rocky Mountains and is found in several northwestern states threatening the large apple industry there. In the summer of 1998, western Washington was quarantined due to an outbreak of apple maggots (The Seattle Times, 1998). To transport apples to areas where the apple maggot does not exist and could possibly become established, quarantine protocol require the fruit be subjected to a treatment to make certain that no apple maggots are also shipped in the load. The Animal Plant and Health Inspection Service along with similar agencies in other countries provide the leadership, management and coordination of national and international activities to protect the health of national resources and facilitate the commodities movement in commerce (Shannon, 1994) Presently, methyl bromide is used as a fumigation treatment to kill apple maggots. Methyl bromide is considered a significant ozone depleting substance. According to the EPA, the world uses 76,000 tons of methyl bromide every year, with the U.S using 43% which is the highest usage of all nations (EPA, 1995). Non-fumigant quarantine alternatives that are currently being explored are irradiation, controlled atmospheres, cold-storage, hot water immersion and hot air treatments (Hallman and Quinlan, 1994).

Hot air quarantine treatments use heated air through convection and water vapor to heat fruit without desiccation. The idea of heated air to kill larvae inside fruit was originated by Crawford in 1927 (Hallman and Armstrong, 1994). In Florida in 1929, the commercial use of vapor heat was used in the eradication of the Mediterranean fruit fly in citrus; and in the 1930's to 1950's vapor heat was used in the eradication of the Mexican fruit fly (Hallman and Armstrong, 1994). With the efficiency and low cost of methyl bromide fumigation, heated air treatments were replaced for many years. In more recent studies of commodities infested with fruit flies, Caribbean fruit fly larvae were killed using vapor heat in carambolas at chamber temperatures of 47°C (Hallman, 1990) and infested grapefruit required 48°C to kill the larvae. Nevin (1998), is presently doing research on coddling moth larvae infesting in apples. She recommends a maximum heating rate of 12 degrees/hour to prevent fruit damage. Hot air temperatures of 44°C for 4 hours or 46°C for 2 hours are used, followed by either a cold storage at 0-2°C for up to 28 days or combining a controlled atmosphere, manipulating carbon dioxide and oxygen levels with the hot air treatment. The objective of our research was to develop a hot air treatment for apples infested with third instar apple maggot larvae. Apple maggot mortality was the emphasis of this study, not apple quality.

MATERIALS AND METHODS

Organic red 'Delicious' apples provided by the USDA-ARS in Wapato, Washington were used as the host. Colonies of *Rhagoletis pomonella* were reared on apples and adults fed on a diet consisting of three parts table sugar and one part hydrolysate yeast along with a purified water supply. Forty to forty-five apples were divided into four cages with over 100 *R. pomonella* adults per cage. Additional flies were added daily to replace those that died. Infested apples were taken out every 2-3 days, put in plastic, breathable containers and stored in a room at 25°C for 12 to 14 days. At the time the experiment was to be performed, the larvae were in the third instar, and just at the time of emergence from the apple.

The infested apples were randomly selected for those to be used on the treatment and the control. Filler apples, which were also red 'Delicious', or filler grapefruits, were used to increase numbers, to help create a more commercial type of application, and also helped slow down the heating rate of the chamber. Thermocouples, calibrated with a thermometer that had been calibrated to specific U.S. standards, were used to measure surface and core temperatures. Three filler apples had a copper thermocouple placed in the core and were held in place by plastic tape. Another three filler apples were selected to measure surface temperature and thermocouples were taped on the surface of the apples, soldered tips touching the skin.

The infested apples and filler apples were placed in the plastic box with a grated bottom in the hot air chamber. The chamber had three boxes and the infested fruit was put in the middle container, in the center of the hot air machine. The filler fruit was put inside the box with the infested fruit and also in one of the other chamber boxes. Two additional thermocouples were attached to the top of the container to measure the chamber temperature. For each trial, the fruit was exposed to a computer-set temperature of 46°C for various time intervals. The time was set to record after the water in the humidifier was boiling and the core temperature was approximately room temperature. The average core temperature, surface temperature, relative humidity and change in temperature were recorded at 60 second intervals by a computer attached to the chamber. The air flow circulated from the top of the chamber to the bottom. The average flow rate of the forced air was set between 0.3 and 0.4 $m^3 \cdot s^{-1}$, in each trial.

After the apples were exposed to the hot air, they were stored in breathable plastic containers and checked every day for larvae emergence. The data were analyzed based on larvae emergence from the apples. Each treatment time had 15 to 20 apples per replication.

RESULTS AND DISCUSSION

The evaluation of the hot air treatment was based upon the amount of mortality of fly larvae after a certain time period. It was found that a treatment of between 180 and 240 minutes at a chamber temperature of 46°C killed 99 to 100 percent of the third-instar larvae inside the infested apple (Table 1). The only treatment that provided 100 percent mortality was the 240 minute treatment at 46°C chamber temperature. The experiment was repeated twice with 100 percent mortality for this treatment. The average core temperature was 41°C and the average surface temperature was 43.9°C with an average of 81.1 percent relative humidity inside the chamber (Table 2).

Table 1. The relationship between average larvae emergence in each time interval exposed to hot air at 46°C, set chamber temperature.

Time	No. of reps.	Total No. of treated apples	No. of larvae per treated apple	No. of larvae per control apple	Mortality
45 min.	1	18	15.2	15.8	4%
60	1	18	14.7	15.8	7
120	1	20	6.6	7.3	10
150	2	40	7.2	7.3	10
180	4	80	0.2	13.7	99
210	1	20	1.05	9.4	99
240	2	30	0	4.3	100

Table 2. The relationship between the average and maximum temperature of the core and surface of treated apples, the average relative humidity, and the change in temperature after the first hour, in each of the time intervals exposed to hot air at 46°C, set chamber temperature.

Time	Average core temp.	Maximum core temp.	Average surface temp.	Maximum surface temp.	Relative Humidity	Change
min.	°C				%	$°C \cdot hr^{-1}$
45	33.9	39.3	38.6	38.9	69.4	X
60	30.1	39.3	41.8	44.7	72.9	13.2
120	34.6	37.7	38.1	38.4	86.5	11.7
150	36.1	42.8	39.7	44.1	83.1	9.6
180	39.9	44.7	43.1	44.9	84.4	17.1
210	39.7	44.1	41.9	44.4	81.6	15.5
240	41	45.6	43.9	45.9	81.1	17.9

The highest temperature the core reached was 45.6°C, and the highest temperature the surface reached was 45.9°C (Table 2).

In conclusion, it is possible to kill third instar apple maggot larvae in apples with hot air treatments at 46°C for 240 minutes. In order for it to be accepted as a quarantine treatment, the probit 9 level of security established by Baker (1939), which is a statistical standard for the development of laboratory data on quarantine treatments for fruit flies in commercial fruit, must be studied. The probit represents a mortality of 99.996832 percent or a survival of approximately 3.2 out of 100,000 insects (Shannon, 1994). This will require further replications of the experiment. It will also be necessary to study the effect this treatment has on younger larvae and eggs of the apple maggot. Future studies should also be done on the amount of fruit damage caused at the present heating rate of the chamber. If further studies support the present data without significant fruit damage, hot air treatments will provide a quick, feasible means to kill infested apple maggots in apples.

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