seed dormancy. It is of interest that where a nematicide, Nemadi® (a.i. 1950g L^{-1} EDB) was used to control cereal cyst nematodes (*Heterodera avenae*) in cereals during the early to mid 1980s the emergence of *E. australis* was visually far greater than in adjacent untreated areas (T. Dillon personal communication and personal observations). This tended to suggest that the active ingredient (EDB) may have had some effect on seed dormancy.

Emex spp. are a proclaimed weeds under the Animal and Plant Control Act, 1986 and the objectives of the *Emex* spp. policy are to eradicate small isolated infestations of *Emex* spp., to minimize spread from generally infested areas and to prevent introduction of *Emex* spp. to clean areas. Landowners are required to destroy the plant and inhibit its propagation as far as is reasonably possible (R. Carter personal communication).

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Emex australis and dried vine fruit production in Sunraysia

Deidre Pohlner, Sunraysia Horticultural Centre, PO Box 905, Mildura, Victoria 3502, Australia.

Abstract

Australia is renowned for the production of quality dried sultanas free of contaminants. However, one contaminant which poses a threat to Australia's reputation is *Emex australis*. Because of the spined nature of the seed, it readily contaminates fruit during the harvest and drying processes conducted on growers properties. Once in the fruit they are difficult to remove despite rigorous cleaning at packing sheds. Controlling *E. australis* in the vineyard is difficult and costly with growers seeking an alternative control strategy which is cheaper and more effective than cultivation, mulch, cover crops or weedicide.

Introduction

The thought of biting into a piece of cake or muesli bar and ending up with a mouthful of prickles is enough to put anyone off buying products containing dried sultanas! People bearing witness to such experiences to family members and friends, rapidly develop concerns about buying products from the same company or even buying sultanas full stop. This is a very real problem for companies such as Kellogg's and Uncle Tobys who buy thousands of tonnes of Australian dried sultanas each year and it only takes one seed to cost these companies thousands in lost sales.

In 1990 a workshop was held in Mildura initiated by the Dried Fruits Research and Development Council, to investigate a group of weeds called Spiked Weed Seeds (which included *Emex australis*) and their control in vineyards (Buchanan 1990). As a result of this workshop the project 'Spiked Weed Seed Management and Elimination' was developed to try and prevent spiked weed seed contamination of dried vine fruit by identifying the points during production that are at risk of contamination, evaluating cleaning methods used in packing sheds and developing vineyard management practices to prevent growth and seed production from these weeds (Pohlner 1994).

How do the seeds of *E. australis* get into the fruit in the first place?

In order to minimize the amount of contamination which occurs on growers properties, the points during production which are at risk of contamination were identified during the two main steps conducted on growers properties; picking and drying.

During picking plastic buckets are used to collect the fresh grapes from the vineyard. These are the main source of contamination. When these buckets are thrown into the vineyard or dragged between vines during picking, the *E. australis* seeds on the ground stick into the sides or bottom of the soft plastic. This was observed to occur mainly in the undervine area where the buckets are left until they are collected. When the buckets are stacked on a trailer to take them to the drying racks, the seeds dislodge and fall onto the full bucket of fruit beneath it resulting in direct contamination.

Drying of grapes starts on drying racks where fruit is spread evenly over different levels of wire netting and left for a couple of weeks to reduce the moisture levels in the berries. When they have reached a certain moisture level they are shaken down through the levels of wire netting and spread over a plastic ground-sheet to 'finish' dry in the sun. During finish drying, seeds may flick into the fruit when people walk past the plastic, when corners of the plastic flap in the wind or when the edges of the plastic are folded in to prevent the fruit from taking up moisture overnight and when it rains. During this process seeds are scraped off from the underside of the plastic and fall directly into the fruit. Fruit is then collected into bulk bins (½ tonne) and delivered to central packing sheds for cleaning.

Measures employed to remove *E. australis* from dried vine fruit

It is difficult to remove seeds from dried vine fruit as they are similar in terms of size and colour to dried sultana berries. Many seeds actually embed into the dried berries camouflaging themselves. Packing sheds employ extensive cleaning processes whereby the fruit is washed, put through vibrating sieves, passed through blowers, vacuum extractors, an infra-red laser sorter and hand sorted in an attempt to remove all contaminants before the fruit is packed.

Trials conducted in the packing shed, which involved sorting through trash to recover *E. australis* seed removed at each extraction point during cleaning, indicated that the majority of seeds were extracted by 'blowers' because loose seeds are lighter in weight than the fruit. Infrared laser sorters are a relatively recent addition to packing sheds. A lot of emphasis is placed on the laser sorter to remove every trace of contamination from the dried vine fruit. Our trials did not recover any seed from the trash removed at the laser-sorter during the processing of 100 tonnes of dried vine fruit.

When cleaning dried sultanas, there are no guarantees that the final product will be completely free of *E. australis* even if it has passed through a laser-sorter. The only way to guarantee this is to make sure there is no seed on the property on which the fruit is produced.

The dried vine fruits industry has undertaken a couple of methods to minimize the amount of *E. australis* seeds in the fruit delivered to the packing sheds. Financial penalties are in place which vary depending on the amount of contamination in the fruit. The effectiveness of this technique is limited because of the difficulty in detecting the seeds by sight at the shed door, with few growers having received a penalty. A more positive approach has been to offer a financial incentive of $40 per tonne of dried sultanas to those growers who can show that their property is 'spiked weed seed free'. Few growers are registered for this scheme as stringent conditions apply making many growers ineligible.

Review of vineyard management practices to control *E. australis*

Treatments

A field trial was set up to test combinations of four primary weed control methods commonly used in vineyards to control weeds; mulching, cover cropping, chemical use and cultivation. Treatment applications are summarized in Table 1.

Treatments were replicated and randomly applied over 274 plots (1 × 10 m) using an incomplete block design over three separate sites.

All plots were cultivated initially and every following May and September (except plots with permanent cover crops and mulch) to simulate block operations of incorporating fertilizers, sowing cover crops or incorporating winter weed growth for frost control.

Cultivations Cultivations were conducted using a 1.4 m wide rotary cultivator to a depth of approximately 5 cm as this is the documented depth from which the majority of seeds germinate.

Herbicides Herbicides were applied using a hand pushed, covered spray unit designed to cover the width of the plots. The unit had three outlets (Dalveen color jet LF 110°2 nozzles) and ran at 150 kPa.

The herbicide unit was passed over the plots twice ensuring a uniform distribution of chemical, and spray mixes were calibrated accordingly. Rates of herbicides applied were; Basta 5 L ha^{-1}, Tribunil 550 mL ha^{-1}, simazine 5 L ha^{-1}, Diuron(800) 1.7 L ha^{-1}, Solicam 5 kg ha^{-1} (year 1) and 2.5 kg ha^{-1} (year 2).

Solicam applied for treatments G and K appeared to severely inhibit the development and growth of the cereal cover crops and failed to effectively control the growth of *E. australis.* In the second year Diuron(800) was substituted for Solicam, at the rate 1.7 kg ha^{-1}, recommended to control three cornered jacks in wheat and barley. Diuron(800) is registered for use in vineyards as a residual herbicide. The rate used in conjunction with the cover crop was half the recommended rate for vineyards making it cheaper with less risk of vine damage from chemical leaching.

Treatments H, I, J and K, were assigned a single summer application of Basta (Table 1) but an application error saw three sprays applied at five weekly intervals. These treatments differed by a final spray from treatments D, E, F, and G where Basta was applied every five weeks.

Table 1. Treatments developed for spiked weed seed control in vineyards including three cornered jack.

	Summer control	Winter control
A	Cultivated every five weeks	Cultivated every five weeks
B	Plots left untreated until March cultivation	Plots left untreated until September
C	Plots left untreated until March cultivation	Solicam applied once after cultivation
D	After weed emergence, Basta was applied every five weeks	After weed emergence, Basta was applied, annual legume cover crop was sown late May
E	After weed emergence, Basta was applied every five weeks	After weed emergence, Basta was applied, annual cereal cover crop was sown late May
F	After weed emergence, Basta was sprayed every five weeks	Annual cereal cover crop was sown immediately after cultivation and Tribunil was applied in April and mid June
G	After weed emergence, Basta was sprayed every five weeks	Annual cereal cover crop was sown immediately after cultivation and separate applications of Tribunil and Solicam were made on the same day, mid May
H	After weed emergence, Basta was sprayed once	After weed emergence, Basta was applied, annual legume cover crop was sown late May
I	After weed emergence, Basta was sprayed once	After weed emergence, Basta was applied, annual cereal cover crop was sown late May
J	After weed emergence, Basta was sprayed once	Annual cereal cover crop was sown immediately after cultivation, Tribunil was applied mid May and mid June
K	After weed emergence, Basta was sprayed once	Annual cereal cover crop was sown immediately after cultivation, Tribunil and Solicam were applied mid May as separate sprays on the same day
L	Winter cover crop mulched	After weed emergence, Basta was applied, annual cereal cover crop was sown in April, Tribunil was applied mid May and mid June
M	Perennial cover crop	After weed emergence, Basta was applied, perennial cover crop was sown in April, Tribunil was applied mid May and mid June
N	Perennial cover crop	Perennial cover crop was sown (no herbicides)
O	Cultivated every five weeks	Annual cereal cover crop was sown (no herbicides)
P	Winter cover crop was mulched	Annual cereal cover crop was sown (no herbicides)
Q	Cultivated every five weeks	High density cereal cover crop was sown (no herbicides)
R	Winter cover crop was mulched	High density cereal cover crop was sown (no herbicides)
S	Solicam was applied late October	Solicam was applied late April
T	Mulch topped up	Grapemark Mulch was applied
U	Simazine was applied late October	Simazine was applied late April

Cover crops All plots with cover crops were fertilized annually with double super phosphate at a rate of 1200 kg ha^{-1}, distributed evenly on the soil's surface using a mechanical broadcaster and watered in with a 4 h overhead sprinkler irrigation.

The annual cereal cover crops used in the first year was rye corn at a rate of 90 kg ha^{-1}. The rye corn produced few tillers, leaving the soil's surface uncovered and exposed to sunlight. It appeared to have little competitive effect against the germination and growth of the *E. australis* and so was replaced with Forest barley in the second year. Forest barley was chosen for its early tillering and high bulk density offering an early dense soil cover. Forest barley was sown using a Connor Shea seed drill at a rate of 66 kg ha^{-1}. Paraggio medic was the annual legume cover crop used in both years of the trial at a rate of 1.5 kg ha^{-1}.

High density cover crop treatments Q and R, consisted of rye corn at a rate of 180 kg ha^{-1} and Forest barley at a rate of 132 kg ha^{-1}.

Summer mulching of cereal cover crops, using a Nobili BNE Triturator mulcher, was conducted in September (treatments L and P), leaving the mulch on the soil surface to suppress summer weed growth.

The permanent cover crop sown was a seed mix called 'Blockout' composed of rye corn, fescue, and clover seed at rate 160 kg ha^{-1}. Permanent cover crops were mulched with a Triturator mulcher in August simulating frost control practices in vineyards.

Mulch Plots assigned to the mulch treatments were initially sprayed with Solicam at 5 kg ha^{-1} with grape mark (dried grape bunch stems) applied to a depth of approximately 30 cm. Weeds that grew through the mulch, or germinated from seed settling on top of the mulch, were controlled with a single application of Basta (5 L ha^{-1}) in early spring, to simulate frost control practices, and in autumn to control summer weed growth. After the first year the mulch was topped up where it had decomposed to maintain its effective volume. The mulch depth was maintained throughout the experiment.

Results

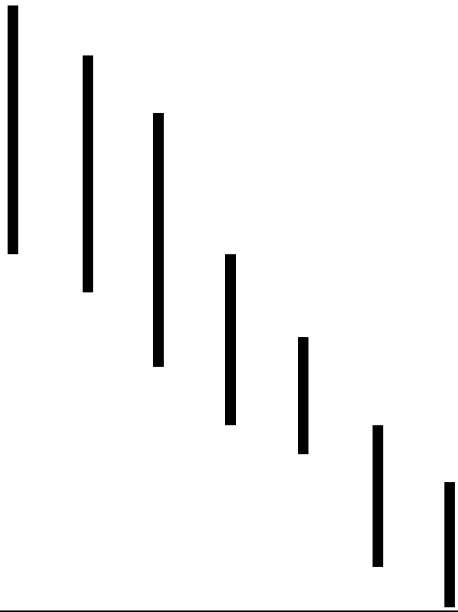
A 20 inch soil auger was used to take three soil samples for each plot at the start of the trial and after two years of treatment application. The seeds from these soil samples were removed and counted.

A Genstat analysis, with a $\log_{10}$ +1 transformation, was conducted using soil seed counts to determine the amount of seed production over the two years for the various treatments. Changes in the number of seeds present was expressed in terms of 'per cent change' over the two years (Table 2). 'Per cent Change' was calculated using the equation; per cent change = 100 x [$10^{(\text{mean difference})}$ -1]. A negative 'per cent change' indicated a reduction in seed number and a positive 'per cent change' indicated an increase in seed number from the original seed count for each plot conducted before the application of treatments.

Table 2. Changes in seed numbers for various treatments after two years of treatment application (1992–94).

Treatment	% change	Mean difference
J	-82.4	-0.755
F	-82.3	-0.752
T	-81.0	-0.722
I	-78.7	-0.672
E	-75.2	-0.606
G	-74.4	-0.593
A	-74.2	-0.588
K	-73.9	-0.584
U	-70.6	-0.532
D	-68.5	-0.502
O	-62.4	-0.425
Q	-60.5	-0.403
S	-53.6	-0.334
R	-48.9	-0.291
H	-47.2	-0.277
C	-27.4	-0.139
B	-8.5	-0.039
M	-2.0	-0.009
L	1.0	0.005
P	10.0	0.042
N	59.8	0.204

LSD (mean difference) = 0.2364



Cultivation effects Cultivating every five weeks during summer and winter (treatment A) reduced the level of seed produced by 74% and was significantly more effective than applying no control measure after an initial cultivation (treatment B).

Herbicide effects

Solicam A single application of Solicam in the winter (treatment C) resulted in seed levels not significantly different from applying no control treatment over the two years. However applying Solicam in summer, in addition to the winter application (treatment S) was more effective than no control (treatment B).

Simazine Simazine applications in summer and winter (treatment U) resulted in significantly fewer seed than applying no control (treatment B). Over the two years this treatment was equally as effective as cultivating every five weeks (treatment A) in reducing the level of seed production.

Tribunil Tribunil applications combined with cereal cover crops (treatments J, F and G, K) resulted in reduced seed levels that were amongst the best control treatments used. Although still in the processes of being registered for use in vineyards, this chemical has great potential for use in Sunraysia vineyards.

When Tribunil was used in conjunction with the perennial cover crop Blockout (treatment M) the seed levels produced were not significantly different from treatment N, where no Tribunil was applied. These treatments were significantly less effective at preventing seed production than when no treatment was applied (treatment B).

Diuron Diuron application in conjunction with a cereal cover crop, although not evident in the seed counts, resulted in fewer seedlings of three cornered jacks, emerging. After a number of years of application, it is suspected that this treatment has great potential in reducing soil seed levels. Because of Diuron's high solubility in water it has the potential to damage the vines if it enters the root zone. However, the rates used in the trial were at least half the rate recommended for use in vineyards on the label (1.7 L ha^{-1} compared with 3.5 to 7.2 L ha^{-1}), thereby reducing the risk of leaching.

Cover crop effects Legume cover crops (treatments D and H) produced seed levels that were not significantly different from the levels produced when a cereal cover crop was used (treatment E and I). The advantages of having legumes, which fix atmospheric nitrogen, growing between the vine rows is that the nitrogen is released into the soil as the legumes breakdown. This improves the fertility of the soil and encourages vine growth, but it also encourages the growth of *E. australis* (Gilbey and Weiss 1980). Therefore in areas of high infestation levels of *E. australis* it may be better to use a cereal cover crop rather than a legume until numbers are reduced.

Table 3. A summary of recommended vineyard control methods for *E. australis*.

Between -row	Undervine
• cultivate once every five weeks beginning in March for first year, or • sow a cereal cover crop (e.g. Barley) early in March, apply a selective herbicide to control the weeds during cover crop establishment e.g. Diuron, or • sow a perennial cover crop (e.g. Blockout) in March and apply a selective herbicide during establishment	• apply and maintain a thick layer of mulch (regions not prone to frost (damage) • apply Simazine in March and again in September.

Mulch effects Grapemark mulch (treatment T) was equally as effective at controlling *E. australis* as cultivating every five weeks (treatment A), and significantly more effective than no treatment application (treatment B).

Discussion

Those treatments which best control *E. australis* (i.e. with the largest negative percent change), while maintaining the productivity of the vineyard, are those with cereal cover crops used in conjunction with herbicides e.g. treatments J and F. Cultivating every five weeks over winter and summer is a short term method which may be used to rapidly reduce the number of seeds in a property with high levels of infestation but would not be recommended for a long term practice as it rapidly destroys soil structure, impeding root growth and water infiltration. Under the vine, simazine is effective in reducing the number of seeds produced or in areas not prone to frost damage, grapemark as mulch may be used (Table 3).

Problems with controlling E. australis

There are many problems involved in the control of *E. australis* in vineyards. Firstly the timing of weed growth coincides with the busy season of pruning vines. After the post-harvest clean up of summer weed growth little attention is paid to controlling weeds in the vineyard. During spring growers will either slash mulch or cultivate, into the soil, winter weed growth to reduce frost risk. By this stage most of the seedlings have grown to full maturity depositing enormous amounts of seed on the soil's surface ready to contaminate the fruit in the coming season.

The growth of winter cover crops in Sunraysia relies heavily on rainfall. In the past few years when the winters have been relatively dry these crops have not established well enough to prevent *E. australis* emergence or growth. Sowing dates for medics and clovers falls around February–early March. This coincides with the harvest period so that many such cover crops are sown late, i.e. in April, reducing the potential bulk for the cover crop.

Cultivating or spraying with knockdown herbicides every five weeks to prevent seed set, is a costly form of weed control in terms of time and fuel and may be degrading on the soil structure over a long period.

Confining the problem of *E. australis* growth is also difficult in Sunraysia vineyards as often property boundaries exist as headlands which are shared by neighbouring growers. It is common to see one grower surrounded by three or four neighbouring properties. Seed deposited on these headlands may be spread with vehicle movement within and between properties.

Growers themselves do not directly feel the effect from 'loss of sales' due to contaminated fruit because of pooled-marketing of dried vine fruit by packing sheds. If a grower receives no penalties, but is ineligible for the $40 per tonne premium, he would be reluctant to spend the extra time, effort and money required to control *E. australis* and their attitude toward doing so is largely negative. Many growers comment that it is 'too much work' and 'too expensive' to even start thinking about. Growers who do make a concerted effort to try and control *E. australis* are often disappointed when they continually find outbreaks on their property each year.

Conclusion

Eliminating *E. australis* from vineyards is a challenging task for all growers. Success will be achieved only by those growers who continue with regular control treatments of the weeds for many years. With emphasis placed on the need to reduce the amount of chemicals used in food products and the trend toward minimal cultivation the options for weed control are becoming increasingly limited. I believe that the level of contamination with *E. australis* will not be reduced until growers individually feel the benefits of improving weed control or until an alternative form of control, which is more cost and time effective, is discovered and adopted.

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