



Management of *Bactrocera* Pest species (Diptera: Tephritidae) in a Subtropical Commercial Fruit Orchard in South East Queensland

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ABSTRACT: In a persimmon (*Diospyros kaki* Thunberg) orchard growing under wet sub-tropical conditions in South East Queensland within a district carrying high density populations of four major fruit fly pest species, the crop was protected successfully from fruit fly attack by applications of Fruition Natflav 500 protein bait and the Fruition® Nova trap. *Bactrocera tryoni*, *B. jarvisi*, *B. neohumeralis* and *B. cucumis* all were present. Trapping data revealed the presence of low numbers of immature female flies, probably due to the impact of the protein bait treatment. Large numbers of mature females were trapped on the Fruition Nova traps around the perimeter before these flies could enter the orchard. Over a 6.5-week period, 102 tons of fruit were harvested with fruit fly damage estimated at an average of less than three percent. Indications place this success to an appropriately long period (11 weeks) of protein bait applications and early placement (seven weeks) of Fruition Nova traps, before the start of harvest. This new Fruition technology already is having an international impact. A discussion is presented also on our knowledge of protein baits, traps and lures, and also on the critical underlying importance of accurate pest species identification.

Keywords: fruit flies, genus *Bactrocera*, pest management, Fruition.

INTRODUCTION

Fruit fly pest species in the tephritid subfamily Dacinae inflict major crop losses to a wide range of horticultural crops throughout the tropics and subtropics of the world. Further, as reported by Zhao *et al.* (2024), some of these pest species are responsible for a number of incursions into countries at great cost in terms of monitoring and eradication programs incurred. Although they are recognised as tropical insects, they have the potential to survive in a wider range of climatic zones (Zhao *et al.*, 2024).

In South East Queensland there are four major fruit fly pest species that inflict considerable damage on fruit and vegetable crops. These are *Bactrocera cucumis* (French), *B. jarvisi* (Tryon), *B. neohumeralis* (Hardy) and *B. tryoni* (Froggatt). While *B. tryoni* (Queensland fruit fly) is 'public enemy number one', all four have the potential to attack fruit tree crops. With their short overlapping life cycles and availability of multiple host fruits, these species rapidly build up to large populations, especially in suburban areas and native forests, and then disperse often over long distances to commercial orchards.

Dominiak & Ekman (2013) provided a comprehensive and valuable assessment of the demise of six major insecticide groups over the past century that were used in fruit fly field control in Australia and the most recent loss of the systemic organophosphates, Dimethoate and Fenthion due to health and environment concerns. These authors also reviewed the current potential alternative strategies available at that time and encouraged a 'systems' approach using multiple tools. De Faveri (2016) reviewed and researched farm-wide management systems for tropical fruit crops in North Queensland based on protein baiting and male annihilation. This research evaluated the efficacy of a range of protein baits, the phytotoxic effects of these baits, protein bait delivery stations to replace sprays, and the efficacy of male annihilation. Perimeter protein baiting also was evaluated for vegetable crops but not for fruit orchards. That report provided a comprehensive and valuable overview of the current strategies and associated products available to growers for fruit fly control in Australia but did not reveal any new technologies. Brief reviews of management strategies for fruit flies in fruit

crops (Reddy *et al.*, 2020; Dias *et al.*, 2018; Manrakhan, 2020) on the international scene also advocated taking a multi-tool approach using existing technologies.

Drew (2017) reviewed the fruit fly management strategies that are being implemented in a wide range of communities and cropping systems nationally and internationally. These strategies included Physical control (using protective barriers), Cultural control (crop hygiene, early harvesting), Biological control (parasitoids, predators), Insecticide cover sprays and Behavioural control (utilizing olfactory and visual attributes of the species). For commercial producers in South East Queensland most of these strategies are ineffective, especially as farms are interspersed, over a very large area, between extensive native forest, village and suburban ecosystems, all of which breed populations of the fruit fly pest species. Physical control and cultural control are rarely used while biological control has proven ineffective in the ecosystems encountered over the past seven decades. New insecticides were value added by Senior *et al.* (2017), but they have not been registered for use as cover sprays. However, they may have value as toxicants in protein bait sprays.

In the post-insecticide cover spray era, it is essential to be able to identify the actual pest species and to understand the biology/behaviour of these fruit flies in their host plants in contrast to the ecology of populations within a particular ecosystem. The host plant behaviour of species within fruit tree crops remains relatively consistent whereas the population structures over different climatic zones and thus production areas can vary. We now have an excellent knowledge of host plant behaviour upon which we can build new and effective field pest control strategies for pest fruit fly species. While there are a wide range of definitions of the fruit fly host plant (Aluja & Mangan 2008), often dependent on the economic significance of an infestation, under behavioural control, Drew & Lloyd (1987); Drew (2017) defined the host plant as the 'Centre of Activity for a Fruit Fly Population' as within this habitat adult feeding, courtship and mating, oviposition, larval growth and pupal development all occur. This definition is more applicable when discussing direct field pest management.

Over several decades, using different sampling techniques, we have measured the female fruit fly population entering a maturing crop as being approximately 80% immature and 20% mature individuals (Drew & Lloyd 1987). Protein bait sprays target the immature flies seeking protein for development but, to date, we have not had a tool to target the mature females that enter the crop to oviposit in ripening fruit and which are not attracted to feed on protein. The new Fruition lure and trap based on volatiles produced by ripening host fruits now fills this gap and in conjunction with protein baiting targets the whole female population.

In this paper we describe and present data on a fruit fly field control trial undertaken in a persimmon orchard in South East Queensland 2023/2024 where the field

treatments were Fruition Natflav 500 protein bait in conjunction with the Fruition Nova fruit fly trap.

MATERIALS AND METHODS

The Orchard

The field trial was conducted on an isolated subtropical persimmon orchard (*Diospyros kaki* Thunberg), unique to the district of Amamoor, Queensland, 26.35 degrees S, 152.65 degrees E. The area contained 10.2 ha of persimmons, 7.5 ha (5990 trees) of the variety Jiro and 2.7 ha (1450 trees) of the variety Fuyu. The Amamoor region is an authentic subtropical one with a high rainfall (historical mean monthly total for the period of the trial is 138.4 mm) and a mean monthly maximum temperature of 31.7°C for the same period, 6 December 2023 to 7 April 2024. These figures are the long-term averages over 20 years, provided by the Australian Bureau of Meteorology.

Persimmons are a deciduous plant, losing foliage during the Winter months June to August with new shoots, flowers and fruit developing in Spring (September to November). By early December the fruits were approximately mid-sized, hard green and would be ready for harvest nine weeks later in mid-February. The fruit were harvested over a period of approximately seven weeks from mid-February to early April, 2024.

Fruit Fly Susceptibility

Persimmons are highly susceptible to fruit fly attack with four major *Bactrocera* pest species recorded from the crop during the trial, viz., *B. cucumis* (French), *B. jarvisi* (Tryon), *B. neohumeralis* (Hardy) and *B. tryoni* (Froggatt). Wild and cultivated host fruits of all four species occur in the region with the Amamoor State Forest to the north-west of the farm being a significant source of flies, in addition to fruits such as guava growing wild in the hill country surrounding the farm.

Fruit fly host records in Hancock *et al.* (2000a) do not reveal the true impact of fruit flies on commercial persimmon crops. These host records are based on flies emerging from field collected fruits held in laboratory rearing facilities. However, oviposition always results in large black spots (Fig. 1) leaving the fruit unmarketable while the eggs often are encapsulated under the fruit surface within a cyst which prevents larval development, subsequent fruit decay and fly emergence.

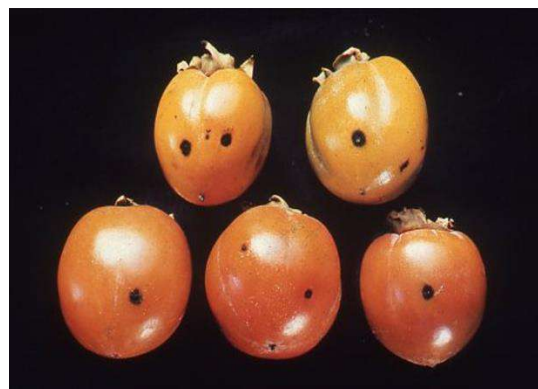


Fig. 1. Image of Persimmon fruit with black spots due to fruit fly oviposition (Photo: R.A.I. Drew).

With the withdrawal of permits for the application of systemic insecticide cover sprays for fruit fly control in Australia in 2011, the farm on which this trial was conducted reported up to 50% crop loss in subsequent years. *Bactrocera* pest species in particular demonstrate a consistency in levels of crop losses which enabled Follett *et al.* (2021) to publish a host suitability index for many species. These losses occurred under the combined treatments of protein bait sprays and male trapping. The male trapping with cue lure would have attracted only males of *B. neohumeralis* and *B. tryoni*, respectively. Barclay and Hendricks (2014) reported results of modelling the impact of male annihilation of *Bactrocera* spp. using the male lure methyl eugenol and concluded that the attraction and killing of large numbers of male fruit flies to suppress populations was rather ineffective. This is especially correct on small area farms, whereas in area-wide situations over extremely large regions, male annihilation has been used successfully to eradicate invading populations (Hancock *et al.*, 2000b). Drew *et al.* (2024) noted the value of male annihilation in the total eradication of pest species of fruit fly where treatments were applied over long time periods and large geographic areas whereas, in contrast, male lure baiting on farms has very little impact.

Fruit Fly Sampling and Data Analysis

All fruit flies collected were identified to species and numbers of females and males, respectively, were counted. Female fruit flies were dissected for assessment of sexual maturity. This work including species identification was undertaken by one of the authors (R. Drew), the leading world authority in the taxonomy of the genus *Bactrocera*. The dissections of the female flies were undertaken under a Carl Zeiss Stemi 2000 stereomicroscope. In this procedure the abdomen ventral membrane was cut to expose the ovaries, and if mature eggs were identified then the female fly was recorded as mature. If no eggs were present the fly was recorded as immature. Male flies were not dissected for assessment of sexual maturity.

The data comparing the two groups of trapped immature and trapped mature female fruit flies in Table 1 and Table 2 were analysed by the two-sample *t* test, assuming unequal variances, using the Analysis Toolpak in Microsoft Excel with the threshold for statistical significance being *P* less than 0.05.

The data in Table 3 containing three groups were analysed by a two factor ANOVA with replication test using the Analysis Toolpak in Microsoft Excel with the threshold for statistical significance being *P* less than 0.05.

Fruit Fly Field Control Treatments

The treatments applied were combinations of Fruition Natflav 500 Protein Bait sprays and Fruition Nova traps with sachets of synthetic fruit lure and Fruition Natflav 500 protein.

Protein Bait

Fruition Natflav 500 protein bait was applied to the crop and native vegetation around the perimeter of the orchard. The protein was mixed at the rate of 2.5 L/100 L water thickened with Xanthan Gum (at 200 g/100 L

water) and Hymal malathion at 0.175% a.i. The bait mixture was applied to every row within the 10.2 ha orchard the rate of 10 L/ha and additional 100 L applied to the perimeter vegetation. Regarding the timing of the protein baiting, the mixture was applied weekly (on some occasions several times per week due to rain), resulting in 52 applications over the 18-week period from 6 December 2023 to 7 April 2024. A decision was made to begin the protein baiting on 6 December 2023 when the fruit was medium-sized, approximately 5 cm diameter, hard green and not susceptible to fruit fly attack, in order to prevent the build-up of the fly populations before fruit became susceptible. This was an 11-week period before the beginning of harvest on 20 February 2024. Protein baiting was continued for a further 6.5 weeks until the end of harvest at 7 April 2024.

Fruition Nova Trapping

Fruition Nova traps are designed to attract and kill mature egg-laying female fruit flies of all pest species present including those not attracted to other trap types. The trap contains a synthetic fruit lure designed to last about 10-12 weeks. In the last week of December 2023, single Fruition Nova traps were set 20 metres apart in vegetation around the perimeter of the orchard. At seven of these trap positions an additional Fruition Nova trap with the standard lure plus a Fruition Natflav protein lure sachet was set within one metre of the standard Fruition Nova trap in order to assess the addition of protein lure to the trap. An additional five traps with the standard lure plus a Fruition Natflav protein lure sachet were set at approximately 20 metres apart and 20 metres inside the north-western sector of the orchard. This area consisted of young trees without fruit. New like-for-like traps were set beside the 19 traps being sampled for fruit flies at mid-February 2024 and the old traps were not removed. At the same time new Fruition Nova traps were placed at all other trap sites around the perimeter of the orchard.

All fruit fly specimens were taken from the five traps in the north-western sector of the orchard and from the traps at the seven perimeter locations on three occasions, i.e. 10 January 2024, 10 February 2024 and 9 March 2024.

Fruit Harvest and Damage Assessment

102 tons of fruit were harvested over 36 days between 20 February 2024 and 12 April 2024, a 6.5-week period. During the process of grading, washing and packing for the market, daily samples of fruit ca. 100 kg were taken and assessed for fruit fly damage and also for surface damage not due to fruit flies. This involved weighing the total daily samples of damaged fruit and calculating the percent over the overall fruit weight harvested.

Weather

For the period of the trial the mean monthly rainfall from December 2023 to March 2024 was 174 mm, 36 mm higher than the long-term average of 138.4 mm. The mean maximum daily temperature over these four months was the same as the long-term average, 31.7°C. The harvest and thus the trial were completed at the end of the first week of April 2024 so weather data for this short period are not included.

RESULTS

Trap Data. The four pest species known to occur in the Amamoor area were trapped on the Fruition Nova traps during the trial, i.e. *Bactrocera tryoni*, *B. jarvisi*, *B. neohumeralis* and *B. cucumis*.

The data for female flies were analysed by the two-sample t test, assuming unequal variances, using the Analysis Toolpak in Excel. The calculated t statistic of 7.4 exceeded the two-tail t critical value of 4.3, therefore

significantly more mature female flies than immature female flies were trapped over the three-month period of the trial, on all traps combined for the three sampling occasions (Table 1). Data for male flies were not analysed as they were not assessed for maturity.

As expected, more mature female fruit flies than immature female fruit flies were trapped. We did not attempt to divide the male numbers by sexual maturity status.

Table 1: Total number of *Bactrocera* pest species flies trapped over the January to March 2024 sampling period from the 19 designated traps. Numbers represent the total number of mature females, immature females and males.

Sample Date	Mature females	Immature females	Males	Total
10 January	72	8	63	143
10 February	48	3	40	91
9 March	58	8	48	114
Mean	59.33	6.33	50.3	116

Table 2: Total number of mature and immature females of each *Bactrocera* pest species trapped over the January to March 2024 sampling period from the 19 designated traps.

Species	Mature females	Immature females
<i>B. tryoni</i>	69	10
<i>B. jarvisi</i>	77	2
<i>B. cucumis</i>	17	3
<i>B. neohumeralis</i>	15	4
Mean	44.5	4.75

Similarly using the two-sample t test (as for Table 1), the calculated t statistic of 2.38 exceeded the one-tail t critical value of 2.35 but did not exceed the t statistic of 3.18 for the two-tailed test. Whilst the level of significance is not high, for the four species, significantly more mature female flies were trapped compared to the numbers of immature female flies over the three-month period of the trial on all traps combined for the three sampling occasions (Table 2). When the data were analysed by a two-factor ANOVA without replication, there were no significant differences between the numbers of the different species trapped even though the numbers of *B. tryoni* and *B. jarvisi* dominated.

All four species have been recorded from persimmon fruit while *B. tryoni* and *B. jarvisi* are recognised as the

major pest species in Queensland horticulture. During the 10 February 2024 sampling we observed *B. jarvisi* and *B. cucumis* ovipositing in persimmon fruit on a perimeter tree. On the 9 March 2024 sampling a Fruition Nova trap in the same tree had trapped newly emerged specimens of both species.

Numbers of flies trapped on the Fruition Nova traps at the seven designated peripheral sites were larger on those traps in the south-east quarter. During the trial period, morning winds when fruit flies are most active were 2 to 6 km/h from the south-east. Previous field trials have indicated that flies move into light winds (Drew *et al.*, 2024).

Table 3: Total numbers of *Bactrocera* pest species females and males collected at the seven designated peripheral sites on 9 March 2024 from old traps (7 to 12 weeks) and new traps (1 to 4 weeks) with and without Natflav protein sachets. FN = Fruition Nova trap.

Trap Age	No. females	No. males	Total	Mean
FN (7 to 12 weeks)	4	2		
FN + Natflav 7 to 12 weeks)	9	5	20 (7 to 12 weeks traps)	5
FN (1 to 4 weeks)	25	23		
FN + Natflav (1 to 4 weeks)	27	18	93 (1 to 4 weeks traps)	23.25
Total	65	48	113	

The data were analysed by a two-factor ANOVA with replication using the Analysis Toolpak in Excel. There was a significant difference between the mean number of fruit flies on the newly placed traps compared to the mean number of flies on those traps that had been in the field for a longer period, ($F(1, 4) = 84.5$, $p = 0.0007$). However, there was no significant difference between the mean number of female flies compared to the mean number of male flies on the traps, ($F(1, 4) = 4.58$, $p = 0.09$).

While the addition of a Fruition Natflav 500 protein sachet did not increase the numbers of flies attracted to the traps, there was a significant increase in numbers when new traps and lures were added to the network (Table 3).

Fruit Harvest and Damage Assessment

During the processing of fruit in the packing shed all fruit with fruit fly oviposition black spots and with non-fruit fly surface damage were set aside into two separate crates and weighed. From these samples for each harvest day the percent fruit loss to fruit flies and other damage were calculated. The crop loss to fruit fly damage over the entire harvest period was averaged out at 2.87% by weight, excluding a heavy rain period 15 March to 18 March 2024 when the loss ranged between 11.4% and 25.2%. The loss of crop to other non-fruit fly damage was considerably larger. Fruit fly oviposition sites in persimmons are efficiently identified as circular black spots approximately 3-4mm diameter. The physical damage inflicted on the fruit by other organisms was observed, in contrast, as destruction of the fruit surface.

DISCUSSION

Along the subtropical and tropical coastal areas of eastern Australia there are high density populations of a number of major pest fruit fly species. In this wider region a large range of crops highly susceptible to fruit fly attack are grown while we are now in an era when new pest management strategies are required as explained by Dominiak and Ekman (2013). In these regions fruit flies have multiple life cycles per year (Meats, 1989), breed in a wide range of wild and edible fruits (Hancock *et al.*, 2000) and disperse over long distances between breeding localities (Drew, 2017). Adding to the complexity of crop protection, most farms exist within different ecosystems each with different fruit fly population structures. This trial was conducted on an isolated persimmon farm unique to the district and subject to invasion from locally bred populations and long-distance dispersal. Long distance movement of fruit fly populations into farms is significant, as reported by Fletcher (1973, 1974, 1989); MacFarlane *et al.* (1987); Drew (2017); Froerer *et al.* (2010), and adds to the high fruit fly pressure on orchards, especially in tropical and subtropical climatic zones.

While most producers can tolerate losses below 10% as economically acceptable, crop losses of 50-90% are common in uncontrolled situations. Persimmon crops are no exception with reports of 50% losses due to fruit fly attack even under protein bait spraying and male annihilation. The field trial reported herein was

conducted on a persimmon orchard in South East Queensland with high fruit fly populations of four pest fruit fly species, and regular rainfall detrimental to the persistence and efficacy of protein bait sprays. In the wider region, fruit fly breeding occurs in forest and rural locations adding fly pressure to the commercial cultivated crops.

Data from the Fruition Nova traps indicated that small numbers of immature females were present, probably due to the protein bait program. These data demonstrated the combined efficacy of protein baiting to attack the immature fly population and the Fruit on Nova traps to attract and kill the mature females. In this field trial the fact that the protein bait treatments began eleven weeks before harvest would have prevented the early build-up of the immature fruit fly population within the orchard – many of which, otherwise, would have developed into mature egg-laying females.

The growers cover each row of trees with bird netting and while this cover will still allow fruit flies to pass through, they report reduced fly activity both in trap numbers and crop damage under this situation.

When using traps and attractant baits to control fruit fly populations, the correct timing and placement of the treatments are essential and often are specific to a particular crop, the manner in which it is cultivated, and the wider ecosystem in which it exists (Drew, 2017). Further, phytotoxic effects can be experienced with most protein baits and thus they should be applied in a strategy that minimizes such impacts (Manrakhan *et al.*, 2015; De Faveri, 2016). These authors found that an increase in size of spray droplets, coverage and wetness and increased concentration all contributed to increasing phytotoxicity. In this field trial the application of boundary bait sprays and Fruition Nova traps together with an early start to the baiting resulted in a successful outcome of less than three percent crop loss. The success of this trial adds to evidence from other trials in South East Queensland and in southern India and Taiwan that this new fruit fly pest control technology is having global impact in alleviating crop losses to a wide range of fruit fly pest species (Drew *et al.*, 2024).

ADDITIONAL NOTES ON BAITS, TRAPS AND LURES

Protein Bait Technology

Protein bait technologies have been used in the management of *Bactrocera* pest species since the inception of the first protein baits in the early 1950s in Hawaii (Steiner, 1952; Allwood, 1997). While there have been advancements in the development of improved formulations, and currently increased calls for acquiring more effective products, there has been little emphasis on the flies' nutritional requirements as to how and when they respond to the protein baits, and to the ecological environment within which the protein baits are applied. Further, little emphasis is placed on the timing of the application and its position on the plant in application in order to achieve maximum impact. Protein in the form of amino acids is an essential nutrient for immature adult female flies for them to develop to

maturity and produce fertile eggs. Because in *Bactrocera* species these proteins, and other essential nutrients, are not transferred to the adult fly from the larvae they must be obtained from external sources. In particular, leachates on the surfaces of fruits and leaves of fruiting host plants provide a wide range of amino acids, sugars and minerals that can be ingested, especially under moist conditions of rainfall and condensation. Records have demonstrated that the females ingest food from the fruit surfaces and the males from vegetative parts of the host plant (Courtice & Drew 1984).

There has been extensive research and publications on the role that protein plays in the diet of Queensland fruit fly and other tephritid species, too numerous to reference here. In laboratory studies, Holmes (1983); Meats and Leighton (2004) concluded that protein intake by females peaked eight to ten days and five to seven days after emergence, respectively. Further, Dalby-Ball and Meats (2000) demonstrated that the odour of yeast protein increased flight frequency of immature *B. tryoni* but had no effect on mature females. Conversely, the odour deriving from ripe guava fruits increased the flight activity of mature females. Research on Queensland fruit fly by Howie (2007) concluded –

1. Protein feeding was greatest in immature females while mature females spent very little time in protein feeding.
2. Sugar feeding was greatest by mature mated females.
3. Mature egg laying females respond to fruit odour, not protein. The low response of mature females to protein explains why they are not attracted to protein baits, as they have no further need of protein, having reached maturity and developed eggs.

More recently, this pattern of behaviour was recorded by Balagawi *et al.* (2014) who reported a ‘poor response of mature females to protein’.

Given that our research has demonstrated that a large proportion of the female fruit fly population that enters a fruiting orchard consists of immature individuals (Drew & Lloyd 1987), protein bait sprays are an essential technology to prevent these individuals from reaching sexual maturity and laying eggs. From our research and that of others, we recommend the following methodology in applying protein baits –

1. Apply to fruiting host plants.
2. Begin applications as early as possible preferably before the fruit is medium-sized and attractive to fruit flies. This will prevent an early build-up of flies in the orchard.
3. Apply to the middle and upper foliage as demonstrated by Senior *et al.* (2016).
4. Apply in the mornings when the flies are actively feeding.
5. Apply at five to seven-day intervals or within this period immediately after heavy rain.

The inclusion of Xanthan Gum to water before mixing the protein and toxicant has been shown to increase the toxicity of the bait formulation (Pathan *et al.*, 2022). This is most likely due to Xanthan Gum being a feeding stimulant. All known protein baits can have a phytotoxic effect on leaves and fruit. However, the baits are only

effective when applied to these sites and not to tree trunks, branches, posts, artificial sites such as fabric or bags.

Fruition Trap Technology

Because mature egg-laying females are the stage that inflict crop losses and because these are not attracted to nor controlled by protein baits, we undertook extensive laboratory and field research, and invoked chemical analyses on volatiles emitted by ripe fruit in nature. This, together with a wide knowledge of fruit fly feeding and attraction cues concerning shape and colour (Drew *et al.*, 2003), led to the development of the Fruition Nova trap (Drew, 2017).

While the traps attract and kill mature and immature males and females, their dominant catch consists of mature egg-laying females. After some eight years of further field trials undertaken in commercial orchards in Queensland, the following features of the Fruition Nova trap have proven significant (Drew *et al.*, 2024).

1. Targets, in particular, mature egg-laying females.
2. Attracts the four major pest species in Queensland, six over the Indian subcontinent and South East Asia and two in Tonga. A further eight species have been trapped in Queensland, making a total of 20.
3. It is a powerful trap for *B. cucumis* (Cucumber fly) in Queensland, which is highly important due to this species not responding to male lures and only weakly so to protein and fruit juice traps.
4. In a wide range of commercial crops, it has made an impact on reducing crop losses, especially when combined with protein baiting.
5. In some crops such as gherkins in southern India and pumpkins in South East Queensland, the trap alone has made a major contribution in reducing crop losses.
6. The three attractive components, shape, colour, and the synthetic lure that contains volatiles produced by two ripe fruit fly host fruits, combine to result in a highly effective trap technology. The traps should be placed within or adjacent to fruiting host plants.
7. The traps should be placed about 20 metres apart around the boundary of an orchard. Within an orchard we recommend 20 traps per hectare but this density is best refined by experience over time depending on the nature of the orchard.

Male Lure Trapping

Male lure trapping makes very little contribution to fruit fly pest management in an orchard for the following reasons (Drew, 2020) –

1. The mature female fruit flies that enter an orchard are already fertile and do not seek mates, while the immature females are killed by the protein baits before mating occurs.
2. Some pest species are not attracted to known male lures.
3. The long-distance attraction of the male lures results in attracting large numbers of flies into an orchard which is not an indication of the natural population that is moving into the crop and definitely is not a measure of the invading female population.

INTEGRATED PEST MANAGEMENT OF FRUIT FLIES

Over the past three decades there has been significant international focus on Integrated Pest Management (IPM) and the application of a range of treatments for the field control of fruit flies and, in particular, pest species in the genus *Bactrocera*. Further, the use of IPM in Area-Wide pest management has been researched in the Asian-Pacific region. Advancements in IPM were discussed by Wang *et al.* (2024) for *Bactrocera dorsalis* (Hendel), however their strategies were based on protein baiting and male lure trapping which are known to fail under conditions of high fruit fly population pressure and fruit crops which have high susceptibility to fruit fly. Further, these authors had a confused understanding of the *dorsalis*-complex species, leading to incorrect definitions of host and distribution records.

The male annihilation technique, generally used as part of an IPM program was tested by Ndlela *et al.* (2016) on *B. dorsalis* (actually *B. invadens*) in a mango plantation in Kenya. Although they achieved a 99.5% reduction in the male population, it did not result in commercially acceptable crop damage reduction. Similarly, Lloyd *et al.* (2010) conducted an extensive Area-Wide fruit fly management trial in the Central Burnett district of Queensland, based on a combination of male lure trapping and weekly protein bait applications. Over a one-year period this resulted in a reduction of fruit fly infestation in suburban fruit crops to 20% but no data were presented for the impact on commercial fruit crops. An important consideration for IPM to be successful is the training of growers as noted by Chang *et al.* (2021). Such training is vital due to the complexities of the treatments available and the position and timing of these across a very wide range of horticultural crops and their various methods of cultivation.

Over the past three to four decades, IPM has been practised successfully in the Queensland citrus industry (Smith & Papacek 1985, 1992). This program, while covering a range of insect pests, has included a multi-treatment approach to managing fruit fly, based primarily on protein bait treatments and male trapping. Similarly for South Pacific countries, Allwood (1997) recommended a multi-treatment approach for fruit fly control which included Physical control (netting and bagging), Cultural control (farm hygiene, growing low susceptible crops, early harvesting), Biological control (enhancing the activity of natural enemies), Behavioural control (protein bait sprays, male trapping). A combination of these methods was proposed as an IPM strategy (Allwood, 1997). To date, all IPM recommendations for fruit fly control have been founded on protein bait treatments where natural enemies and pollinators were preserved. With the decline in insecticide cover sprays, growers in eastern Australia have combined protein bait applications with male lure trapping with limited success particularly in locations where highly susceptible crops are grown under conditions of high fruit fly population pressure. While protein baiting is extremely efficient in taking out immature female fruit flies, both this and the

combination with male trapping do not prevent the incursion of mature female fruit flies with fertile eggs into the crop. Now with the addition of the Fruition female trap a more successful IPM strategy has been achieved.

We have published over 150 papers (over 4,000 pages) in some 30 international refereed journals over the past five decades, and over this period many international researchers have sought the development of a successful female fruit fly lure. This Fruition technology is the result of years of research and is the first such technology developed worldwide. Fruition, as a unique, effective fruit fly management solution that is safe to humans and the environment, is now used in tropical/subtropical Australia as the primary field control technology and is now being introduced into Taiwan, India, Fiji and Tonga (Ref. AgNova Technologies Pty Ltd., Australia). Its development benefits from exhaustive trials carried out in many situations. Hence the research merits publication, using the experience of one orchard enterprise which retained and shared some historical crop data and valued the opportunity to be part of applied research seeking to maximise outcomes and viability.

TAXONOMIC SUPPORT

The success of IPM and Area-Wide management depends on the identification of the targeted species and a knowledge of their biology. In the Asian-Pacific region there are 48 known pest fruit fly species, mostly in the genus *Bactrocera*. Within this genus there are also a number of cryptic species complexes which contain some of the major pest species. Whether or not pest species are within a complex, they usually have differing geographic distributions and host plants, the knowledge of which over an Area-Wide operation can be crucial to the success of IPM treatments. Of great importance is the fact that within an Area-Wide targeted zone, different species can exist utilizing different host plants to maintain their breeding populations and also occupy different geographic distributions. Over the past decade a large number of publications have presented fruit fly pest management methodologies based on inaccurate species identity under the name *Bactrocera dorsalis*. Examples are those of Wang *et al.* (2024); Ndlela *et al.* (2016) who had not recognised the withdrawal of *B. invadens* and *B. papayae* from synonymy with *B. dorsalis* (Drew & Romig 2016) and the subsequent dissertations on the status of these species (Drew & Romig 2022; Drew & Hancock 2022). The population in the Indian subcontinent that has spread across Africa is clearly *B. invadens*, not *B. dorsalis*. Accurate diagnosis also has significant international biosecurity implications (Zhao *et al.*, 2024). Two incursions into New Zealand in January and February 2025 were identified as *B. invadens* from the Indian subcontinent while another in February 2026 was *B. dorsalis* from South East Asia, each from different geographic sources.

CONCLUSION

The new Fruition technology developed from research that focused on attracting and trapping mature egg-laying female fruit flies, combined with an effective

protein bait, has proven successful in its goal. Exemplified in this trial, the new technology reduced persimmon crop loss from the 50% loss incurred in previous seasons to three percent crop loss, a significant and commercially favourable end result. The timing and placement of the trap and bait applications were important also to the success of the trial.

FUTURE SCOPE

While the new Fruition female trap technology has begun to transform tropical fruit fly pest management, there will be a need to focus further on the timing and placement of the traps and supporting protein bait applications in different crop settings to ensure maximum success. The implementation of these treatments need to be modified for the different horticultural crops and their varying cultural methods. Further research into these field applications is needed and will prove beneficial, as is publishing of results in the relevant literature. This documentation is important to foster advancement of knowledge for growers and the benefits of human and environmental health, particularly given that Fruition involves no insecticide application.

Conflict of Interest. None.

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