OPTIMISING CONTROL OF INVASIVE CACTUS USING BIOLOGICAL CONTROL

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ABSTRACT

Invasive opuntioid cacti pose significant impacts to the environment, agriculture, and recreation in Australia. The cochineal insects, *Dactylopius* spp., are effective biological control agents for a number of invasive cacti species in Australia, e.g., *Dactylopius opuntiae* 'US' lineage on *Opuntia stricta*, *D. opuntiae* 'Mexico' lineage on *O. robusta*, *D. ceylonicus* on *O. monacantha*, and *D. austrinus* on *O. aurantiaca*. Studies have found that these agents might also be suitable for control of some emerging invasive cacti. *Dactylopius austrinus* and *D. ceylonicus* have relatively narrow host ranges, whereas both *D. opuntiae* lineages feed and develop on a wider number of cactus species. Routine post-release field surveys of *D. opuntiae* lineages on *O. tomentosa* revealed biotic interactions that provide potential explanations for why the cochineal is generally not as effective on larger tree-form cacti. The presence of a predatory ant, *Crematogaster* spp., was often associated with poor establishment and low population build-up of the cochineal. Other significant predators include the "mealybug destroyer" *Cryptolaemus montrouzieri* and several Neuropteran species. The cactus longhorn beetle, *Lagocheirus funestus*, was rediscovered at one field site where it was observed causing significant damage to *O. tomentosa*. The rediscovery of this agent and its observed impact in the field, suggests its rearing and redistribution could complement cochineal biological control of *O. tomentosa*.

Keywords: Biocontrol, *Opuntia*, *Dactylopius*, *Lagocheirus.*

INTRODUCTION

Opuntioid cacti were first introduced to Australia during European settlement of the east coast. By the late 1890s, prickly pear was a serious pest to Queensland and New South Wales (Alexander 1925). The Commonwealth Prickly Pear Board was formed in 1920, and a biological control program was initiated (Dodd 1940). Native range surveys were conducted in Argentina, United States, and Mexico, resulting in 48 prospective biological control agents being imported and tested. Twenty-five agents were ultimately released (Dodd 1940).

Cochineal species (*Dactylopius* spp.) (Hemiptera: Dactylopiidae) are some of the more successful cactus biological control agents released in Australia. These agents have a complicated importation history (Table 1). Several species and lineages have become established in Australia, where they provide effective control against some of the major cactus pest species e.g., *Dactylopius opuntiae* 'US' lineage on *Opuntia stricta*, *D. opuntiae* 'Mexico' lineage on *O. robusta*, *D. ceylonicus* on *O. monacantha*, and *D. austrinus* on *O. aurantiaca*. While some of these cochineal species have been used to control other cactus species in Australia, their full host-range has never been properly studied.

Despite an otherwise long history of successful biological control, the larger tree-form cactus, *Opuntia tomentosa* (velvet tree pear), remains persistent in the Australian environment. It is generally accepted that the released cochineal agent *D. opuntiae* is ineffective on large mature tree pears. However, in some circumstances, large outbreaks of the cochineal have been observed to kill very large mature *O. tomentosa* trees. Anecdotally, this phenomenon happens after a period of stress, such as a drought. Population dynamics of cochineal on *O. tomentosa* has never been studied, despite the agent having the capacity to kill these large trees.

This paper reports on the host range of the already established cochineal agents and whether they can be used to effectively control any potential emerging invasive cacti (e.g., *O. microdasys*, *O. elata*). This paper also reports on regular monitoring of the two lineages of *D. opuntiae* released on *O. tomentosa* at two sites in southeast Queensland.

Table 1. Dactylopius spp. importations and field releases (Johnston and Tryon 1914, Dodd 1940). NQ – north Queensland, FNQ – far north Queensland, CQ – central Queensland, SEQ – southeast Queensland, QLD – Queensland, SWQ – southwest Queensland, CNSW – central New South Wales, CCNSW – central coast New South Wales.

Species	Imported	Origin	Released	Location	Established
D. ceylonicus (Green)	1913	Sri Lanka, India	1914	NQ & FNQ	Yes
D. confusus (Cockerell)	1913	South Africa	1915	NQ	No
D. opuntiae (Cockerell)	1920	California, USA	1921	CQ	Yes
D. confusus (Cockerell)	1921	South Africa	1926	FNQ	Unknown
D. coccus (Costa)	1921	South Africa	1926	SEQ	No
D. opuntiae (Cockerell)	1921, 1922	Texas, USA	1923	QLD	Yes
D. confusus (Cockerell)	1922	Florida, USA	1923	Unknown	No
D. opuntiae (Cockerell)	1922	Arizona, USA	1924	QLD	Yes
D. austrinus (De Lotto)	1922	Argentina	1933	SWQ & CNSW	Yes
D. confusus (Cockerell)	1924	Texas, USA	1925	SWQ	Yes
D. opuntiae (Cockerell)	Unknown	Mexico	1927	CQ	Unknown
D. opuntiae (Cockerell)	1931	Texas, USA	1933	CQ	Unknown
D. confusus (Cockerell))	1932	Florida, USA	1933	CQ	Yes
D. austrinus (De Lotto)	1932	Argentina	1935	CNSW	Yes
D. ceylonicus (Green)	1934	Argentina	1935	CCNSW	No
D. opuntiae (Cockerell)	1934	Mexico	1936	Unknown	Yes

MATERIALS AND METHODS

Dactylopius spp. host screening

Colonies of *D. opuntiae* 'US' and 'Mexico' lineages, *D. ceylonicus* and *D. austrinus* were maintained on preferred host cladodes of *O. stricta, O. ficus-indica, O. monacantha,* and *O. aurantiaca* respectively, under controlled glasshouse conditions (27±3C° and 65±5% relative humidity). Cladodes used for the rearing colonies were sourced from potted host plants cultivated at a shade house facility located at the Ecosciences Precinct, Brisbane.

Host suitability was determined by testing mature, pest free, cladodes of 14 cactus species: *Austrocylindropuntia subulata, O. aurantiaca, O. elata, O. engelmannii, O. ficus-indica, O. microdasys* (yellow & white bristle varieties), *O. monacantha*, *O. puberula, O. robusta, O. rufida, O. streptacantha, O. stricta, O. sulphurea and O. tomentosa.* Cladodes were placed on a wire rack (15 cm x 10 cm x 1 cm) within individual plastic containers (17 cm x 12 cm x 7 cm), lined with a paper towel and fitted with a ventilated domed lid (17 cm x 12 cm x 2 cm).

Thirty mobile neonate nymphs (1-2 days old) of each agent were individually transferred using a fine paintbrush onto test cladodes of the 14 cactus species (Musengi, Mbonani et al. 2021). A total of five replicates were completed for each cactus test species and each *Dactylopius* species. Cladodes were monitored weekly until either the cochineal adult females laid eggs, or the individuals died. The suitability of each cactus species was rated on the reproductive developmental success of the cochineal agents, with <25% being low, 25-49% moderate and >50% highly suitable (Musengi et al. 2021).

Opuntia tomentosa field monitoring

Two field monitoring sites were established: Ingoldsby and Rathdowney, Queensland. Field sites are situated in open eucalypt forest, with historic cattle grazing through the area and a variety of natives and other invasive species. The Ingoldsby field site had two distinct clusters of *O. tomentosa*, one situated in dense *Acacia* spp. regrowth, with high levels of canopy cover, and another located in open eucalypt forest, with varying levels of canopy cover.

Both the 'Mexico' and 'US' lineages of *D. opuntiae* were released at both monitoring sites. Releases were made by attaching cochineal-infested *O. tomentosa* cladodes to the trunks and crowns of mature *O. tomentosa* trees. On some occasions multiple field releases were needed to facilitate establishment of the cochineal. Field surveys were conducted monthly to monitor establishment, population build up and spread of the cochineal, as well as presence of predators, cochineal-predator interactions, and the impact of the cochineal to the plants.

RESULTS

Dactylopius spp. host screening

Dactylopius ceylonicus was shown to have a very narrow host range, reaching maturity on only two other cactus species, apart from its preferred host. *Dactylopius austrinus* had a wider host range, reaching maturity on seven additional species. *Dactylopius opuntiae* lineages ('Mexico' and 'US') both had the widest host ranges, reaching maturity on nine additional cactus species, although their host preferences were different (Table 2).

Opuntia engelmannii, white bristle *O. microdasys*, *O. robusta, O. streptacantha, O. sulphurea,* and *O. tomentosa* were highly suitable hosts and supported high development success of at least one *Dactylopius* species. *Opuntia elata, O. puberula,* and *O. rufida* were at best, only moderately suitable hosts while *Austrocylindropuntia subulata* and yellow bristle *O. microdasys* were unsuitable hosts for all four *Dactylopius* spp. (Table 2). Efficacy trials have commenced to determine the extent to which the cochineal reduce vigour of the test plants and whether or not they are capable of killing the plant.

Table 2. Host suitability of cactus species for the four *Dactylopius* species. NT = Not tested, ND = No development. Number of replicates are displayed within parenthesis.

Test species	*D. austrinus*	*D. ceylonicus*	*D. opuntiae 'Mex'*	*D. opuntiae 'US'*
A. subulata	ND (5)	ND (5)	ND (5)	ND (5)
O. aurantiaca	High (14)	NT	ND (5)	NT
O. elata	Low (10)	Moderate (10)	Moderate (10)	Low (10)

O. engelmannii	ND (5)	ND (5)	Moderate (5)	High (5)
O. ficus-indica	ND (5)	ND (5)	Moderate (16)	ND (5)
O. microdasys WB	Low (5)	ND (5)	High (5)	Moderate (5)
O. microdasys YB	Low (5)	ND (5)	Low (5)	Low (5)
O. monacantha	NT	High (13)	NT	NT
O. puberula	Moderate (5)	Low (5)	Moderate (5)	Moderate (5)
O. robusta	ND (5)	ND (5)	High (5)	Low (5)
O. rufida	Low (5)	ND (5)	Moderate (5)	Moderate (5)
O. streptacantha	ND (5)	ND (5)	High (5)	Low (5)
O. stricta	ND (5)	ND (5)	ND (5)	High (15)
O. sulphurea	High (5)	ND (5)	ND (5)	ND (5)
O. tomentosa	High (5)	ND (5)	High (5)	High (5)

Opuntia tomentosa field monitoring

Establishment of both *D. opuntiae* lineages at their respective release sites was slow and patchy. Some releases on individual trees were successful but others not and required additional releases. Release cladodes were often observed to be stripped of cochineal, but the cause of this was unknown. Even after the cochineal had established on most of the trees at both of the sites, the population build up was variable within each site. Populations of the insect increased rapidly on some trees, but not on others.

A number of ant species and generalist predators were observed at both field sites interacting with the cochineal (Table 3). Adults and larvae of the native Australian lady beetle, *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae), were often observed predating on all life stages of the cochineal. Numerous Neuropteran species (lacewings) eggs were found consistently on or near the cochineal, but relatively few larvae were ever observed.

An ant species, in the genus *Crematogaster* (Hymenoptera: Formicidae), was observed consistently over several months on multiple trees at both sites preying on the cochineal. These ants were observed systematically removing the protective wax from around the settled (typically third instar) females, by pulling stands of wax in straight lines from the centre of the cochineal. This process of “splaying” the wax resulted in an exposed cochineal, which was then preyed upon.

In March 2023, a single adult cerambycid beetle was observed on a cladode of *O. tomentosa,* subtle signs of stem-boring damage was also observed. The incidence of stem-boring damage increased (i.e., about 30%) over time, with branches breaking off. Destructive sampling of a non-survey *O. tomentosa* tree nearby, confirmed the presence of cerambycid larvae feeding within the trunk and branches. The cerambycid was identified to be *Lagocheirus funestus* (formerly *Archlagocheirus funestus*), a stem-boring beetle released in Australia in the mid-1930’s.

Table 3. List of insects recorded present on *O. tomentosa* and putative interactions with *Dactylopius opuntiae* ‘Mexico’ and ‘US’ lineages.

Species recorded	*Common Name*	*Interaction Type*

Cryptolaemus montrouzieri	Mealybug ladybird	Predation
Neuropteran sp.	Lacewing	Predation
Crematogaster sp.	Saint Valentine ant	Predation
Rhytidoponera metallica	Green-head ant	Possibly Predation
Calomyrmex sp.	Camponotine ant	Present
Dolichoderus sp.	Spider ant	Present
Dolichoderus sp.	Tyrant ant	Present
Polyrhachis sp.	Golden-tailed spiny ant	Present
Opisthopsis sp.	Strobe ant	Present
Apis mellifera	European honeybee	Present
Lagocheirus funestus	Cactus longhorn beetle	Biological control agent

DISCUSSION

Despite a long history of biological control research on invasive cactus species in Australia, quantitative host range testing for many *Opuntia* species has not been undertaken. This study confirms the potential for *D. opuntiae* 'US' lineage to be effective against *O. engelmannii*; *D. opuntiae* 'Mexico' lineage to be effective against *O. microdasys* (white bristle)*, O. robusta, O. streptacantha* and *O. tomentosa*; and *D. austrinus* to be effective against *O. tomentosa* and *O. sulphurea*.

Options for biological control of *O. elata, O. puberula and O. rufida* are less obvious. None of the *Dactylopius* spp. performed well on these species. However, they may still cause some impact to the plants and might have value in being used given that no other agents are currently available in Australia. Efficacy trials will help determine the level of impact these *Dactylopius* spp. may have on these three *Opuntia* spp. There are no cochineal that feed on either *Austrocylindropuntia subulata* or yellow bristle *O. microdasys*. Should these species become established and widespread, it is recommended that native range surveys of these species be undertaken to identify novel biological control agents.

Control of *O. tomentosa,* by *D. opuntiae* is variable, and the reasons for this are not well known. This study has confirmed variable impact of the cochineal to large *O. tomentosa* trees and the presence of key predator interactions impeding the establishment, population build up, and spread of the cochineal. *Crematogaster* species appear to target the larger third instar cochineal, while *C. montrouzieri* and lacewings prey upon the younger and smaller early instar nymphs. A single *C. montrouzieri* has the capacity to prey upon >6000 *D. opuntiae* nymphs during its lifecycle (El-Aalaoui et al. 2019), the equivalent to the total progeny produced by about 10 reproductive females.

Historically, *O. tomentosa* infestations were considered under control through the combined impact of the 'Mexico' lineage of *D. opuntiae* and the cerambycid *Lagocheirus funestus* (Dodd 1940). The cerambycid was reported to have a large impact in the few years after its initial release. However, subsequent years of drought contributed to the decline in its numbers in the field, and it was thought to have died out in Australia (Hosking et al. 1988). The discovery of this agent damaging *O. tomentosa* in southeast Queensland is promising because of its potential to complement existing cochineal impact. Rearing this agent is reportedly straight forward (Dodd 1940) and a redistribution project may provide the high impacts reported historically.

ACKNOWLEDGEMENTS

The study was funded by the Advancing Pest Animals and Weeds Control Solutions Competitive Grant Program (Commonwealth Government), and Queensland Department of Agriculture and Fisheries.

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