Biological and insecticidal control of *Arotrophora arcuatalis* (Walker) (Lepidoptera: Tortricidae): an important pest of banksias in Western Australia

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Summary
Biological control of the banksia insect pest, *Arotrophora arcuatalis* (Walker), by the native trichogrammatid wasps, *Trichogramma carverae* and *Trichogrammatoidea bractrae* alone or with the use of a biological insecticide does not adequately effect control of *A. arcuatalis* on commercial plantations of *Banksia prionotes*. However, successful control of this insect pest can be achieved using either of the insecticides Thiodan® or Dominex® on a regular basis from the appearance of immature blooms to anthesis.

Introduction
Indigenous species of *Banksia* (Proteaceae), such as *B. hookeriana* Meissner and *B. prionotes* Lindley are grown in plantations in the south west of Western Australia. The blooms of these species are exported to Japan, Europe and the USA where they are sold as premium cut flowers (Pegrum 1988). However, only blooms in perfect condition and free from insect damage are marketable on these discriminating markets (Seaton *et al.* 1989).

The major insect pest attacking banksias grown in cultivation (*B. ashbyi* E.G. Baker, *B. baxteri* R.Br., *B. burdetti* E.G. Baker, *B. coccinea* R.Br., *B. hookeriana*, *B. prionotes*, *B. sceptrum* Meissner and *B. speciosa* R.Br.) is *Arotrophora arcuatalis* (Walker) (Lepidoptera: Tortricidae), the 'banksia boring moth'. Eggs are laid on the developing blooms (Figure 1). On hatching, the larvae (Figure 2) feed first on the bracts and then burrow into the central woody rachis of the bloom (Scott 1982). Their feeding causes death of individual florets and distortion of the bloom (Figure 3).

Fuss and Sedgley (1990) classified the flowering of banksias into 10 stages:
1. vegetative apex
2. initiation of involucral bracts marking the transition of the apex to reproductive development
3. initiation of common bracts
4. initiation of floral bract primordia in the axils of common bracts
5. initiation of florets in the axils of floral bracts
6. macroscopic appearance of the bloom
7. macroscopic appearance of florets
8. floret extension
9. style extension
10. anthesis, the stage at which blooms are harvested.

Immature blooms (stage 6) of *B. hookeriana* are first visible in February and most blooms reach anthesis (stage 10) by July (Röhl unpublished results). Therefore, blooms must be protected from insect damage for at least five months. *B. prionotes* need protection for three months from the appearance of immature blooms in December to harvest at the end of February (Röhl unpublished results).

Although the *A. arcuatalis* eggs are often heavily parasitized by native trichogrammatid wasps (Woods 1988), most banksia growers apply broad-spectrum insecticides on a regular basis in an attempt to prevent insect damage. Control by insecticide applications has been disappointing, especially on *B. prionotes*, with up to 80% of the crop being damaged (Röhl unpublished results). This lack of control maybe due to the use of ineffective insecticides, too few applications or insecticide application after damage has already occurred.

Other researchers have used insecticides against *A. arcuatalis* on banksias but with varying results. Such studies have had an ecological basis, concerned with the effect of insect damage on seed set (Vaughton 1990, Wallace and O'Dowd 1989, Zammit and Hood 1986). In these studies, the number of undamaged flowers that set seed was of importance, and the fact that some flowers on a bloom may have been damaged was irrelevant.

When immature blooms of *B. spinulosa* Smith were sprayed with endosulfan (0.3%) every two weeks (Wallace and O'Dowd 1989) and three weeks (Vaughton 1990) no central axis damage occurred. Similarly Zammit and Hood (1986) found that *A. arcuatalis* did not cause damage to the central axis of *B. ericofolia* L.f. blooms when sprayed with 0.3% endosulfan every three weeks even though they had many larvae on them that chewed the bracts and floral parts. In contrast they observed 43% of the *B. oblongifolia* Cav. blooms following spraying had central axis damage from another species of banksia boring moth, *A. canthelias* Meyr. They concluded this was because the experiment on *B. oblongifolia* started when the blooms were at anthesis and the damage had already occurred.

However, in commercial production of banksias, any damage is significant and even one damaged floret on a bloom may effect the marketability of the bloom (Woods 1988). Thus our aim was to develop techniques for more effective control of *A. arcuatalis*, utilizing either:
- the biological insecticide Dipel® (*Bacillus thuringiensis*),
- the "soft" broad spectrum insecticide Thiodan® (endosulfan) or
- the persistent broadspectrum insecticide Dominex® (alphamethrin).

To assist this we determined the timing of macroscopic bloom development of
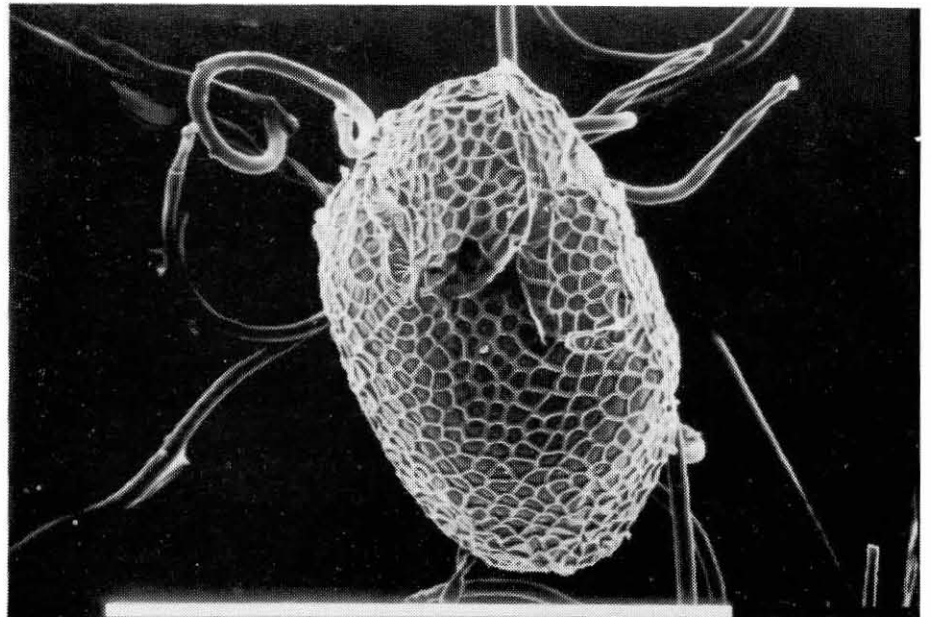

Figure 1. Scanning electron micrograph of a *Arotrophora arcuatalis* egg (Scale bar = 1 mm).

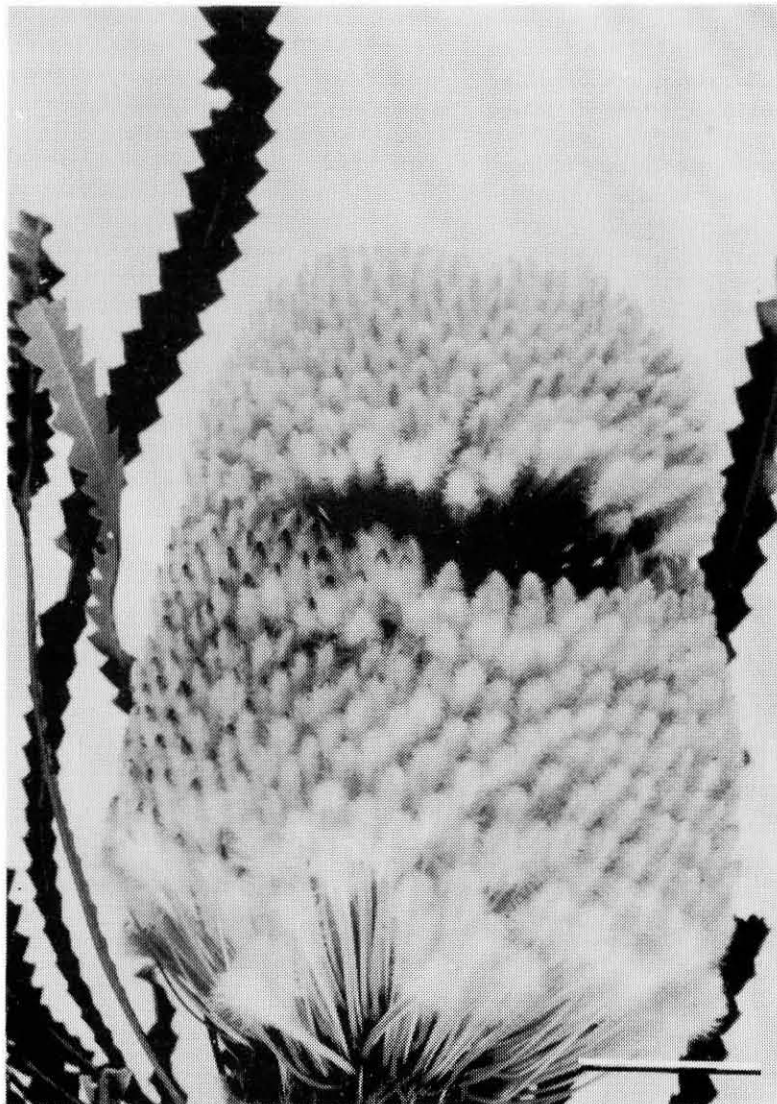Figure 2. A larvae of *Arotrophora arcuatalis* (Scale bar = 2 mm).

Figure 3. *Banksia hookeriana* bloom, showing damage caused by *Arotrophora arcuatalis* (Scale bar =14 mm)

the banksias involved, and the degree of parasitism which could be expected by the native trichogrammatid wasps.

Materials and methods

Experiments were carried out from October 1989 to February 1992 on a cut flower plantation at Muchea, 61 km north-east of Perth, Western Australia (31°35'S, 115°58'E). The area was originally virgin bush, before being cleared and planted with *Banksia* and *Dryandra* seedlings. Banksias were planted in double rows with 2.5 m between plants within rows and 3.5 m between rows for *B. hookeriana* and 3.0 m between plants within rows and 4.0 m between rows for *B. prionotes*. The soil was free draining, deep uniform siliceous sand (form: Uc5.11, Northcote 1979) with a pH of 5.9.

Insecticide trials

The first experiment was conducted on *B. hookeriana* plants arranged within rows approximately two metres high and wide. Ten bushes were used per treatment with 20 bushes between treatments within the double rows thus permitting three treatments per row. There was a buffer row between each treatment row to minimize the effect of drift. There were three replications per treatment and only the middle five bushes of each treatment were sampled. The treatments were unsprayed, sprayed fortnightly from 26 March 1990 to 4 September 1990, with Dipel® at 25 g 100 L^{-1} or Thiodan® at 70 g 100 L^{-1}. Treatments were applied by spraying with hand lances to run off from a trailer mounted sprayer.

Five immature blooms at stage 6 were tagged per bush per treatment with flagging tape. As each tagged bloom reached anthesis (stage 10) it was harvested and assessed for damage. An analysis of variance (ANOVA) was used to test for differences in the amount of insect damage between treatments.

In the second experiment, 30 *B. hookeriana* bushes were chosen at random from 10 rows. The 30 plants were randomly separated into two treatments, unsprayed and sprayed with Dominex® at 20 g 100 L^{-1}. Treatments were applied monthly from appearance of immature blooms (12 February 1991) to harvest (1 July 1991) as described for experiment 1. Blooms were harvested and assessed as for experiment 1. The proportion of damaged blooms per treatment at harvest were compared using a t-test.

For the third experiment , 16 *B. prionotes* bushes were used and 10 immature blooms (stage 6) per bush were tagged. The 16 bushes were divided into four treatments with four replications. The four treatments were unsprayed, sprayed with Dipel® at 25 g 100 L^{-1}, Thiodan® at 70 g 100 L^{-1}, or Dominex® at 20 g 100 L^{-1}.
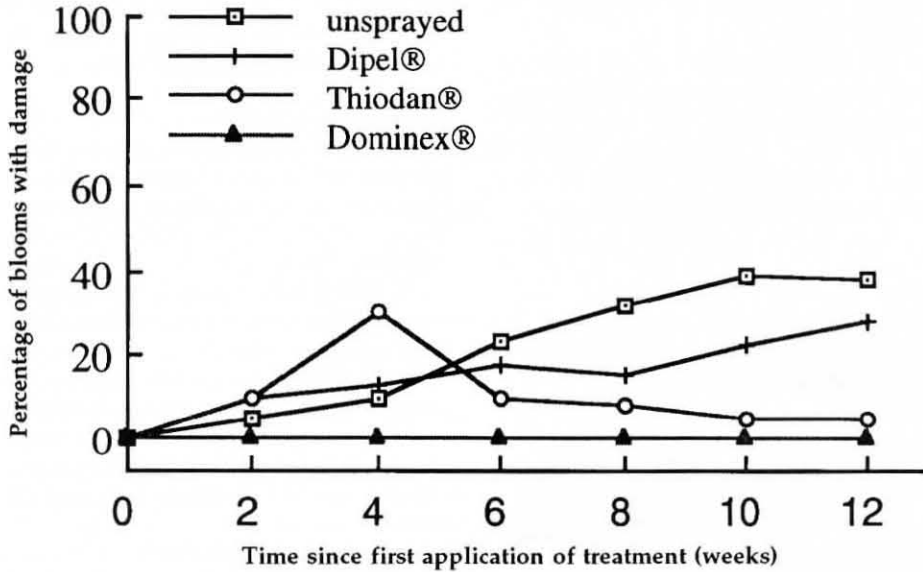
Figure 4. The percentage of *Banksia prionotes* blooms with external damage caused by *Arotrophora arcuatalis*.

Treatments were applied with a back pack sprayer to run off to tagged blooms, at fortnightly intervals from 18 December 1990. The percentage of blooms with insect damage was determined fortnightly. The final assessment was made at harvest, 12 weeks after commencement of the experiment. Differences between the unsprayed, Dipel® and Thiodan® treatments at the final assessment were tested using ANOVA. A 5% LSD was then performed to distinguish which treatment was best. Finally a t-test was used to test whether the proportion of damaged blooms for the Thiodan® treatment was significantly greater than zero.

Egg parasitism
At intervals throughout the experimental period, *A. arcuatalis* eggs were collected from developing blooms of various *Banksia* species (*B. burdettii*, *B. coccinea*, *B. hookeriana* and *B. prionotes*) growing at the experimental site. The eggs were placed individually in vials and held until either a larva or parasite emerged. The number of eggs collected and the per cent parasitism were recorded for each sampling date.

Damage studies
To determine the stages of bloom development on which eggs of *A. arcuatalis* are laid, 20 blooms at each stage 6, 7 and 8 were randomly collected from an unsprayed area of *B. prionotes* on January 14 and 20 1992 and assessed for the presence or absence of eggs. On January 28 1992, 20 blooms at each stage 9 and 10 were collected and assessed.

To determine the resultant damage caused by this level of oviposition the 20 stage 10 blooms were dissected to determine whether damage was to individual florets and/or the rachis.

Results

Insecticide trials
In experiment 1, the average percentage of *B. hookeriana* blooms damaged by *A. arcuatalis* was low in all treatments, 4.7±1.8% (SE) for the unsprayed blooms, 5.3±1.8% (SE) for the Dipel® treated blooms and 2.0±1.2% (SE) for blooms treated with Thiodan®. There was no significant differences between the treatments (P=0.355).

Very little bloom damage was also observed in *B. hookeriana* in experiment 2. Only 3.2±0.4% (SE) of the unsprayed blooms were damaged and none of those treated with Dominex®. The proportion of damaged blooms from the unsprayed treatment was significantly greater than zero (P=0.0008).

For experiment 3 the percentage of blooms damaged, at anthesis (stage 10), on *B. prionotes* by *A. arcuatalis* was 0% for blooms treated with Dominex®, 5% for Thiodan® treated blooms, 28% for Dipel® treated blooms and 38% for the unsprayed blooms (Figure 4). There was a significant difference between the unsprayed, Dipel® and Thiodan® treatments (P<0.05). The percentage of damaged blooms treated with Thiodan® was significantly less than the unsprayed and the Dipel® treated blooms. The proportion of damaged blooms treated with Thiodan® was not significantly greater than zero.

Egg parasitism
The proportion of *A. arcuatalis* eggs parasitized by trichogrammatid wasps varied from 0–85% over the sampling times, with the average being 50.5±5.2% (SE) (Figure 5). The highest per cent of parasitism were recorded in October 1989 and 1990. The trichogrammatid wasps were identified as *Trichogramma carverae* Oatman and Pinto and *Trichogrammtoidea bractrae* Nagaraja.
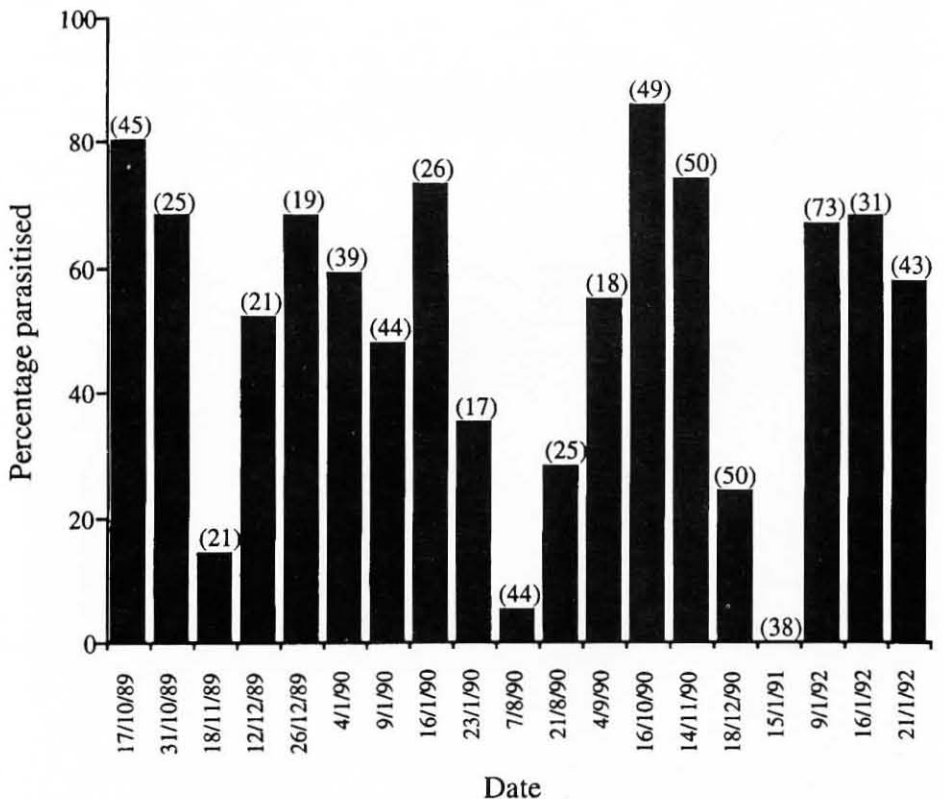

Figure 5. The percentage of *A. arcuatalis* eggs parasitised by trichogrammatid wasps. The number of eggs collected at each sampling time are given in parenthesis.

Damage studies

Eggs were laid on all visible stages of bloom development, from stage 6 (macroscopic appearance of the bloom) to stage 10 (anthesis). Stage 8 had eggs laid on 75% of blooms, whereas only 12.5% of stage 10 blooms had eggs on them. Stage 6, 7 and 9 had eggs laid on 52.5%, 65% and 40% of blooms respectively. Of the stage 10 blooms 85% had *A. arcuatalis* damage, of which 35% had damage only to the florets, 30% to the rachis only and 35% had damage to both the florets and the rachis.

Discussion

In this study *B. prionotes* blooms had a higher percentage of damage than *B. hookeriana* blooms, despite blooms of the latter having a slower rate of bloom development and therefore being exposed to insect attack for at least two months longer. A likely explanation is that *A. arcuatalis* is more abundant during the period when *B. prionotes* is flowering (December-February), or that *A. arcuatalis* is more fecund at this time and therefore is able to lay more eggs on *B. prionotes* blooms than on developing *B. hookeriana* blooms.

The period of attack on *B. prionotes* follows the spring flush of wildflowers when temperatures and nectar sources are favourable for insect development and many species of insect become abundant (Andrewartha and Birch 1974). *A. arcuatalis* may be breeding up on developing *B. grandis* Willd. and *B. attenuata* R.Br. blooms, between the months of July and November and July and December respectively (Taylor and Hopper 1988), growing in the nearby native vegetation and invading the plantation as *B. prionotes* flowers become available.

Eggs were laid on immature blooms and oviposition continued throughout the period of floral development. It appeared that on very immature blooms the larvae tunnel into the developing rachis causing bloom distortion as the rachis elongates. Larvae emerging from eggs that were laid on later stages of bloom development, when the rachis had extended, caused minimal damage. Both forms of damage cause rejection of product on overseas markets (Woods and Grimm 1990), and hence this pest must be controlled to maximize crop returns.

Both synthetic insecticides gave effective control of *A. arcuatalis*. Despite 30% of the *B. prionotes* blooms treated with Thiodan® showing *A. arcuatalis* damage four weeks after the commencement of the spraying program, the proportion of blooms damaged decreased to 5% by the end of the experiment. It appears that Thiodan® kills the early stage larvae inside the immature blooms resulting in the damage appearing to decrease as the bloom matures and becomes harvestable. No blooms treated with Dominex®, a long lasting broad spectrum insecticide, had any insect damage. Either Dominex® penetrates and kills all larvae on the blooms, or it is persistent on the bloom, killing any additional eggs laid on the bloom and/or the young larvae on hatching.

Parasites and biological insecticides are used to control pests in a range of horticultural crops (Croft and Hoyt 1983). Parasitism of *A. arcuatalis* eggs by *T. carverae* and *T. bactrae* was high (average of 50%). Despite this level of parasitism, bloom damage in the unsprayed treatment was unacceptable. Thus the level of parasitism needs to be considerably higher to be an effective method of control in it's own right. To achieve such a result, inundative release of trichogrammatid wasps may be required (Oatman and Platner 1985).

T. carverae has been reared from papilionid, noctuid, lycaenid and tortricid eggs collected in Victoria and South Australia (Oatman and Pinto 1987), but this is the first recording in Western Australia. *T. bactrae*, on the other hand, is wide spread and polyphagous throughout the Australo-Oriental region (Polaszek personal communication). These two species, in particular *T. carverae*, may have potential for mass culture for inundative release against a range of lepidopterous pests.

The use of the biological insecticide, Dipel® plus high natural populations of parasitic trichogrammatid wasps, appeared to be ineffective in controlling *A. arcuatalis*. The number of blooms damaged in the unsprayed treatment and the Dipel® treatment were similar. Dipel® does not provide effective control of all types of caterpillars and probably does not kill the larvae of this insect pest. New biotypes of *B. thuringiensis*, the active ingredient in Dipel® are being developed which may act as an adjunct to high levels of parasitism.

In this study, both Thiodan® and Dominex® gave good control of *A. arcuatalis* on *Banksia* species when sprayed as soon as the immature blooms became visible. The use of biological control alone or in conjunction with a biological insecticide did not effectively control *A. arcuatalis*. However, the high level of parasitism observed is a good basis for developing a low pesticide approach to *A. arcuatalis* control in the future.

Acknowledgements

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