

# Fruit flies and avocado production – a world perspective

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## INTRODUCTION

Fruit flies (Diptera: Tephritidae) includes about 4 300 species in almost 500 genera (White, 2006). It is amongst the largest families of Diptera and one of the most economically important. The larvae of many species develop in the seed bearing organs of plants. Several species are known to attack different types of commercially grown crops, causing considerable damage. The female punctures the fruit with her ovipositor and deposits eggs within the host fruit. Larval development within the fruit causes direct damage, which as a result may become rotten. Larvae then drop to the soil to pupate. Losses are due to direct feeding damage and also to loss of export markets as a result of quarantine restrictions imposed by importing countries free of these pests. Countries free of the fruit fly pest can require commercial fruits to undergo protective and postharvest treatments prior to export. With globalisation and the increase inter-continental movement of people it is likely that the problem of invasive fruit fly species will increase. The increased international trade in fresh commodities will also contribute to the risk of new species being introduced into novel areas.

There are about 100 fruit fly species that are considered pests (White & Elson-Harris, 1994; White, 2006). These mostly belong to five genera, namely *Bactrocera* Macquart, *Ceratitis* MacLeay, *Dacus* Fabricius, *Anastrepha* Schiner and *Rhagoletis* Loew. The avocado, *Persea americana* Mill. (Lauraceae) is associated with three fruit fly genera, i.e. *Bactrocera*, *Ceratitis* and *Anastrepha*. The genus *Bactrocera* is a large genus in Asia and Oceania and comprises of 520 described species (Norrbon, 2004). Certain species are regarded as some of the most destructive pests of fruit and vegetables world-wide (White & Elson-Harris, 1994). *Bactrocera* species are well documented as invaders and rank high on quarantine lists. In Africa, only a few indigenous species are known and only the olive fruit fly, *Bactrocera oleae* (Rossi), which is a notorious pest of cultivated olives in the Mediterranean regions, is of economic importance (White & Elson-Harris, 1994; White, 2006). However, four Asian *Bactrocera* pest species were introduced to Africa, i.e. the melon fly, *Bactrocera cucurbitae* (Coquillett); the Solanum fruit fly, *Bactrocera latifrons* (Hendel); the peach fruit fly, *Bac-*

*trocera zonata* (Saunders) and the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (White, 2006; De Meyer *et al.*, 2014). *Ceratitis* is predominately an Afrotropical group that comprises over 89 species, subdivided into six subgenera (De Meyer, 2005). *Anastrepha* is a genus of about 200 described species in the American tropics and subtropics (Foote *et al.*, 1993).

## DISCUSSION

### *Ceratitis* species

Various fruit fly species of the genus *Ceratitis* are associated with the avocado, i.e. *Ceratitis anonae* Graham, the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann); the Mascarene fruit fly, *Ceratitis catoirii* Guérin-Ménéville (according to De Meyer & White, 2004, identification considered questionable); the Marula fruit fly, *Ceratitis cosyra* (Walker); *Ceratitis fasciventris* (Bezzi) and the Natal fruit fly, *Ceratitis rosa* Karsch (White & Elson-Harris, 1994; De Meyer & White, 2004).

The Mediterranean fruit fly is widespread in Africa and is endemic to most sub-Saharan countries. This fruit fly is a highly invasive species. It has a high dispersive ability, a very wide host range and a tolerance of both natural and cultivated habitats over a relatively wide temperature range. It has a high economic impact and affects market access. It has successfully established itself in many parts of the world and outside Africa. It has been reported in Australia, several European countries, Central, North and South America, the Middle East, Oriental Asia, the Atlantic Islands, Indian Ocean Islands, Pacific Ocean Islands, the West Indies and nearby islands (CABI 2015). *Ceratitis anonae*, *C. fasciventris* and the Natal fruit fly is a complex of three closely related species. *C. fasciventris* and *C. anonae* occur sympatrically in both East and West Africa, while the Natal fruit fly is more restricted to Southern and Eastern Africa where its distribution partially overlaps with that of *C. fasciventris*, but not with *C. anonae* (De Meyer, 2001; Copeland *et al.*, 2006). The Natal fruit fly is also distributed outside Africa and is known from Mauritius and Réunion. The Marula fruit fly is only present in Africa. Mascarene fruit fly is present in the Indian Ocean islands, Mauritius and Réunion (De Meyer, 2000).

The Mediterranean-, the Marula- and the Natal



fruit fly are important fruit fly pests for the production of subtropical crops in South Africa (Prinsloo & Uys, 2014). All three species were present in avocado orchards, although the most abundant species trapped was the Natal fruit fly and this species is probably responsible for most damage caused by fruit flies (Du Toit & Tuffin, 1980; Grové *et al.*, 1998; Grové & De Beer, 2013).

Schwartz (1978), working in South Africa, stated that fruit flies do not develop in avocado. 'Fuerte' avocado fruit at different stages of development were exposed to the Mediterranean- and Natal fruit fly in orchards in the Limpopo Province of South Africa (Du Toit *et al.*, 1979). The results indicated that the Mediterranean fruit fly did not lay eggs in the fruit, while the Natal fruit fly did. Fruit-fly damage by the insect's ovipositor developed into a typical crack or star shaped lesion. Studies conducted in the same area found that the Natal fruit fly played an economically unimportant role in 'Fuerte' avocado fruit drop for the two month period following petal drop, although high numbers of the fruit fly were present (Du Toit & Tuffin, 1980). Brink *et al.* (1997) artificially infested 100 fruit of five different cultivars ('Hass', 'Fuerte', 'Ryan', 'Edranol' and 'Rinton') with 250 Mediterranean fruit fly eggs per fruit. No survival occurred after cold storage between 5.5 and 6.5°C for 28 days. Ten fruit of each cultivar were artificially infested with 250 eggs per fruit and left at room temperature. Live larvae were only found in the cultivar 'Ryan' and the survival rate from egg to larvae was 1.28%. De Villiers and Van Den Berg (1987) stated that under normal orchard practices no larval development takes place in the avocado fruit. According to Du Toit and De Villiers (1990), fruit fly larvae do not develop in the fruit of commercial avocado cultivars.

De Graaf (2009) conducted research on the susceptibility of 'Hass' avocados to the Mediterranean-, the Marula- and the Natal fruit fly in South Africa. Findings of the study were that the Mediterranean fruit fly was not able to reproduce in undamaged 'Hass' avocado when fruit were exposed up to 6 hours after harvest, or when attached to the tree. However, some development took place when punctured fruit were exposed. The results indicated that the exocarp is a physical barrier for oviposition and that antibiosis mechanisms in the fruit pulp are probably also involved. Therefore it was concluded that 'Hass' is a conditional non-host for the Mediterranean fruit fly. The Marula- and the Natal fruit fly were able to reproduce when exposed to 'Hass' avocado under high-density no-choice conditions. The results showed that 'Hass' avocado was a potential host for the latter two species, but that anti-oxenosis and antibiosis mechanisms severely restricted development. The Marula- and the Natal fruit fly females could penetrate an undamaged fruit. No successful reproduction took place when exposing Marula- and Natal fruit fly to 'Hass' avocado while attached to the tree and not immediately followed by harvest. Therefore it was concluded that the reproductive success declined when fruit were exposed while attached to the tree and no successful reproduction took place

if fruit was exposed between 8 and 18 days before harvest. Pre-export 'Hass' fruit (n = 16 882) sourced from nine pack houses situated in Limpopo and Mpumalanga during 2008 were inspected for the presence of internal pests and none were detected. Exported 'Hass' fruit from South Africa that arrived in Paris and Rotterdam was sampled for the presence of any internal pests from 2005 to 2008 and none were found. In conclusion, the study showed that the quarantine risk of fruit flies associated with 'Hass' avocado in South Africa is negligible under standard export conditions.

Studies conducted in Argentina showed that 'Hass' avocados exported without a quarantine treatment do not constitute a quarantine risk for countries free of the Mediterranean fruit fly (Willink & Villagrán, 2007; Villagrán *et al.*, 2012). Trapping data from 1998 to 2006 showed that the Mediterranean fruit fly was present in avocado orchards, especially early in the harvest season. In total, 2 250 hard, mature green avocado fruit were exposed to 11 250 sexually mature females for 24 or 48 h after harvest in laboratory or field cages, and no infestations were found. During 11 seasons, 5 949 fruit in total were sampled from the trees and 992 fruit were collected from the ground. No live or dead fruit fly larvae were found. Inspection of >198 000 commercial fruit at the packing house from 1998 to 2011 showed no fruit fly infestation. These data exceed the Probit 9 standard for development of quarantine treatments.

Studies by De Lima (1995) in Australia demonstrated non-host status for hard 'Hass' avocado for the Mediterranean fruit fly. These studies found that when hard fruit were exposed to gravid Mediterranean fruit fly for up to three days after harvest, the eggs were unable to complete development.

Experiments were conducted in Peru to determine the host status of mature green 'Hass' avocado to Mediterranean fruit fly (Liquido *et al.*, 2011). Data collected from field studies showed that commercial grade, mature green Peruvian 'Hass' avocado is not a suitable field host of the Mediterranean fruit fly. Females successfully oviposited in four of 240 intact 'Hass' avocados in choice tests. Five of 480 intact and 23 of 240 punctured avocados were successfully oviposited by the Mediterranean fruit fly during no choice tests. However, all eggs oviposited were observed to be encapsulated by callous tissues, and eventually died. Liquido *et al.* (2011) concluded that mature green 'Hass' avocado is a conditional non-host of the Mediterranean fruit fly.

Armstrong *et al.* (1983) and Armstrong (1991) reported that Hawaiian grown 'Sharwil' avocados were shown to be non-host for the Mediterranean fruit fly at the mature green stage of ripeness. They suggested that fruit could be exported safely when fruit are harvested with stems attached, brought to the pack house within 12 hours, sorted to remove damaged fruit and packed in fruit fly-proof cartons. 'Sharwil' avocado became an increasingly favourable host for the Mediterranean fruit fly as it ripens and softens after harvest (Oi & Mau, 1989; Armstrong, 1991; Chen *et al.*, 2009; Follett, 2009). Harvested and pre-



harvest 'Sharwil' fruit were exposed by Oi and Mau (1989) to Mediterranean fruit fly and they concluded that 'Sharwil' fruit can serve as a potential host under reasonable normal harvesting and handling conditions. Liquido *et al.* (1995) studied natural infestation rates in the field and found no infestation by Mediterranean fruit fly. Jang (1996) exposed eggs and larvae of the Mediterranean fruit fly to mature green 'Sharwil' avocado. Results showed a high mortality associated with being in the fruit without a treatment. Liquido *et al.* (1995) studied natural infestation rates in the field and found no infestation by Mediterranean fruit fly. The Mediterranean fruit fly was not capable of successfully infesting 'Sharwil' fruit when exposed within 24 hours of harvest (Follett, 2009). Klungness *et al.* (2009) found no naturally Mediterranean fruit fly infested 'Sharwil' fruit in a study in the Kona district in Hawaii. Therefore, data from Liquido *et al.* (1995), Klungness *et al.* (2009) and Follett (2009) suggest that only the oriental fruit fly is a quarantine pest of concern for 'Sharwil' avocado in Hawaii.

### **Anastrepha species**

Six fruit fly species of the genus *Anastrepha* are associated with avocado production, i.e. the South American fruit fly, *Anastrepha fraterculus* (Wiedemann); the Mexican fruit fly, *Anastrepha ludens* (Loew); the West Indian fruit fly, *Anastrepha obliqua* (Macquart); the sapote fruit fly, *Anastrepha serpentina* (Wiedemann); the guava fruit fly, *Anastrepha striata* Schiner; and the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (White & Elson-Harris, 1994; Aluja *et al.*, 2004). The record for the South American fruit fly is considered questionable (Aluja *et al.*, 2004). The guava fruit fly attack fruit of the genus *Psidium* and is considered stenophagous (Aluja *et al.*, 2000). The Mexican fruit fly is a very serious pest of various fruits, particularly citrus and mango, in Mexico and Central America. The West Indian fruit fly occurs throughout the Caribbean, South to Southern Brazil and is the most abundant species of *Anastrepha* in the West Indies and Panama and is an important pest of mango. The sapote fruit fly is an important pest species in Mexico because its larvae infest sapote, sapodilla and various other fruits. This species is one of the most widely distributed in the genus *Anastrepha*. Its range extends from Northern Mexico south to Peru and Northern Argentina, and is recorded from the West Indies. The Caribbean fruit fly is indigenous to the West Indies and attacks several kinds of tropical and subtropical fruits.

Enkerlin *et al.* (1993) conducted experiments to determine whether Mexican grown 'Hass' avocado fruits were hosts for laboratory reared Mexican- and sapote fruit fly, and wild guava fruit fly. Experiments included exposure to fruits at various stages of ripeness under semi-natural and laboratory conditions. When fruits were attached to the tree and exposed under no-choice conditions to gravid females of the Mexican-, the sapote- and the guava fruit fly, no infestation occurred. Only if fruit have been removed from the tree and exposed artificially under

no-choice conditions over a period of up to 4 days to gravid females, infestations were recorded. Seventeen avocado selections were bioassayed for antibiosis to the Caribbean fruit fly (Hennessey *et al.*, 1995). Selections were artificially infested after harvest. Fourteen of the selections did not support any development of immature stages to the adult stage. The results support the contention that highly resistant cultivars would not pose a high risk of spreading the Caribbean fruit fly to foreign markets, even without postharvest disinfestation treatment. The host status of Mexican grown 'Hass' to the Mexican-, the West Indian-, the sapote- and the guava fruit fly was determined. *Anastrepha* adults were trapped in all orchards. No eggs or larvae were detected in any of the fruit from foraging behavior studies or dissected fruit from orchards or pack houses. In this study, 5 200 fruit attached to the tree were artificially exposed to 26 000 gravid females of the Mexican-, the West Indian-, the sapote- and the guava fruit and only four ended up infested by the Mexican fruit fly, but no adults emerged. 'Hass' avocados only became marginally susceptible to attack by the Mexican fruit fly (but not to the West Indian-, the sapote- and the guava fruit fly) 24 hours after being removed from the tree. Aluja *et al.* (2004) came to the conclusion that 'Hass' should not be considered a natural host of the Mexican-, the West Indian-, the sapote- and the guava fruit fly in Mexico.

Experiments were conducted in Peru to determine the host status of mature green 'Hass' avocado to the guava- and the South American fruit fly (Liquido *et al.*, 2011). Data collected from field studies showed that commercial grade, mature green Peruvian 'Hass' avocado is not a suitable field host of the guava- and the South American fruit fly. Experiments showed that mature green 'Hass' avocado is not a host of the guava fruit fly and is a conditional non-host of the South American fruit fly. Therefore, with the appropriate safeguards before and during harvest, during packing and during shipment and arrival at port of entry, mature green 'Hass' avocados from Peru do not pose risks of introducing the guava- and the South American fruit fly.

Commercially ripe 'Hass' avocados, artificially exposed to wild Mexican fruit fly females 24 hours after harvest were placed in a cold storage facility to determine the effect of low temperature on larval survival and adult viability (Aluja *et al.*, 2010). Fruit were left for 3, 6, 9 and 12 days at 5°C followed by a 20 to 25 day period at ambient temperature. 'Hass' avocados exposed for 12 days to 5°C yielded no puparia. However, fruit exposed for 6 and 9 days yielded puparia, but no adults. Aluja *et al.* (2010) concludes that exposing fruit to cold storage after packing and during transport represents an effective risk-mitigating procedure in the highly improbable event that a gravid Mexican fruit fly female might lay eggs in a 'Hass' fruit in a pack house.

### **Bactrocera species**

*Bactrocera* species found in association with avocado



include Northern Territory fruit fly, *Bactrocera aquilonis* (May); the melon fruit fly, *Bactrocera cucurbitae* (Coquillett); the oriental fruit fly, *Bactrocera dorsalis* (Hendel); *Bactrocera facialis* (Coquillett); the Fijian fruit fly, *Bactrocera passiflorae* (Forggatt); the Queensland fruit fly, *Bactrocera tryoni* (Froggatt), (White & Elson Harris, 1994). The Northern Territory fruit fly is present in Australia, the northern areas of Western Australia and in the Northern Territory. The melon fruit fly is native to Oriental Asia and has also been reported from Africa, Hawaii, Iran, the Indian Ocean Islands, the New Guinea area and Seychelles. Plants in the family Cucurbitaceae are, however, the usual hosts. The oriental fruit fly, *Bactrocera dorsalis* (Hendel), is a very destructive pest of fruit in areas where it occurs. It is established in numerous areas in Asia, the Philippines and Hawaii. *Bactrocera dorsalis* was found in Africa in Kenya in 2003 (Lux *et al.*, 2003) and initially described as a new species – *Bactrocera invadens* Drew, Tsuruta and White (Drew *et al.*, 2005). *Bactrocera invadens* was synonymised with the oriental fruit fly (Schutze *et al.*, 2014). The oriental fruit fly was detected in South Africa in 2010 (Manrakhan *et al.*, 2011). *Bactrocera facialis* and the Fijian fruit fly are present in the South Pacific. Queensland fruit fly is native to eastern Queensland and north eastern New South Wales and has spread to urban and horticultural areas in Queensland, New South Wales, Victoria and the Northern Territory. Armstrong (1991) showed that Hawaiian 'Sharwil' avocados are not a host for the Solanum fruit fly, *Bactrocera latifrons* (Hendel). Various studies in Hawaii indicated that 'Sharwil' avocado is not naturally infested by the melon fruit fly (Armstrong *et al.*, 1983; Armstrong, 1991; Liquido *et al.*, 1995; Klungness *et al.*, 2009).

Armstrong *et al.* (1983) and Armstrong (1991) reported that Hawaiian grown 'Sharwil' avocados attached to the tree are not naturally infested by oriental fruit fly at harvest maturity. They suggested that fruit could be exported safely when fruit are harvested with stems attached, brought to the pack house within 12 hours, sorted to remove damaged fruit and packed in fruit fly-proof cartons. Harvested and pre-harvest 'Sharwil' fruit were exposed by Oi and Mau (1989) to oriental fruit fly and they concluded that 'Sharwil' fruit can serve as a potential host under reasonable normal harvesting and handling conditions. 'Sharwil' avocado became an increasingly favourable host for fruit flies as it ripens and softens after harvest (Armstrong, 1991; Oi & Mau, 1989; Chen *et al.*, 2009; Follett, 2009). A systems approach for export of Hawaii 'Sharwil' avocados to the U.S. mainland, based on non-host status, was approved by U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), but the rule was rescinded in 1992 when live oriental fruit fly larvae were found in mature green fruit attached to the tree. Liquido *et al.* (1995) studied natural infestation rates in the field and found a low level of infestation by oriental fruit fly. Therefore, 'Sharwil' avocado is naturally a poor host, rather than a non-

host for this pest. The oriental fruit fly was capable of successfully infesting 'Sharwil' fruit when exposed within 24 hours of harvest (Follett, 2009). Klungness *et al.* (2009) found naturally oriental fruit fly infested 'Sharwil' fruit in a study in the Kona district in Hawaii. Therefore, data from Liquido *et al.* (1995), Klungness *et al.* (2009) and Follett (2009) suggest that only the oriental fruit fly is a quarantine pest of concern for 'Sharwil' avocado in Hawaii. A modified systems approach for oriental fruit fly was developed for export of 'Sharwil' avocados, based on poor host status, low prevalence and limited sales distribution (Follett & Vargas, 2010).

The oriental fruit fly was reported infesting avocados in Africa (Ekesi *et al.*, 2006; Mwatawala *et al.*, 2006; Rwomushana *et al.*, 2008; Goergen *et al.*, 2011; Akol *et al.*, 2013). Ware *et al.* (2012) developed a cold mitigating treatment against the oriental fruit fly in 'Hass'. Fruit ripeness or softness was found to be a factor improving larval survival. The third instars were the most cold tolerant life stage. There were no survivors in a treatment of an estimated 153 001 individuals at an average fruit pulp temperature of 2°C for 18 days, satisfying the Probit 9 level of efficiency at a confidence of >95%. The data provide evidence that a continuous cold treatment of 1.5°C or lower for 18 days would provide phytosanitary security.

A quarantine disinfestation treatment for 'Hass' avocados against the Queensland fruit fly was developed in Australia and the treatment entitled a hot fungicide dip followed by a cold treatment of 1°C for 15.63 days (Jessup, 1994). Two cultivars, 'Hass' and 'Lamb Hass', have been shown to be conditional non-hosts for Queensland fruit fly, provided fruit is hard with undamaged skin. The cultivars 'Shepard' and 'Wurtz' did not meet conditional non-host requirements and a cold treatment of 5 days at 2.5°C was developed that meets the efficacy requirements for interstate trade (99.5% efficacy at 95% confidence) and is a much more acceptable option for growers than the long cold treatment of 1°C for 16 days (Hamacek *et al.*, 2005).

#### Mechanism of resistance

The avocado is a climacteric fruit that ripens after harvest. Increase in infestation is correlated with decrease in fruit firmness (Follett, 2009). However, relatively hard fruits are susceptible to attack, although rarely. The thick exocarp of some cultivars and the short aculei of some fruit fly species can potentially also play a role (De Graaf, 2009). Callus tissue formation around the fruit fly eggs deposited in the pulp has been reported (Armstrong *et al.*, 1983; Liquido *et al.*, 1995; Aluja *et al.*, 2004). Another potential source of resistance in avocado is idioblast oil cells that contain persin and avocado furans with antifeedant and toxic effects (Rodriguez-Saona *et al.*, 1998; Follett, 2009).

#### CONCLUSION

Avocado fruit is a non-host, a conditional non-host or a poor host for the development of fruit fly lar-





vae, depending on the cultivar and the fruit fly species. Natural infestations are usually low and often associated with defect fruit. The poor host status of avocado cultivars with low infestation rates makes a systems approach a practical option for pest risk management of fruit flies (Follett & Neven, 2006).

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