Subtropical Plant Science. 47: 12-25.1995

# Post-Harvest Treatment of Citrus, Mango and Other Fruit Status for Quarantine Security Against *Anastrepha* Species (Diptera: Tephritidae)

**Dan A. Wolfenbarger**

*USDA, ARS, Crop Quality and Fruit Insects Research, 2413 East Highway 83, Weslaco, Texas 78596, USA*

## ABSTRACT

**Development of postharvest quarantine treatment methods against several *Anastrepha* species that infest citrus, mango, peaches, plums, nectarines, and pears is reviewed. Quarantine treatment technologies including refrigeration, vapor heat, fumigants, etc. are discussed and the future of treatments against these pests is speculated. Irradiation does not kill all late instar immature stages present in the fruit at 30,000 rads. Modified atmospheres with carbon dioxide have shown promise. Fumigants are effective against these pests, but heat and cold still serve as useful treatments. Dry heat has shown promise on citrus and mango. Combinations of treatments may be useful because doses or times of each treatment can be reduced. Each treatment could kill immatures with different modes of action. Effects on fruit quality must be minimal.**

## RESUMEN

**El desarrollo de métodos de tratamiento de cuarentena en la postcosecha contra varias especies de *Anastrepha* que infestan cítricos, mango, duraznos, ciruelas, nectarinos, y peras es revisado. Se discuten las tecnologías de tratamiento empleados en cuarentena como son refrigeración, vapor caliente, fumigantes, etc. y se especula sobre el futuro de estos tratamientos contra estas plagas. La irradiación a 30,000 rads no mata los estadíos larvarios avanzados presentes en la fruta. La modificación de atmósferas con dióxido de carbono ha mostrado ser promisorio. El uso de fumigantes es efectivo contra estas plagas, pero el uso del calor y el frío todavía resultan ser tratamientos útiles. El uso de calor seco ha mostrado ser prometedor en cítricos y mango. Una combinación de estos tratamientos puede ser útil debido a que las dosis o tiempos utilizados en cada tratamiento pueden ser reducidos. Cada tratamiento pudiera matar los estadíos inmaduros con diferentes modos de acción. Los efectos sobre la calidad de la fruta deben ser mínimos.**

The eggs and larvae of the genus *Anastrepha* (Family Tephritidae) are quarantine pests of various commercially important fresh fruits in the Americas. Throughout this century various postharvest methods have been devised and tested for disinfesting these crops of fruit fly eggs and larvae, without damaging fruit quality to prevent the geographical spread of the pests. Quarantine procedures or schedules that achieve quarantine security were developed against the Caribbean fruit fly, *Anastrepha suspensa* (Loew), a pest of peach (*Prunnis persicae* L.), plum (*P. salicina* Lindl.), nectarine (*P. persicae* L. Batch nectarina), pear (*Pyrus communis* L.), and many other hosts, and the Mexican fruit fly, *A. ludens* (Loew), a pest of *Citrus* species, and mangos, *Mangifera indica* L., and the West Indian fruit fly, *A. obliqua* (Marquart) also a pest of mangos. No protocols were found for post-harvest treatments of the South American fruit fly, *A. fraterculus* (Wiedemann) or *A. serpentina* (Wiedemann), a pest of citrus in Central and South America (Aluja-S. and Martinez-G., 1984) or *A. distinctus*, a pest of mango, Sharp and Picho (1990). Yet they are collected infrequently from the fruit listed above.

During the 1920's and 1930's, the United States Department of Agriculture (USDA) conducted research on refrigeration and vapor heat techniques (Baker et al., 1944) for post-harvest control of fruit flies in the Caribbean Islands and Mexico. During the next two decades, (USDA) researchers working in Mexico City found that fumigation of citrus and mango with ethylene dibromide (EDB) was effective against eggs and larvae of *A. ludens*. EDB fumigation was used for more than 30 years but was eliminated by the United States Environmental Protection Agency (EPA) for use on citrus and other fruits in 1984 (Ruckelshaus, 1984) because of human health concerns. Therefore, those results are not presented here. Richardson (1958), prior to the banning of EDB in 1984, summarized the literature on cold storage, frozen pack, vapor-heat, and methyl bromide (MB) against *A. ludens* and *A. obliqua*. MB will be banned from use in the year 2000 in the United States.

The loss of EDB created a need for alternative treatments for quarantine security of citrus and mango. Hot water immersions, refrigeration, irradiation, fumigation with MB and phosphine (PH3), and certain combinations of these treatments were evaluated or reevaluated. Progress toward developing alternative treatments has been made, but more research is needed to develop control measures as effective and economical as EDB fumigation. However, any type of treatment that results in discernible cellular or physiological damage to the commodity, such as flavor change, increased susceptibility to rot or rind blemishes, is unacceptable. The treatment must then be modified since the commodity will not be accepted by consumers.

Since the 1930's USDA researchers based the efficacy of

**Table 1.** Toxicity of Phosphine Fumigation to Immatures of *A. suspensa* Determined by Adult Emergence.

| | Mortality (%) After Indicated Days of Fumigation | | | |
|---|---|---|---|---|
| Dose (g/m³) | 1 | 2 | 3 | 4 |
| 0.58[a/] | 99.57 | 99.51 | | 100.0 |
| 0.71[b/] | | 100.0 | | |
| 1.24[b/] | | | 99.97 | |
| 1.41[b/] | 99.98 | 99.99 | | |
| 1.47[c/] | | | | |
| 1.77[b/] | | 99.99 | 100.0 | |
| 2.12[b/] | | | | 100.0 |
| 2.96c/ | | 99.96 | | 100.0 |

[a/]Taken from von Windeguth et al. (1976).
[b/]Taken from Hatton et al. (1982).
[c/]Taken from Table 1 shown by von Windeguth et al. (1977).

a particular post-harvest treatment against an *Anastrepha* species for infested fruits on populations of 100,000 to 200,000 estimated numbers of insects with times (cold and heat) or concentrations of fumigants. Estimated numbers of insects are based on populations found in each untreated fruit and the number of fruit treated at each at 3 to 15 doses or time period with a specific treatment (Baker, 1939). Chew and Ouye (1985) suggested that 1000 to 1500 insects per single dose or time, for a commodity, would suffice for this purpose when testing a post-harvest treatment or combination of treatments against an *Anastrepha* spp. I concur with these numbers. From probit transformation of mortality doses or times are determined. Baker (1939) proposed that post-harvest quarantine security required a kill of 99.9968% of the insects infesting fruit. This is equivalent to 3 survivors in 1,000,000 insects. When a shipment of a commodity is found with 1 live insect at a border station, the shipment is rejected. However, Landolt et al. (1984) stated that this level of quarantine security was unreasonable for *Anastrepha* spp. They recommended that quarantine security be based on the probability that no more than one mating pair per shipment would survive, arrive at the market destination, find each other, reproduce, and find a host suitable for oviposition.

Presented here is a resume highlighting postharvest research on methods of disinfesting fresh edible fruit of *Anastrepha* spp., including a survey of the effects of various treatments on quality of citrus and mangos to 1993. Based on original research I also show the effect of vacuum on populations of the Mexican fruit fly in grapefruit and effects on fruit quality. This resume is then projected into treatments used now or which might be tested and used in the future.

## RESUME AND DISCUSSION OF POST-HARVEST TREATMENTS

Hosts of *Anastrepha* spp. are grown in tropical and subtropical areas of North, Central and South America, and the Caribbean basin, including Puerto Rico and Haiti. They

**Table 2.** Estimated numbers of pupae (which reflects populations of eggs and larvae) of *Anastrepha ludens* in 'Manila' mangos and percentage mortality resulting from vapor-heat treatments, 1948-50.

| | Time (in hours) fruit pulp temperature to reach desired °C | | | |
|---|---|---|---|---|
| Fruit pulp temperature at time of removal (°C) | 2 | | 3 | |
| | Estimated population (and percentage mortality)[1/] | | | |
| 50.6 | 105,792 | (100%) | — | |
| 50.0 | 101,023 | (100%) | 95,152 | (100%) |
| 49.4 | 104,165 | (100%) | 139,726 | (100%) |
| 48.9 | 96,537 | (100%) | 122,432 | (100%) |
| 48.3 | 87,548 | (100%) | 128,410 | (100%) |
| 47.8 | 126,814 | (100%) | 114,459 | (100%) |
| 47.2 | 35,967 | (100%) | 93,860 | ( 99.990%) |
| 46.7 | 34,899 | ( 99.997%) | 40,424 | ( 99.978%) |
| 46.1 | 34,299 | ( 99.997%) | 44,224 | ( 99.993%) |
| 45.6 | 34,899 | ( 99.951%) | 34,200 | ( 99.927%) |
| 45.0 | 42,468 | ( 99.593%) | 28,933 | ( 99.133%) |
| 44.4 | 27,709 | ( 97.467%) | 28,933 | ( 98.078%) |
| 43.9 | 17,297 | ( 92.467%) | 27,709 | ( 97.835%) |
| 43.3 | — | | 34,200 | ( 86.550%) |

[1/]Based on number of pupae recovered from control fruit.

**Table 3.** Toxicity by hot water dips at 46-47°C of immatures of *Anastrepha* species in mango in the Americas.

| Anastrepha species | Source | Time (min) for 99.9968% Mortality (95% Confidence Interval) | Slope of Regression |
|---|---|---|---|
| *A. obliqua* | Wild from Peru[2/] | 113.4 (93.2 - 150.2) | |
| *A. obliqua* | Wild from Mexico[1/] | 83.6 (74.0 - 98.3) | 0.062 |
| *A. fraterculus* | Wild[2/] | 75.6 (70.1 - 82.5) | |
| *A. ludens* | Wild[1/] | 71.4 (68.7 - 74.5) | 0.062 |
| *A. obliqua* | Laboratory[1/] | 66.8 (59.5 - 78.1) | 0.08 |
| *A. distincta* | Wild[2/] | 65.8 (59.5 - 74.4) | |
| *A. serpentina* | Wild[1/] | 64.5 (58.4 - 73.3) | 0.081 |
| *A. ludens* | Laboratory[1/] | 56.0 (43.3 - 91.0) | 0.082 |
| *A. suspensa* | Laboratory[1/] | 44.3 (39.1 - 53.3) | 0.14 |

[1/]Taken from Sharp (1988)
[2/]Taken from Sharp and Picho-M. (1990).

included all citrus fruit, mango, almendra, pears, peaches, nectarines and plums.

Fumigation. The first published information on the effect of MB on an *Anastrepha* species was provided by Benschoter (1979b) who determined that a dosage of 44.4 g/m³ caused ≤ 99.9968% mortality of *A. suspensa* in grapefruit. Then, Williamson et al. (1986) found that 39.8 g/m³ killed ≤ 99.9968% of *A. ludens* in grapefruit.

Residues of organic MB were determined by King et al (1981) in grapefruit and by Stein and Wolfenbarger (1989) in mango. Organic residues were below tolerance (i.e. 20 ppm) in and on grapefruit and mango within 2h on grapefruit and 1 h on mango after a treatment with 64 g/m³. Within 0.17 h after treatment at 64 g/m³, residues of MB were 41.8 mg/kg and were equal in the peel and flesh of mango (Stein and Wolfenbarger, 1989). In 1 hr residues were below tolerance levels. In the only other MB residue study, Balock et al. (1945a) measured the loss of inorganic MB onto containers in the fumigation chamber.

Richardson (1958) stated that ethylene chlorobromide (ECB) was a very effective fumigant for *A. ludens* in citrus. Benschoter (1960) showed that ECB was toxic to all stages of *A. ludens*; from most to least susceptible the stages were larvae (mature), adult (2 to 21 days old) egg (1 d old), and pupae (5 to 9 d old). Although no regression models were applied to the data, one or more of the dosages tested caused ≥ 98% mortality. All the stages were susceptible to this fumigant at 1.5 to 8 oz./1000 ft³ (= g/m³).

Benschoter (1963) found that ECB was not more toxic than EDB to *A. ludens* in citrus and mangos. McPhail et al. (1969) showed that the dosages of ECB tested also killed 98 to 99% of *A. ludens* in mango.

Von Windeguth et al. (1976) and Hatton et al. (1982b) reported that fumigation with phosphine killed 99 to 100% of *A. suspensa* in grapefruit in 1-4 days (Table 1); 100% mortality occurred after 4 days at all dosages to a minimum of 0.53 g/m³. von Windeguth et al. (1976) showed that exposure to phosphine caused mortalities of 85.2% and 95% to *A. suspensa* after 6 and 12 h, respectively.

*A. suspensa* infestations in California peaches, nectarines, and plums are controlled (≥ 99.9968% kill) by fumigation with MB at 48 g/m³ at 20°C and 30°C after 2 h and 1 h, respectively. Also, the same amount of kill was observed after 1.5 h with 32 g/m³ at 30°C. The recommended MB dosage at 30°C for nectarines is 38.3 g/m³ and 20.4 g/m³ for 2 h for plums (Benschoter, 1988).

Carroll et al. (1980, 1982) reported that exposures for 24h to 2.2 mg/liter and 3 h to 2.2 mg/liter of 1-isothiocyanate-2-propene and 3-isothiocynate-1-propene, killed 100% and 93% of *A. suspensa* larvae, respectively; these were 2 of 179 nonhalogenated compounds tested. When Carroll (1984) exposed the same insect to 3.2 mg/liter of methyl cyclopropanecarboxylate, 100% mortality occurred in 24 h. In addition to these results, Benschoter et al. (1981) showed that the most effective compounds had an oxygen containing functional group on a carbon adjacent to a single or double bond, such as allyl alcohol, allyl acetate or allyl proprionate. Benschoter et al. (1986) then showed that toxicity of ethyl fluoroacetate, as a fumigant, was outstanding and about equal to EDB at 8 g/m². Weber et al. (1987) stated that of the 62 compounds they tested, the most active was 3-butyne-2-one which killed 100% of *A. suspensa* at 2.2 mg/liter, while 22 of the other compounds showed some fumigant activity.

EDB was the treatment of choice of mango and citrus for 40 years by shippers and packers prior to the ban in 1984. Until its ban, little research was conducted on alternative treatments. MB is as effective against *A. suspensa* and *A. ludens* today as it was 30 years ago. Information on efficacy against other *Anastrepha* species is lacking but MB will be banned from use on citrus by the year 2000. MB was previously discontinued as a quarantine treatment of mango because of human health concerns. Residues are short lived in grapefruit and mango. No other fumigant is approved for use against *Anastrepha* species on any other crop although several experimental compounds were tested and found to be effective. New fumigant chemistries need to be evaluated as alternative treatments.

Space Treatments. Redfern et al. (1970) was the first to show that the synthetic pyrethroids, allethrin and tetramethrin,

**Table 4.** Visual rating classes of grapefruit to evaluate post-harvest treatments caused by brominated fumigants to.

| Visual Rating | Stem End Breakdown[a] | Damage[b] on total surface of fruit as defined by Hatton et al. (1982) | Damage[b] on total surface of fruit as defined by Houck et al. (1984) | Marketability of fruit as defined by Hatton et al. (1982) | Marketability of fruit as defined by Houck et al. (1984) |
|---|---|---|---|---|---|
| 1 | None | 0 to 10 mm | 1/10 | Acceptable | No damage |
| 2 | 0.1 to 1.5 mm | 11 to 20 mm | 1/10 to 1/5 | Acceptable | Slight damage |
| 3 | 1.6 to 3.0 mm | 21 to 35 mm | 1/5 to 1/2 | Unacceptable | Moderate damage |
| 4 | 3.1 to 6.5 mm | > 35 mm | 1/2 | Unacceptable | Severe damage |

[a]Stem end rot breakdown is physiological aging as described by Hatton et al. (1982). Based on surface distance spread from the same.

[b]Includes both rindburn (or scald) (superficial brown discoloration) and rind pitting (dark, sunken surface lesions (Hatton et al. 1982).

were more toxic to *A. ludens* than the standard natural pyrethrum-DDT mixture in an aerosol spray. The pyrethroid insecticides, d-phenothrin and fenvalerate as 30% dusts, killed 100% of *A. suspensa* on treated surfaces of carpet and aluminum according to Cawley and Fons (1981). Von Windeguth and Arner (1981, 1986) showed that dusts and aerosol sprays of the new pyrethroid insecticides (developed in the mid 1970's), permethrin, cypermethrin, sumithrin, and bifenthrin killed 90 to 100% of this fly 24 h after the application and that after 30 minutes 75 to 88% knockdown occurred.

Abamectin, could be used as a dip because it rapidly penetrates the rind. Sprays and dusts of pyrethroid insecticides are toxic to the *S. suspensa*. None have been tested against other *Anastrepha* species.

Modified Atmospheres. Benschoter et al. (1981) exposed immature stages of *A. suspensa* that were developing in artificial diet to atmospheres of ethylene, nitrogen and carbon dioxide and determined that only carbon dioxide was toxic. However, $CO_2$ was slow acting and affected only the eggs and small larvae. Benschoter et al. (1981) showed that carbon dioxide (100%) killed 100% of the immature *A. suspensa* in 4 h, ethylene and nitrogen, applied in the same manner were ineffective. $CO_2$ was lethal to immature stages of *A. suspensa*; data needs to be explored on the other anastrepha species with this treatment which are quarantine insects.

Benschoter (1987) showed that mortalities of *A. suspensa* eggs and larvae in agar diet were not affected by different concentrations of oxygen and temperatures of 10°C and 15.6°C but were killed by carbon dioxide concentrations at different times of exposure. A multiple linear regression showed that the combination of exposure time (2h) and $CO_2$ level (g/l) or (%) produced 100% mortality.

Vacuum Treatment. No information is available on the usefulness of vacuum, another physical treatment, against immatures of any *Anastrepha* species infesting grapefruit. For this reason its usefulness was evaluated by the author against larvae of *A. ludens* to determine its level of efficacy. "Ruby-Red" grapefruit were harvested in late season and immediately placed in a cage with sexually mature flies and infested 6 to 7 d by the same method and with the same strain of A. ludens used by Williamson et al. (1986). Larvae were 6-13 d old at the time of treatment. Tests were replicated 7 times. From control fruit (280) the infestation was to be determined 14.1 pupae/fruit and 13.2 adults/fruit. The pupae reared from 305 fruit held in vacuum (29.5 to 40 inches of mercury) for 30 minutes (after 10-12 minutes to create the vacuum) were counted, as were the number of adults which eclosed from pupae. The vacuum chamber, National Appliance Co., Portland, OR, Model 5851, was used in all experiments; operational aspects of this equipment are described by Anonymous (1978). From the number of adults reared from pupae we determined 98.9753% and 99.8376% mortality for estimated larvae (determined as pupae) and pupal (determined when adults do not eclose) mortalities.

**Table 5.** Visual rating scale of decay of mangos caused by post-harvest treatments[a]

| Visual Rating of Surface | For Anthracnose and Penicillium Based on Percentage of Area Showing Symptoms | For Stem-end Rot Based on Spread from the Stem (mm) | Marketability of Fruit |
|---|---|---|---|
| 1 | None | None | Acceptable |
| 2 | Up to 1% | Up to 1.5 | Acceptable |
| 3 | 1 to 2% (trace) | 1.6 to 3.0 | Acceptable |
| 4 | 3 to 5% (slight) | 3.1 to 6.5 | Acceptable |
| 5 | 6 to 10% (slight) | 6.6 to 12.5 | Acceptable |
| 6 | 11 to 15% (moderate) | 12.5 to 19.0 | Unacceptable |
| 7 | 16 to 20% (moderate) | 19.1 to 25.0 | Unacceptable |
| 8 | 21 to 50% (severe) | 25.1 to 37.5 | Unacceptable |
| 9 | 51% or greater (severe) | 37.6 or more | Unacceptable |

[a]Taken from Spalding (1986)

**Table 6.** Visual and pressure rating scale for ripeness or firmness of mangos after post-harvest treatment[a].

| Visual or Pressure Rating | Observation | Marketability of Fruit |
|---|---|---|
| | Firmness or Ripeness of Fruit | |
| 1 | Overripe, past use | Not acceptable |
| 2 | Soft ripe, yields to moderate pressure, best for eating | Acceptable |
| 3 | Firm ripe, yields slightly to moderate pressure, not quite ready for eating | Acceptable |
| 4 | Firm, yields very slightly to moderate pressure | Acceptable |
| 5 | Hard, does not yield to moderate pressure | Not acceptable |
| | Scald or Purpling | |
| 0 | No injury | Acceptable |
| 1 | Up to 2% total fruit area, less than 3 mm | Acceptable |
| 2 | 2 to 10% area | Not acceptable |
| 3 | 10% to 20% area | Not acceptable |
| 4 | Over 20% area | Not acceptable |

[a]Taken from Spalding (1986). Total percentage acceptable fruit are those fruit, of the original number of fruit in the test, which are acceptable from the total number of fruit tested.

Results suggest that reduced pressure caused death of eggs and larvae. Treatment did not kill 99.9968% or greater but suggest that this treatment could be used with methyl bromide or an atmospheric gas ($CO_2$) in a combination treatment. Estimated populations of 4749 pupae were determined from fruit held in vacuum. This is the first report showing the efficacy provided by vacuum alone to larvae 6 to 13 days of age of *A. ludens* in grapefruit.

Vapor Heat and Hot Water Immersion. The use of heated water has the longest history of any postharvest treatment against immatures of *Anastrepha* species. The history of vapor heat and its use was discussed by Baker (1952). Herrera et al. (1900) studied the effects of high water temperatures on *A. ludens*. Crawford (1918) found that 46°C was lethal to immature stages of insect in fruit. Darby (1929) and Darby and Kapp (1933) determined "thermal deathpoints" for exposed *A. ludens* larvae and for *A. ludens* larvae in mangos.

In 1941 and 1942, Baker (1942) exposed eggs of A. ludens on pieces of mango skin to vapor heat to test their ability to survive an 8 h gradual increase from 20.3 to 43.3°C and found that hatch decreased with length of exposure to only 0.4% after 8 h.

Balock et al. (1945a) reported that quarantine security for *A. ludens* in mangos could be obtained after 14 h of exposure to vapor heat. In 1948-1951, Stone et al. (1951) determined the effects of 2 and 3 h vapor-heat atmosphere on treatments *A. ludens* in mangos (Table 2). They showed 100% mortality of immatures when pulp temperature reach 47°C in 2 hrs. Vapor heat, at 46.4-47.4°C inside fruit killed 99.9968% *A. ludens* was with confidence intervals of 45.4 to 50.1°C in 120 minutes in mango based.

The vapor heat treatment of mango developed in the early 1940's provided quarantine security but required 14h. When EDB became available, producers enjoyed the shorter treatment time (2h) and ease of application. In grapefruit, Hallman (1990) showed that vapor heat at 43.3-43.7 °C for 252.0 min (4.2 h) (95% C.I. 235.3-272 min) killed 99.9968% of mostly 3rd instar *A. suspensa*. While direct comparisons cannot be made, these data show 3°C difference for 99.9968% mortality, but less time was taken for the same kill in mangos than in grapefruit.

In carambola, Hallman (1990) showed that vapor heat at 46-46.3°C (air speed of 1-1.1 m/s) for 90 min followed by cooling in still air at 23 ± 0.5°C provided probit 9 security with 95% confidence. Shelf life and color quality at these temperatures were not significantly reduced.

Beginning in 1983, Sharp and others made concerted efforts to determine efficacy of hot-water dips and their lethality to immatures of *A. suspensa* (Sharp and Spalding, 1984; Sharp, 1985, 1986; Sharp et al., 1988; Sharp et al., 1989), *A. ludens* (Sharp et al., 1989), *A. obliqua* (Sharp et al., 1988 and Sharp et al., 1989) and *A. serpentina* (Sharp et al., 1989) and *A. distinctus* (Sharp and Picho, 1990) in mangos. In addition, Sharp (1988) described inexpensive equipment used to conduct these experiments.

Sharp and Chew (1987) showed that submersion time of "naked" eggs (not inside a fruit) of Caribbean fruit fly to reach 99% mortality were 24.8, 8.3, 2.0, 1.2, and 0.9 min. at 43.3, 46.1, 48.9, 51.7, and 54.4°C. When 1-2 day old larvae were submerged in hot water using the same regime of temperatures 99% mortality were 30.7, 6.6, 2.4, 1.5, and 0.7 min. When mature "naked" larvae were submerged in water at 40.5, 41.9, 43.3, 46.1, 48.9, 51.7, or 54.4°C submersion times for 99% mortality were 77.8, 43.7, 13.5, 5.3, 2.0, 1.3, and 1.6 min., respectively. At 43.3 and 46.1°C eggs were more resistant to hot water than mature larvae and at 43.3°C, 1-2 day old larvae were more resistant than mature larvae. Based on these data hot water dips of mango are part of a new approved schedule against *A. ludens* and *A. obliqua*.

Sharp (1988) showed that 44.3 and 113.4 minutes at 46-47°C (Table 3) were required to kill 99.9968% of a laboratory strain of *A. suspensa* from Florida and wild strain of *A.*

*obliqua* from Peru in different varieties of mango fruit (Sharp and Picho, 1990). This is the first information showing variation of response of strains of *Anastrepha* species to a postharvest treatment and suggest that treatment times need to be different for strains of *Anastrepha* species. Significant differences were also shown in time to kill 99.9968% of the larvae of 2 strains of *A. obliqua* using hot water; one was collected in southwestern Mexico and the other in Peru. Also regression slopes were flat depending on the species indicating that many factors may be responsible for the response to heat between strains and species of *Anastrepha* species. Mortalities of 99.9968% of a laboratory strain of *A. obliqua* from Haiti, a wild and a laboratory strain of *A. ludens* from Mexico and Texas respectively, and a wild strain of *A. serpentina* from Mexico were statistically similar; their 95% confidence intervals overlapped.

Results showed quarantine security (99.9968%) by most of the treatments but different species and strains from different countries responded differently to hot water temperatures. This information is important because 1 dose will not be satisfactory in all countries. I suggest that different temperatures may be needed to provide sufficient mortalities (≥99.9968) of the different species and strains which are required for quarantine treatment.

With "Marsh" grapefruit Gould (1988) showed that hot water immersion (43.3°C) of 175 minutes would cause 99.9968% mortality of immatures of the Caribbean fruit fly.

In addition to the vapor-heat treatment, a forced hot-air treatment device was evaluated on citrus as well as other commodities against *A. suspensa* (Sharp et al., 1991). Showed that mathematical expressions, i.e. negative exponential and logistical growth curves were accurate for predicting internal commodity temperatures during heat treatments.

Sharp et al. (1989) was the first to describe the forced hot air treatment for grapefruit against *A. suspensa*. When air (from 58 to 90% RH) was blown over the fruit at 0.40 m³/sec for 1, 1.25, 1.5, 1.75, or 2 h at 46°C to grapefruit the probit 9 for treatment time was 2.95 h. Pulp temperatures ranged from 43.5 to 45°C. At 48.0 ± 0.3°C grapefruit was treated for 63, 105, 135, and 195 min with forced hot-air at and infested with *A. Suspensa* eggs and larvae when center pulp temperatures were 28-29, 36-37, 40-41, and 44-45°C. Probit analysis estimated exposure time to kill 99.9968% of surviving puparia that developed from treated larvae as 202 min (95% confidence interval of 170-271 min) when mean pulp temperature was ≥ 45.7°C for ≥ 150 min of heating.

All late-third instar *A. ludens* in grapefruit were not killed until fruit center temperature was 46.1 to 48°C according to Mangan and Ingle (1992b) by hot forced air.

When seed surface temperatures of mango were 45 to 46.9°C, 100% mortality of *A. obliqua* was obtained (Mangan and Ingle, 1992). Because of variation in the data the probit regression predicted 48.7°C. Subsequent tests showed 100% mortality for ≤ 100,000 insects indicating that quarantine security was achieved.

Refrigeration. Benschoter (1983) determined that storage for 14 and 28 days at temperatures of 1.7°C and 4.4 °C, respectively, resulted in 100% mortality of the immature stages of *A. suspensa* in grapefruit. In addition, grapefruit infested with *A. suspensa*, and stored for 7 d at 10 or 15.6°C before storage at 1.7°C required an additional 30 and 18.6 d, respectively, to assure 99.9968% mortality of the immature insects within the fruit.

Benschoter and Witherell (1984) found that the susceptibility of immature stages of *A. suspensa*, reared on artificial diet and exposed to 7.2°C, was larvae ≥ eggs ≥ pupae, and that the older the eggs, the less susceptible they were to cold treatment. In addition, temperatures of 7.2°C, 10°C, and 12.8°C killed an estimated 95% of the larvae in ≤ 7, 10.3, and 31 d, respectively.

Burditt and McAllister (1982) determined that refrigeration of mangos at 0.56°C and 1.11°C provided quarantine security against *A. obliqua*. Benschoter (1988) showed that -0.56°C (31°F) killed 99.9968% of eggs and larvae of *A. suspensa* in pears and peaches after 8.3 d. Baker (1944) found that 50% mortality occurred among *A. obliqua* and *A. serpentina* adults held at 10°C for 10 d, but at the same temperature 120 d were required to kill 50% of *A. ludens* adults.

Von Windeguth and Gould (1990) showed that cold (1.1°C) killed 99.87%, 98.65%, and 93.07% Caribbean fruit fly immatures present in grapefruit after 8, 6, and 4 d, respectively.

Irradiation. Brownell and Yudelovitch (1962) determined that a dosage of 5000 rads of $^{60}$Co provided quarantine security against *A. ludens* in grapefruit based on emergence of adults.

Benschoter and Telich (1964) provided data that I used to calculate the numbers of grays and their 95% confidence interval (in parentheses) needed to kill 99.9968% of eggs (1 day old), larvae (11 day old), pupae (3-6 day old), and adults of *A. ludens* developing in petri dishes, were 58.36 (39.89-106.13), 2332 (∞ - ∞), 652.67 (480.36 - ) and > 500.00, respectively. Slopes of these regressions of probit were steep; they were 4.33, 11.92 and 4.67 for eggs, larvae, and pupae, respectively. Burditt et al. (1981) determined that X-ray and 10.0-20.0 gray of gamma irradiation provided 99.9968% mortality of adult *A. suspensa* in grapefruit. Von Windeguth (1982) obtained similar results with this insect but neither reference shows > 99.9968% mortality of larvae. Results show that the fruit are able to protect the developing larvae because 150.00-300.00 gray were required to kill 95% larvae in fruit yet 23.32 rads killed 99.9968% in petri dishes.

Spalding and Davis (1985) found that irradiation at 150 and 300 grays caused larval mortalities of 98.9% and 99.4%, respectively, of *A. suspensa* present in grapefruit and survivors were sterile. Also, 60-90 gray caused 100% mortality of larvae. Von Windeguth (1986) determined that 75 gray of gamma irradiation killed 99.9968% of *A. suspensa* in mangos and that 175 gray provided quarantine security of adults of this insect. If larvae (live pupae) are found in a shipment of fruit the APHIS protocol will not allow it to enter the United States. Irradiation will not kill all 3rd stage larvae in fruit (Spalding and Davis, 1985); thus we suggest that it will not be a viable alternative treatment for *A. suspensa* unless it is known that only 1st and 2nd stage larvae are present in the fruit.

With "Marsh" grapefruit 406 and 415 gray killed 100%

immatures of *A. suspensa* while 430 gray were required to kill 100% of eggs (von Windeguth and Ismail, 1987.)

As long as pupae can and do develop from late-instar larvae of *Anastrepha* species following irradiation will probably not be a practical treatment of perishable fruit because APHIS states that no larvae (determined by pupae) can survive the treatment.

Combination of Treatments. Benschoter (1982) reported that 40 g MB/m³ followed by refrigeration at 15.6°C for 3 wk, 32 g/m³ at 10°C for 3 wk, 24 g/m at 7.2°C for 3 wk, and 32 g/m³ at 7.2°C for 17 days, effectively controlled infestations of *A. suspensa* in grapefruit. Von Windeguth & Gould (1990) showed that an irradiation dose of 500.00 gray followed by 5 days of cold storage will exceed 99.9968% mortality of this insect.

In another combination with cold, Gould (1988) showed that hot water emersion (43.3°C) of "Marsh" grapefruit of 100 minutes followed by 7 days of cold temperature (1.1°C) would cause 99.9968% mortality of immatures of *A. suspensa*. This combination treatment killed 99.9968% of the immatures in ca. 40% less time than shown with cold alone.

Refrigeration, in combination with a fumigant, has shown promise as a post-harvest treatment of citrus against *A. suspensa*. If refrigeration killed 90% at a given temperature and time and another treatment killed 99% or more of the insects and no more than 100 insects were present in the shipment (100,000 to 1,000,000 fruit) no more than 1 insect would survive. Perhaps lower doses of the fumigant could be used which would mean lower residues in the fruit. No combination has been tested against any other *Anastrepha* species. The effect on fruit quality of citrus and mango by any of the post harvest treatments has not been clearly elucidated. Industry needs to define how they wish to handle their marketing of fresh mango and citrus to be exported. These evaluations include visible damage, biochemical changes, and increased incidences of plant pathogens induced by the treatment.

Any (=each) treatment in a combination or sequential treatment should require lower dosages or less time. Each quarantine treatment would need to kill only 95% of *Anastrepha* eggs and larvae. For example, if the first treatment (a fumigant) killed 95% of 100 insects which may be present in a commodity of any size and the second treatment, applied after the first treatment, killed 95% of the 5 remaining insects, quarantine security would be achieved. All known treatments will kill at least 95% of *Anastrepha* species. Our first problem is to know we have only 100 insects in each shipment.

## EFFECTS OF POST HARVEST TREATMENTS ON QUALITY OF PERISHABLE COMMODITIES.

Fumigation. McPhail et al. (1969) showed ECB reduced damage to grapefruit by rot organisms by 90% regardless of the dosage tested compared to the untreated check.

Benschoter (1981) stated that the peel of early season Florida grapefruit (harvested in October) were injured by methyl bromide (MB) when treated for 2 h at 24 or 32 g/m³ followed by 3 week storage at 7 to 10°C. Mid-season (harvested in January) and late (harvested in April) fruit suffered no injury. Decay organisms increased at these 2 dosages in mid- and late-season fruit. Thus, peel injury to early fruit and increased decay in mid- and late-season fruit make MB a questionable treatment for Florida grapefruit. However, when early-season fruit were fumigated at the same dosages and then stored at 15°C, no peel injury was evident and had only 0.4 to 3.2% increase in decay over non-treated fruit.

Hatton & Cubbedge (1979) stated that an MB dosage of 40 g/m³ caused unacceptable damage to the fruit. MB induced a 0-20% peel injury as compared to 0 in the control, and a 0-13% of the fruit had an incidence of decay as compared to 0-5% in the control.

Moshonas and Shaw (1982) found changes in flavor in fresh and pasteurized grapefruit juices from fruit treated with MB. Williamson et al. (1986) stated that 40 gMB/m² did not significantly effect firmness or flesh color of 'Ruby Red' grapefruit nor did it cause significant pitting of the rind. However, Spalding et al. (1977) found that MB at 32 and 48 g/m³, but not at 16 g/m³, increased decay of hard mature mango fruit of certain varieties.

Hatton et al. (1982b) found rind injury such as pitting, aging or scald to Florida grapefruit that had been fumigated with dosages of phosphine following 4 weeks of storage at 10°C. Also, fruit injured by phosphine often decayed soon after its removal from refrigeration. In addition, Moshonas and Shaw (1982) found that peel oil aromas of phosphine-treated grapefruit differed from untreated fruit.

Phosphine was found to be phytotoxic to mangos (Spalding et al., 1977) and to grapefruit (Hatton et al., 1982b). However, Hatton et al. (1982b) noted that phosphine-fumigated grapefruit held at 25°C post-treatment showed less injury than that held at 10°C post-treatment. Perhaps the fumigant deserves further consideration as a post harvest treatment of citrus.

Refrigeration. Adsule et al. (1984) showed that storage at 4.4°C for 1 wk followed by 2 wk at 21.1°C did not affect color or general appearance of 'Valencia' oranges or 'Murcott' tangerines and that decay occurred in only 7% of the fruit, but the flavor and pulp quality of the oranges became unacceptable within a week after removal from refrigeration.

Ismail et al. (1986) found that Florida 'Marsh' grapefruit, refrigerated at 1.6°C for 7 d generally appeared fresh and bright yellow in color, firm, and free of internal breakdown 14 days posttreatment.

If time is required, as few as 7 days, for movement of a commodity from 1 country to another then a temperature of 7°C can be used to achieve 90% or greater mortality of *A. suspensa*. Information is lacking on refrigeration of *A. ludens* yet this treatment is approved (Anonymous, 1976) for use as a quarantine treatment on citrus. Treatment time is 12 to 18 days at 1 to ca. 5°C (Anonymous, 1976). Mango cannot endure lengthy cold temperatures less than 12°C (Hatton et al., 1976).

Vapor Heat and Hot Water Submersion Treatments of Citrus and Mangos. Sinclair and Lindgren (1955) found that naval oranges and lemons grown in California were easily

damaged by the vapor heat treatment. Valencia oranges and grapefruit were more resistant to heat injury, but vapor heat treatment did consistently cause some damage to these fruit. Armstrong and Couey (1989) suggested damage to the fruit may have occurred because the citrus fruit was not hydrocooled after treatment. Hallman et al. (1990) in Florida then stated vapor heat at 43.3-43.7°C for 5 h caused no damage to grapefruit, but heat at 46-46.4°C for 3.75 h dried oil glands of the peel and caused increased fruit rot after 60 d storage. Sharp and Spalding (1984) and Sharp (1986) reported mangos submersed in hot water showed a lower incidence of *Diplodia* spp. and anthracnose damage than did untreated mangos, and the treatment did not hasten ripening nor alter flavor.

Sharp et al. (1988) stated that 'Francis' mangos from Haiti submerged in water at 46.1-46.7°C for 75 min. and then stored at 25-27°C for 8d were acceptable. However, percentage acceptable mangos treated with hot water at 46.1-46.7°C decreased as exposure time increased to 4 h. At 4h exposure all the mangos were unacceptable following storage at 11.1°C for 7 d or more. Spalding et al. (1988) found that 'Tommy Atkins' and 'Keitt' mangos from Florida developed peel color faster after hot water dips than did control mangos, but ripening time, pH, total titratable acid, percentage of soluble solids, internal breakdown, and hollow pockets were not affected by immersion in water at a temperature of 46° C for 60-90 minutes followed by storage of fruit at 13°C.

Sharp et al. (1989) stated that the market quality of mango immersed in water at 46.1°C depended on cultivar, size of fruit as well as its shape, maturity at the time of treatment and handling procedures. 'Oro' immersed for 75 min were all acceptable while acceptability of 'Oro' immersed for 90, 105 and 120 min were reduced to 80, 85 and 15%, respectively. 'Kent', 'Tommy Atkins' and 'Keitt' immersed in water at 46.1°C for 90 min and refrigerated at 11.1°C for 7, 11, and 14 days were acceptable. Also 'Haden' immersed in water at 46.1°C for 90 min, not refrigerated and held at 23.9±1°C were acceptable for 12 days. In Mexico (Sharp et al., 1989), the 'Ataulfo' mangos immersed in water at 46.1°C for 90 min were not immediately damaged; however, none were acceptable after 7 d at 23.9°C. Mango varieties other than "Ataulfo" were acceptable (93.3%) if immersed in water at 46.1° for 90 min and refrigerated at 11.1°C for 14 days; only 13.3% were acceptable after 7 days at 23-24°C. Only 10% of 'Ataulfo' were acceptable when immersed in water at 46.1°C for 90 min and refrigerated at 11.1°C for 21 days.

Sharp et al. (1989) was the first to show that forced hot-air did not affect market quality of grapefruit even though pulp temperatures ranged from 43.5 to 45°C. Then, McGuire (1991) determined effects of three different kinds of heat treatments on market quality and condition of grapefruit. Treatment by forced hot-air at 48°C for 3 h resulted in no loss of quality. When fruit was immersed in water at a constant 48°C there was a significant weight loss. The treatment also promoted injury or decay while reducing firmness and color intensity after 4 wks storage. By more slowly heating fruit weight, firmness and natural color were retained and injury was substantially reduced but the incidence of decay remained high. In taste tests, juice from fruit treated in water that was gradually raised to 48°C was preferred over that of fruit treated at a constant 48°C.

McGuire and Reeder (1992) continued their evaluations of forced hot-air treatment of grapefruit by determining effects on market quality of early, mid-, and late-season grapefruit to temperatures of 46, 48, and 50°C for 3, 5, or 7 h. Early and late-season fruit were more easily damaged by the higher temperatures than mid-season fruit. Increased time at lower temperatures had less of a deleterious effect on weight loss, loss of firmness and color and susceptibility to scalding injury and fungal decay than did shorter times at higher temperatures. A regression analysis predicts that 3 h at 48°C or 2 h at 49°C would not adversely affect market quality of early and mid-season fruit. Suitability of linear regression equations to predict that no damage would occur to early and mid-season fruit after 2-8 h at 48°C or 49°C was verified through taste tests of juice. Forced hot-air did not significantly affect grapefruit appearance or flavor ratings of early and mid-season on grapefruit although ratings for flavor and overall performance were lower for treated late season fruit (Mangan and Ingle, 1992b).

McGuire (1991) found that four different kinds of heat treatments of mango cultivars "Tommy Atkins", "Keitt", and "Palmer" did not affect fruit quality, but control of anthracnose and stem end rot varied. Immersion of fruit in water at a constant temperature of 46°C for 90-115 min significantly reduced the two postharvest diseases on 3 of the cultivars by 60-78% and 61-88%. Treatment by forced air at 46-48°C for 150-195 min reduced anthracnose on 2 cultivars but there was no effect on severity of total diseases.

Vacuum. As part of the evaluation of vacuum by the author (described above), late-season "Ruby-Red" grapefruit were harvested and held in 30 min vacuum (20.5 to 40 inches Mercury) under the same conditions the infested fruit were held. On days 1 to 3, 5 to 8, 10 to 12, 15 to 23, 27 to 28 fruit were examined for rindburn, pitting, stem-end breakdown, oil spots and rust symptoms as described by Offers (1987) utilizing a 5 class scale; classes 4 and 5 were unacceptable. When rindburn, pitting and rust symptoms were visible on 51% or more of the surface of the fruit they were classed as unacceptable. When soft tissue is visible to 3 mm or greater distance from the stem end of the fruit or 26% or more of the surface area had oil spots the fruit was classed as unacceptable. Uninfested grapefruit harvested at the same time which were not held under vacuum were used as the control. They were examined by the same scale at the same time with 4 harvest (replicates) dates, i.e. 123, 130, 166, and 171, 1989. Thirty fruit per harvest period of both the vacuum and the control fruit (replicate) were examined. Percentage acceptable vacuumed and unvacuumed fruit were compared by "t" at P 0.05 for each sampling period.

Percentage acceptable grapefruit (of 120 tested per post treatment date) were 70, 70, 68, 48, and 20 for those not held in vacuum and 55, 54, 50, 45, and 0 for fruit held in vacuum on 1-3, 5-8, 10-12, 15-23, and 27-28 days posttreatment, respectively. Acceptability of treated and control fruit was not

significantly different $P<0.05$, $t_{05} = 0.46, 0.51, 0.52, 0.07$ and 2.0 (for df 2 to 6) on the same days posttreatment. Fruit harvested later in the season (days 35 and 39 post treatment) deteriorated quickly, regardless of its treatment. Based on these evaluations vacuum treatment does not adversely affect the visual aspect of fruit quality.

Irradiation. Burditt et al. (1981) found that 250-500 grays of gamma irradiation altered the flavor of grapefruit tissue and juice and destroyed beta-pinene in the flavedo glands. (Grays in excess of 300.00 are beyond dosages required for toxicity to *Anastrepha* species). They also found that the flavor of pasteurized juice from grapefruit that had been exposed to 500.00-600.00 rads of $^{60}Co$ or $^{137}Ce$ was adversely effected. Moshonas and Shaw (1982) showed that compared to control fruit the percentage of oil, brix, acid and the brix-acid ratio was not affected by irradiation, but vitamin C levels were significantly lower in gamma irradiated fruit, regardless of the dosage. They also reported that differences were found in flavor of fresh sections, fresh juice and aroma of peel oil from fruit irradiated with X-ray as compared with products from unirradiated fruit.

Hatton et al. (1984) found that 'Marsh' grapefruit gamma irradiated with 600.00-900.00 grays sustained rind breakdown and scalding after 28 d in storage. Also, rind scald was the dominant injury to early-season fruit, but in mid-season and late-season fruit rind breakdown, especially pitting, was the dominant injury. However, injury to fruit exposed to 75.00-300.00 rad was almost undetectable.

Spalding and Davis (1985) found that 'White Marsh' grapefruit irradiated with 300.00 rads from $^{60}Co$ exhibited no adverse changes in taste and met Grade A standards after 4 wk at 10-16°C followed by 2 wk at 21°C. However, these authors stated that fruits, particularly those harvested and treated in February, April and May, sustained more rind breakdown than did untreated fruit. Fruit harvested and treated during October- December sustained more scald than did untreated fruit. However, none of these differences were significantly different.

Burditt et al. (1981) showed no effect of dosage of irradiation to 'Keitt' mangos on amount of surface blemish on the fruit. Spalding and Reeder (1985) found that irradiation at 75,000 rads inhibited skin color of 'Tommy Atkins' mangos and caused some browning and pitting of the skin.

Combination of Treatments. In Florida, Benschoter (1979a) found that dosages of 40 and 56 g/m$^3$ MB applied to March and April (late-season) grapefruit for 2 h plus cold storage for 4 wk at 10°C caused a significantly greater incidence of decay compared to untreated control fruit held in cold storage for the same time period. Fruit harvested in January (mid-season) were less affected by MB fumigation and/or cold storage than late-season fruit. Cold storage at 10°C alone caused substantial peel injury to October to December (early-season) fruit, and the addition of MB fumigation compounded the damage. Benschoter (1979a) stated that early-season, but not mid- or late-season, grapefruit showed rindburn, pitting, treatment-induced and decay after 2 h of fumigation with 24 and 32 g MB/m3 followed by refrigeration for 3 wk at 7.2°C and 10°C, respectively, was negligible in early fruit but increased as the season progressed.

Spalding and Reeder (1985) found a combination of irradiation at 25,000-75,000 rad and immersion in hot water (50°C, with or without the fungicide imazalil) for 3 min, more effectively controlled anthracnose and stem-end rot of 'Tommy Atkins' mangos than did either of the treatments alone, and the effects of irradiation on skin color, as well as other injury, were partially offset when a hot water treatment preceded irradiation. Spalding (1986) found that mangos immersed for 3 min in hot water (53 degrees C) and then exposed to 25,000 to 75,000 rad sustained less anthracnose and stem-end rot, but that 75,000 rad increased internal breakdown of 'Keitt' and 'Tommy Atkins' mangos.

Modified Atmospheres. Vacuum and $CO_2$ were lethal to immature stages of the *A. ludens* and *A. suspensa*, respectively. All treatments caused damage, although hot water immersion of various mango varieties was observed to cause fewer effects on fruit quality to date if it was part of a combination of treatments. I suggest that fumigation by MB causes less total damage to both citrus and mangos compared to the physical treatments. Researchers have probably conducted more tests on effects of MB on fruit quality of both commodities than of any other single treatment.

MB is effective against *A. ludens* and *A. suspensa* and phosphine against *A. suspensa*. Studies in Florida indicate that MB sometimes affects quality of mangos and citrus, although investigators in Texas did not find MB to affect quality of grapefruit. Perhaps lower dosages of these fumigants, in combination with another treatment, can be used to achieve quarantine security without affects on fruit quality. It is also known that a postharvest cold treatment 7 to 14 days at 1.7°C was adequate to kill 90% or more of *A. suspensa* in grapefruit. Whether combination treatments i.e. MB with cold temperature might significantly reduce time, effort and expense is not fully known, but they deserve further investigation.

Irradiation and cold temperature postharvest treatments are evaluated by Von Windeguth and Gould (1990) and shown to provide quarantine security against *A. suspensa*. Ouye and Gilmore (1985) suggested that lower dosages of irradiation than those presently evaluated may suffice to provide quarantine security against *Anastrepha* species, thus reducing phytotoxic effects.

Citrus, mangos, peaches, plums, nectarines and pears are perishable commodities which must be treated to kill all immatures of *Anastrepha* species at U.S. ports of entry. Other requirements may exist at borders or ports of other countries but the tropical countries where the *Anastrepha* species occur have most of their markets in countries with temperate climates. Also, the treatments must not affect fruit quality. If a treatment or a combination of treatments does affect fruit quality at the U.S. ports of entry its use by producers will be restricted until the problem is solved or another schedule is developed.

Fumigants, irradiation, and the temperature extremes can kill 99.9968% of eggs and larvae of *A. suspensa* in citrus and mango. Fumigants, irradiation and heat kill the same percent-

age of eggs and larvae of *A. ludens*. Heat and cold kill eggs and larvae of *A. obliqua* and heat kills eggs and larvae of *A. distincta* and *A. serpentina*. More research has been conducted with *A. suspensa* than any of the other species yet *A. ludens* remains the most important quarantine pest of citrus in the Americas. *A. obliqua* appears to be the most important quarantine pest of mango although *A. ludens* also readily infest mangos. Methyl bromide was shown to be effective against *A. suspensa* on peaches, plums, nectarines and pears.

Herein shown are results of new chemicals for fumigants of *A. suspensa*. If safety is not an issue these compounds should be further developed for use alone or in concert with physical treatments against *A. ludens* and *A. obliqua* such as the heat and cold. Atmospheric gas treatments, in concert with physical treatments, should be further explored.

## CONCLUSIONS AND RECOMMENDATIONS

Information from the literature indicates that fumigation of citrus with MB and hot water dip of mangos can provide quarantine security against *Anastrepha* species in citrus or mango. In addition to hot-water dip and fumigants alone, combinations of treatments should be further evaluated against the *Anastrepha* species. Fruit quality evaluations should involve biochemical evaluations of the different tissues as organoleptic properties.

Hedley (1990) in New Zealand, states that most of the problems facing quarantine agencies around the world arise from risks associated with private and commercial import of plant produce which include *Anastrepha* species. These pests can not only cause economic loss at the time of the shipment but the quarantine pest can lead to the loss of markets. He states that maximum pest limit for critical quarantine pests is 0.5%, i.e. one infested unit in 200 fruit. The limit can easily be achieved with any treatment.

Baker et al. (1990) proposed that the maximum pest limit is defined as the maximum number of immature fruit flies that may be present in consignments of perishable fruit imported during a specified time to a specified location. They proposed 3 live larvae per day at the port of entry as the maximum allowed in fruit. While these authors did not evaluate any *Anastrepha* species we propose such a limit would be reasonable because time is an important factor in international shipments of perishable commodities.

Mechanisms need to be developed to determine the number of eggs and larvae of any *Anastrepha* species in the commodity so that it is known when all forms are killed. This is not possible today but the rewards would be worth the effort. If it were known what number were present in a group (=load) of perishable fruit then we could confirm 100% kill which is required for quarantine security. The use of 99.9968% (Probit 9) kill cannot be justified by personnel at a border crossing because it is not known how many were present in the fruit before the treatment was applied many miles away.

Sharp (1992) described usefulness and debits of single quarantine treatments of quarantine pest species including heat. Combination or multiple treatments and their usefulness were described as well as their debits is also described (Sharp, 1992).

Sharp (1993) also outlined methods that would eliminate the need for treatments of most any quarantine pests. These include resistant varieties, non-host commodity at harvest time, pests that do not infest a host during part or all of the season (other preferred hosts are available) or where the population is extremely low or not present during part of the season, exclusion of a pest from a geographical area and effective inspection.

Today, in Mexico, the schedule established by APHIS for mango or citrus includes the monitoring for adult populations with McPhail traps from registered groves. If no insects are captured in the traps the fruit is harvested and 600 citrus or 300 mangoes are cut into sections and examined to determine the presence or absence of eggs or larvae of the *Anastrepha* species. If no insects are found then the fruit are treated with the post-harvest treatment schedule to further insure no immatures are present in the fruit. The fruit is then exported to the United States border where it is again examined by inspectors for presence of live insects.

Standards for fruit quality of citrus are defined for Texas, California, and Florida. If the fruit does not meet these standards it is rejected at their border. Most of these standards involve the visual appearance of the fruit. The visual rating scales (Table 5) for Florida (Hatton et al., 1982a, 1984) and California grapefruit are the only ones presently used to measure the phytotoxic effects of treatments capable of providing quarantine security against an *Anastrepha* species.

There are no published fruit quality standards for mangos, but researchers have defined the major factors that affect their appearance. The decision for acceptable fruit is left to the consumer who, through the retailer, dictate the definition or quality the producer will prepare for the market.

Visual rating scales of 1-9 for anthracnose or stem-end rot (Table 5), the most common diseases of the mangos, and visual rating scales for firmness or ripeness and scald or purpling peel injury (Table 6) are shown. These evaluations are the best methods to determine marketability of mangos today. In addition, because certain treatments stress normal development and keeping quality of these fruit only high grade commodities should enter the export market.

## LITERATURE CITED

Adsule, P. G., Ismail, M. A., and Feller, P. J. 1984. Quality of citrus fruit following cold treatment as a method of disinfestation against the Caribbean fruit fly. J. Amer. Soc. Hort. Sci. 109: 851-854.

Aluja-S., M. and Martinez-G., I. 1984. Manejo integrado de las moscas de la fruta (Diptera:Tephritidae). Programa Mosca del Mediterraneo. 241 pp.

Anonymous. 1976. Revised April 1978. Plant protection and quarantine treatment manual. USDA, APHIS, PPQ. Program Sec. IV, Part I and VI Schedules.

Armstrong, J. W. and Couey, H. M. 1989. Fumigation, heat and cold. In A. I. Robinson and G. H. S. Hooper (eds.) Fruit

Flies Biology, natural enemies and control. Elsevier Sci. Publ. Amsterdam, The Netherlands. 10.9.1. 11 pp.

Baker, A. C. 1939. The basis for treatment of products where fruit flies are involved as a condition for entry into the United States. USDA Circular 551. 77 pp.

Baker, A. C. 1942. Survival periods for eggs of *Anastrepha ludens* (Loew) during vapor-heat sterilization. J. Econ. Entomol. 36: 124.

Baker, A. C. 1944. Studies on the responses of fruit flies to temperature. J. Econ. Entomol. 37: 280-283.

Baker, A. C., Stone, W. E., Plummer, C. C., and McPhail, M. 1944. A review of studies on the Mexican fruit fly and related Mexican species. USDA Misc. Publ. 521. 155 pp.

Baker, A. C. 1952. The vapor-heat process. USDA Yearbook. pp. 401-404.

Baker, R. T., Cowley, J. M., Harte, D. S. and Frampton, E. R. 1990. Development of a maximum pest limit for fruit flies (Diptera: Tephritidae) in produce imported into New Zealand. J. Econ. Entomol. 88: 13-17.

Balock, J. W., Stone, W. E., Plummer, C. C., and McPhail, M. 1945a. Absorption of methyl bromide and its residual effect on fruit fly mortality. J. Econ. Entomol. 38: 481-483.

Benschoter, C. A. 1960. Susceptibility of life stages of the Mexican fruit fly to fumigation with ethylene chlorobromide. J. Econ. Entomol. 53: 323-325

Benschoter, C. A. 1963. Evaluation of ethylene chlorobromide as a fumigant for citrus and mangos infested by the Mexican fruit fly J. Econ. Entomol. 56: 394-396.

Benschoter, C. A. 1979a. Seasonal variation in tolerance of Florida 'Marsh' grapefruit to a combination of methyl bromide fumigation and cold storage. Proc. Fla. State Hort. Soc. 92: 166-167.

Benschoter, C. A. 1979b. Fumigation of grapefruit with methyl bromide for control of *Anastrepha suspensa*. J. Econ. Entomol. 72: 401-402.

Benschoter, C. A. 1981. Tolerance of Florida 'Marsh' grapefruit to methyl bromide fumigation and cold storage combination treatments effective against the Caribbean fruit fly. Proc. Fla. State Hort. Soc. 94: 301-304.

Benschoter, C. A. 1982. Methyl bromide fumigation followed by cold storage as a treatment for *Anastrepha suspensa* (Diptera: Tephritidae) in grapefruit. J. Econ. Entomol. 75: 860-862.

Benschoter, C. A. 1983. Lethal effects of cold storage temperature on Caribbean fruit fly in grapefruit. Proc. Fla. State Hort. Soc. 96: 318-319.

Benschoter, C. A. 1984. Low-temperature storage as a quarantine treatment for the Caribbean fruit fly (Diptera:Tephritidae) in Florida citrus. J. Econ. Entomol. 77: 1233-1235.

Benschoter, C. A. 1987. Effects of modified atmospheres and refrigeration temperatures on survival of eggs and larvae of the Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 80: 1223-1225.

Benschoter, C. A. 1988. Methyl bromide fumigation and cold storage as treatments for California stone fruits and pears infested with Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 81: 1665-1667.

Benschoter, C. A., King, J. R., and McGovern, T. P. 1986. Candidate fumigants for control of Caribbean fruit fly, 1983-84. Insecticide and Acaracide Tests. 434-436.

Benschoter, C. A., King, J. R., and Witherall, P. C. 1984. Large chamber fumigations with methyl bromide to destroy Caribbean fruit fly in grapefruit. Proc. Fla. State Hort. Soc. 97: 123-125.

Benschoter, C. A., Spalding, D. H., and Reeder, W. F. 1981. Toxicity of atmospheric gasses to immature stages of *Anastrepha suspensa*. Fla. Entomol. 64: 543-544.

Benschoter, C. A., King, J. R., Plummer, J. R. and McGovern, T. P. 1981. Candidate fumigants for control of Caribbean fruit fly, 1979-1980. Insecticide & Acaricide Tests. 6: 177 (318).

Benschoter, C. A. and Telich, C. J. 1964. Effect of gamma rays on immature stages of the Mexican fruit fly. J. Econ. Entomol. 57: 690-691.

Benschoter, C. A. and Witherell, P. C. 1984. Lethal effects of suboptimal temperatures on immature stages of *Anastrepha suspensa*. Fla. Entomol. 67: 189-193.

Brownell, L. E. and Yudelovitch, M. 1962. Effect of radiation of Mexican fruit fly eggs and larvae in grapefruit. Inter. Atomic Energy. Vienna, Austria. pp. 193-202.

Burditt, A. K., Jr. and McAlister, L. C., Jr. 1982. Refrigeration as a quarantine treatment for fruit infested with eggs and larvae of *Anastrepha* species. Proc. Fla. State Hort. Soc. 95: 224-226.

Burditt, A. K., Jr. and Moshonas, M. G., Hatton, T. T., Spalding, D. H., von Windeguth, D. L., and Shaw, P. E. 1981. Low-dose irradiation as a treatment for grapefruit and mangos infested with Caribbean fruit fly larvae. USDA, ARS, AAR-S-10. 9 pp.

Burditt, A. K., Jr. and von Windeguth, D. L. 1976. Large chamber fumigation of grapefruit infested with the Caribbean fruit fly. Proc. Fla. State Hort. Soc. 89: 170-171.

Carroll, J. F., Morgan, N. O., and Weber, J. D. 1980. Bioassay of three isothiocyanates as fumigants against larvae of a Caribbean fruit fly (*Anastrepha suspensa*) and the apple maggot (*Rhagoletis pomonella*). J. Econ. Entomol. 73: 321-323.

Carroll, J. R., Morgan, N. O., and Weber, J. D. 1982. Evaluation of some nonhalogenated compounds as fumigants against larvae of a Caribbean fruit fly (*Anastrepha suspensa*). J. Econ. Entomol. 75: 137-140.

Carroll, J. F. 1984. Fumigation of Caribbean fruit fly, *Anastrepha suspensa* Tephritidae, larvae with cyclopropyl compounds which inhibits adult emergence. J. Econ. Entomol. 77: 980-983.

Cawley, B. M. and Fons, J. 1981. Residual activity of candidate insecticidal formulations for quarantine control of the Caribbean fruit fly, 1979-80. Insecticide and Acaracide Tests. 6: 178.

Chew, V. and Ouye, M. T. 1985. Statistical basis for quarantine treatment schedule and security. *In* Radiation and

Disinfestation of Food and Agricultural Products. Ed. J. H. Moy, Hawaiian Inst. Trop. Agr. Honolulu, HI. pp. 70-74.

Crawford, D. L. 1918. Insectos y otros invetebrados nocivos. La mosca de la naranja de Mexico, *Anastrepha ludens* (Mex.). Rev. Agr. 2: 458-462.

Darby, H. H. 1929. Unpublished report on temperature tolerance of larvae. Mexican Laboratory Report No. 13 to U.S. Bureau of Entomology. 4 pp.

Darby, H. H. and Kapp, E. M. 1933. Observations on the thermal death points of *Anastrepha ludens* (Loew). USDA Tech. Bull. No. 400. 19 pp.

Gould, W. P. 1988. A hot/cold storage quarantine treatment for grapefruit infested with the Caribbean fruit fly. Proc. Fla. State Hort. Soc. 110: 190-192.

Hallman, G. J. 1990. Vapor-heat treatment of caranbolas infested with Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 83: 2340-2342.

Hallman, G. J., Gaffney, J. J. and Sharp, J. L. 1990. Vapor-heat treatment for grapefruit infested with Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 83: 1475-1478.

Hatton, T. T. and Cubbedge, R. H. 1979. Phytotoxicity of methyl bromide as a fumigant for Florida citrus fruit. Proc. Fla. Hort. Soc. 92: 167-169.

Hatton, T. T., Cubbedge, R. H., Risse, L. A., and Hale, P. W. 1982a. Phytotoxicity of gamma irradiation of Florida grapefruit. Proc. Fla. State Hort. Soc. 95: 232-254.

Hatton, T. T., Cubbedge, R. H., von Windeguth, D. L., and Spalding, D. H. 1982b. Control of the Caribbean fruit fly in Florida grapefruit by phosphine fumigation. Proc. Fla. State Hort. Soc. 95: 221-224.

Hatton, T. T., Cubbedge, R. H., Risse, L. A., Hale, P. W., Spalding, D. H., von Windeguth, D. L., and Chew, V. 1984. Phytoxic responses of Florida grapefruit to low-dose irradiation. J. Amer Soc. Hort. Sci. 109: 607-610.

Hatton, T. T., Reeder, W. F., and Campbell. 1965. Ripening and storage of Florida mangos. Marketing Res. Rpt. No. 725. 19 pp.

Hedley, J. 1990. Improved plant quarantine using bilateral quarantine agreements for the exclusion of high risk pests Plant Protection Bulletin, FAP, Vol. 38: 127-133.

Herrera, A. L., Rangel, A. F., and De La Barreda, L. 1900. El gusano de la fruta (*Instrypetas ludens* I.D.B.) Comision de Parasitologia Agricola. Seccion, Accion de la Temperatura Sobre la Mosca de la Fruta. 1: 77.

Ismail, M. A., Hatton, T. T., Dezman, D. J., and Miller, W. R. 1986. In transit cold treatment of Florida grapefruit shipped to Japan in refrigerated van containers: Problems and recommendations. Proc. Fla. State Hort. Soc. 99: 117-121.

King, J. R., Benschoter, C. A., Burditt, A. K., Jr. 1981. Residues of methyl bromide in fumigated grapefruit determined by rapid headspace analysis. J. Agr. Food Chem. 29: 1003-1005.

Landolt, P. J., Chambers, D. L., and Chew, V. 1984. Alternative to the use of probit 9 mortality as a criterion for quarantine treatments of fruit fly (Diptera:Tephritidae) infested fruit. J. Econ. Entomol. 17: 285-287.

Mangan, R. L. and Ingle, S. J. 1992. Forced hot-air treatment of mangoes infested with West Indian Fruit Fly (Diptera:Tephritidae). J. Econ. Entomol. 85: 1859-1864.

Mangan, R. L. and Ingle, S. J. 1992b. Forced hot-air treatment for grapefruit infested with Mexican fruit fly (Diptera:Tephritidae). J. Econ. Entomol.

McGuire, R. G. 1991. Market quality of grapefruit after heat quarantine treatment. Hort. Science. 26: 1393-1395.

McGuire, R. G. 1992. Concomitant decay reductions when mangoes are treated with heat to control infestations of Caribbean fruit fly. Plant Disease. 75: 946-949.

McGuire, R. G. and W. T. Reeder. 1992. Predicting market quality of grapefruit after hot-air quarantine treatment. J. Amer. Soc. Hort. Sci. 117: 90-95.

McPhail, M., Benschoter, C. A. and Lopez-D., F. 1969. Fumigation of ethylene dibromide and ethylene chlorobromide to reduce development of rot in grapefruit infested with Mexican fruit fly larvae. J. Econ. Entomol. 62: 1238-1239.

Moshonas, M. G. and Shaw, P. E. 1982. Irradiation and fumigation effects on flavor, aroma, and composition of grapefruit products. J. Food Sci. 47: 958-960 and 964.

Offers, J. A. 1987. Citrus diseases and defects found in the marketplace. 1st Edition. Licensed Citrus Survey and Consulting Bureau. 69 pp.

Ouye, M. T. and Gilmore, J. E. 1985. The philosophy of quarantine treatment as related to low-dose radiation. In Radiation Disinfestation of Food and Agricultural Products. Ed. J. H. Moy, Hawaiian Inst. Trop. Agr. Honolulu, HI pp. 67-69.

Redfren, R. E., McGuire, J. V. and Sullivan,. W. N. 1970. Insecticidal aerosols against the Mexican fruit fly. J. Econ. Entomol. 63: 1772-1774.

Richardson, H. H. 1958. Treatments of various fruits and vegetables to permit their movement under fruit fly quarantine. Proc. X Int. Cong. Entomol. 3: 17-23.

Ruckelshaus, W. D. 1984. Ethylene dibromide, amendment of notice of intent to cancel registration of pesticide products containing ethylene dibromide. Fed. Regis. 49: 14182-14185.

Sharp, J. L. 1985. Submersion of Florida grapefruit in heated water to kill stages of Caribbean fruit fly, *Anastrepha suspensa*. Proc Fla. State Hort. Soc. 98: 78-86.

Sharp, J. L. 1986. Hot water treatment for control of *Anastrepha suspensa* (Diptera:Tephritidae) in mangos. J. Econ. Entomol. 79: 706-708.

Sharp, J. L. and Spalding D. H. 1984. Hot water as a quarantine treatment for Florida mangos infested with Caribbean fruit fly. Proc. Fla. State Hort. Soc. 97: 355-357.

Sharp, J. L., Ouye, M. T., Thalman, R., Hart, W. G., Ingle, S. J., and Chew, V. 1988. Submersion of 'Francis' mango in hot water as a quarantine treatment for the West Indian fruit fly and the Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 81: 1431-1436.

Sharp, J. L., Ouye, M. T., Hart, W. G., Ingle, S. J., Hallman,

G. Gould, W., and Chew, V. 1989. Immersion of Florida mangos in hot-water as a quarantine treatment for Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 82: 186-188.

Sharp, J. L. 1988. Status of hot-water immersion quarantine treatment for Tephritidae immatures in mango. Proc. Fla. State Hort. Soc. 101.

Sharp, J. L. 1989. Hot-water immersion appliance for quarantine research. J. Econ. Entomol. 82: 189-192.

Sharp, J. L. and Chew, V. 1987. Time/mortality relationships for *Anastrepha suspensa* (Diptera:Tephritidae) eggs and larvae submerged in hot water. J. Econ. Entomol. 80: 646-649.

Sharp, J. L., Ouye, M. T., Ingle, S. J., and Hart, W. G. 1989. Hot-water quarantine treatment for mangos from Mexico infested with Mexican fruit fly and West Indian fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 82: 1657-1662.

Sharp, J. L., Ouye, M. T., Ingle, S. J., Hart, W. G., Enkerlin, W. R.Celedinio-H., H., Toledo-A., J., Stevens, L., Quintero, E., Reyes-F., J., and Schwartz, A. 1989. Hot-water quarantine treatment for mangos from the state of Chiapas, Mexico infested with Mediterranean fruit fly and *Anastrepha serpentina* (Wiedmann) (Diptera:Tephritidae). J. Econ. Entomol. 82: 186-189.

Sharp, J. L. and Picho-M., H. 1990. Hot water quarantine treatment to control fruit flies in mangos imported into the United States from Peru. J. Econ. Entomol. 83: 1940-1943.

Sharp, J. L. 1989. Preliminary investigation using hot air to disinfest grapefruit of Caribbean fruit fly immatures. Proc. Fla. State Hort. Soc. 102: 157-159.

Sharp, J. L., Gaffney, J. J., Moss, J. I., and Gould, W. P. 1991. Hot-air treatment device for quarantine research. J. Econ. Entomol. 84: 520-527.

Sharp, J. L. and Hallman, G. J. 1992. Hot-air treatment for carambola infested with Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 85: 168-171.

Sharp, J. L. 1992. Effectiveness of conventional commodity treatments (heat, refrigeration, chemical, others) to satisfy quarantine regulations. In Proc. of Final Research Co-ordination Meeting on use of irradiation as a quarantine treatment of food and agricultural commodities. pp. 175-186.

Sharp, J. L. 1993. Hot-air quarantine treatment for 'Marsh' white grapefruit infested with Caribbean fruit fly (Diptera:Tephritidae). J. Econ. Entomol. 86: 462-464.

Simon-F., J. E., Salazar-S., J. and Chavez, W. B. 1976. *Anastrepha fraterculus*: fumigation of mangos with ethylene dibromide. J. Econ. Entomol. 69: 165-166.

Sinclair, W. B. and Lindgren, D. L. 1955. Vapor heat sterilization of California citrus and avocado fruits against fruit fly insects J. Econ. Entomol. 48: 133-138.

Spalding, D. H. 1986. Evaluation of various treatments for control of post-harvest decay of Florida mangos. Proc. Fla. State Hort.Soc. 99: 97-99.

Spalding, D. H., Benschoter, C. A., von Windeguth, D. L., King, J. R. Reeder, W. F., and Burditt, A. K., Jr. 1977. Methyl bromide and phosphine fumigation injury to avocados and mangos. Fla. State Hort. Soc. 90: 268-270.

Spalding, D. H. and Davis, D. F. 1985. Potential for gamma radiation as a quarantine treatment for Caribbean fruit fly in citrus *In* Radiation Disinfestation of Food and Agricultural Products. Ed. J. H. Moy, Hawaiian Inst. Agr. Honolulu, HI pp. 160-165.

Spalding, D. H., King, J. R. and Sharp, J. L. 1988. Quality and decay of mangos treated with hot water for quarantine control of fruit fly. Trop. Sci. 28: 95-101.

Spalding, D. H. and King, J. R. 1986. Quality and decay in mangos treated with hot water. Plant Disease.

Spalding, D. H. and Reeder, W. F. 1985. Effect of hot-water and gamma-radiation on postharvest decay of grapefruit. Proc. Fla. State Hort. Soc. 98: 207-208.

Spalding, D. H. and Reeder, W. F. 1986. Decay and acceptability of mangos treated with combinations of hot water, imazalil and gamma-radiation. Plant Disease. 70: 1149-1151.

Spalding, D. H., Reeder, W. F., von Windeguth, D. L., and Burditt, A. K., Jr. 1975. Effect of ethylene dibromide fumigation on appearance, decay, and ripening time of mangos. Proc. Fla. State Hort. Soc. 88: 471-476.

Stein, E. R. and Wolfenbarger, D. A. 1989. Methyl bromide residues in fumigated mangos. J. Agr. Food Chem.

Stone, W. E., Servin, F., and Helms, I. 1951. A new concept in the vapor-heat sterilization of fruit for fruit flies. USDA, Agr. Res. Adm., Bur. of Entomol. and Plant Quarantine, Fruit Fly and Citrus Blackfly Investigations in Mexico. USDA, PQCA-363-MS 19 pp.

Von Windeguth, D. L. 1982. Effects of gamma irradiation on the mortality of the Caribbean fruit fly of the Caribbean fruit fly in grapefruit. Proc. Fla. State Hort. Soc. 95: 235-237.

Von Windeguth, D. L. 1986. Gamma irradiation as a quarantine treatment for Caribbean fruit fly infested mangos. Proc. Fla. State Hort. Soc. 99: 131-134

Von Windeguth, D. L. and Arner, A. 1981. Insecticides evaluated for quarantine use against Caribbean fruit fly, 1979-1980. Insecticide and Acaracide Tests. 6: 178-179.

Von Windeguth, D. L. and Arner, A. 1986. Candidate pesticides for quarantine use against tropical fruit flies, 1981-1985.Insecticide and Acaracide Tests. 11: 440-442.

Von Windeguth, D. L., Arner, A., Burditt, A. R., Jr., and Spalding, D. H. 1977. Phosphine as a fumigant for grapefruit infested by Caribbean fruit fly larvae. Proc. Fla. State Hort. Soc. 90: 144-147.

Von Windeguth, D. L., Burditt, A. R., Jr., and Spalding, D. H. 1976. Phosphine as a fumigant for grapefruit infested by Caribbean fruit fly larvae. Fla. Entomol. 59: 285-286.

Von Windeguth, D. L. and Ismail, M. A. 1987. Gamma irradiation as a quarantine treatment for Florida grapefruit infested with Caribbean fruit fly, *Anastrepha suspensa* (Loew). Proc. Fla. State Hort. Soc. 100: 5-7.

Von Windeguth, D. L. and Gould, W. P. 1990. Gammas irradiation followed by a cold storage as a quarantine treatment for Florida grapefruit infested with Caribbean fruit fly. Fla. Entomol. 73: 242-247.

Wadley, F. M. and Sullivan, W. N. 1943. A study of the dosage-mortality curve. J. Econ. Entomol. 36: 367-370.

Weber, J. B., Carroll, J. F., and Hayes, D. K. 1987. Synthesis of acetals and esters of propargyl, propenyl and propyl alcohols and the bioassays of these and related compounds as fumigants against *Anastrepha suspensa* (Loew) larvae. J. Stored Prod. Res. 23: 1-7.

Williamson, D. L., Summy, K. R., Hart, W. G., Sanchez-R., M., Wolfenbarger, D. A., and Bruton, B. D. 1986. Efficacy and phytotoxicity of methyl bromide as a fumigant for the Mexican fruit fly (Diptera:Tephritidae) in grapefruit. J. Econ. Entomol.