ECOLOGY OF MAJOR EMERGING WEEDS

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Authors:
Gurjeet Gill, University of Adelaide, Catherine Borger, Department of Primary Industries and Regional Development, WA and Bhagirath Chauhan, University of Queensland.

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GRDC contact details
PO Box 5367
KINGSTON ACT 2604

02 6166 4500
comms@grdc.com.au
www.grdc.com.au

Design and production
Coretext, coretext.com.au

COVER: Flower head of prickly lettuce, wild lettuce.
PHOTO: Michael Moerkerk, Agriculture Victoria

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INTRODUCTION

Why are biological and ecological traits of weeds important?

It is easy to focus on understanding and implementing weed control tactics. However, it is also important to consider aspects of weed biology and ecology. Ongoing weed control cannot be successful until we understand how weeds grow and interact with other species, including crops, management practices and the environment.

Through having increased knowledge of the biology and ecology of weeds, growers will have the tools to implement the most appropriate management strategies for the weed spectrum occurring on their properties. By being aware of weed ecology, the likely weed-related implications of changing farming practices such as new crops, earlier sowing, or soil amelioration can be understood.

Weed scientists and advisers can offer advice on weed control, but it is important to remember individual weed species can behave quite differently across the breadth of Australia. The only way to accurately judge what an individual weed population is doing is to look at it, fairly regularly, and to understand why the weeds are acting or reacting in certain ways.

For each weed in this book, the authors provide information under seven headings, which are discussed below. This introduction explains why each of these sections is important and how each relates to weed control.

Background

The first section considers the name of the weed species and a map of where it is found. Weed species can have many different common names and sometimes may also have different scientific names. This can make identification difficult, but weed control can be compromised by not knowing what weed it is. However, for some species, identification is more important than others. For example, it is very difficult to differentiate between the barley grass species *Hordeum leporinum* or *H. glaucum* without specialist taxonomic knowledge and a magnifying glass. However, many herbicide labels just refer to 'barley grass' without specifying a species, because the product will work equally well on both species.

Description

A description of the weed helps with accurate identification, and this section also highlights similar species that the weed may be confused with. However, the description of the weed also helps to decide which management practices are needed. Is the species a winter or summer annual? This determines when control tactics need to occur. Is the growth of the plant flat (prostrate) or erect? This will influence how competitive a species is with the crop and if harvest weed seed control is possible.

Why is it a weed?

Not every weed is equally bad in every scenario. Capeweed, for example, is one of Western Australia's most common species, but this relatively small, prostrate species is rarely a major economic concern for grain growers. A toxic species is probably a greater problem in an enterprise with livestock than cropping alone. Conversely, a non-toxic, palatable species is likely to be less of an issue in a livestock-dominated enterprise.

Seed

Dormancy and germination

The best time to control weeds is when they are seeds or seedlings; at this stage they are easier to kill and have not caused economic damage. However, it is necessary to understand seed dormancy and germination requirements to know when seedlings will emerge. Initial seed dormancy (after-ripening) determines when a seed will germinate and emerge in the year after seed-set. For example, how many of the seeds of a winter annual weed stay dormant over summer and how many emerge in response to summer rainfall? Germination biology also influences seed germination and seedling emergence. Do the seeds emerge immediately after rainfall events, like sowthistle? Do the seeds need cold temperatures to trigger emergence? Are the seeds sensitive to light or burial, leading to increased emergence following minimum tillage (with moderate seed burial) compared with no-tillage systems (with less than five per cent seed burial)? Aspects of seed biology need to be considered in terms of the broader agronomic system.

Seedbank persistence

How long does the seedbank last? This is a key question in planning an integrated weed management program. Weeds that are more likely to germinate and degrade in one to two years will require different management than weeds more likely to persist in the seedbank for three years or more. However, this can be influenced by the environment. Has the seed been buried? Is the site high or low rainfall? Will the seeds attract granivorous (seed eating) species? Many different factors will influence the dormant seedbank and determine how many years of management are required to get the seedbank to low levels.

Seed production and dispersal

Most weeds have the potential for very high seed production but there can still be more than a 10-fold difference in the maximum seed-set between weed species. However, the timing of seed production and the timing of seed shed and seed dispersal mechanisms all influence management strategies. Do in-crop weeds retain sufficient seed to make harvest weed seed control worthwhile? Do summer weeds set seed quickly and need immediate control, or are there a few weeks of vegetative growth before control actions are needed to ensure complete prevention of seed-set? Is seed dispersal so common and widespread that management programs need to consider what is happening in neighbouring areas, or is it acceptable to just focus on a single paddock?

Competition

How well a weed species competes with the crop is the primary question for most Australian growers. Tall, vigorous annual species such as brome grass and feathertop Rhodes grass are consistently detrimental to yield. Prostrate species, or species with initial emergence later than the crop, such as doublegee, often have less of an impact on crop yield. Summer weeds, in a region with only winter annual crops, in seasons with small rainfall events on sandy soil (poor water-holding capacity) may have little impact on subsequent crop yield.

Table 1 contains a summary of the characteristics of the weed species included in this publication.

Table 1: Summary of the characteristics of the weed species included in this publication.

Common name	Scientific name	Location of research	Main growth period	Maximum seed production/m^2	Seedbank persistence	Competitive ability (in wheat, unless otherwise specified)	Yield reduction resulting from direct competition (in wheat, unless otherwise specified)	Potential seed capture at harvest (in wheat, unless otherwise specified)
Afghan melon	*Citrullus amarus*	Western Australia	Spring-summer	5000	>4 years	Low	0%	None
Barley grass	*Hordeum leporinum, H. glaucum*	Western Australia, South Australia	Winter	877	WA: 4 years SA: 2 years	High	WA: 5 to 36% SA: 9 to 22%	Variable
Bedstraw	*Galium tricornutum*	South Australia	Winter-spring	14,000	4 years	Medium to high	6 to 15%	High
Bifora	*Bifora testiculata*	South Australia	Winter-spring	4768	4 years	Medium; moderate to high in lentils	8 to 10%	Variable
Bladder ketmia	*Hibiscus tridactylites*	Queensland	Summer	21,200	>3.5 years	High in mungbean	65% in mungbean	Medium in mungbean
Brome grass	*Bromus diandrus*	Western Australia, South Australia	Winter	WA: 67,975 SA: 10,534	3 years	High	WA: 5 to 67% SA: 10 to 20%	Variable
Button grass	*Dactyloctenium radulans*	Western Australia, Queensland	Summer	218,700	>3 years	High in mungbean	WA: 0% QLD: 69% in mungbean	Medium in mungbean
Caltrop	*Tribulus terrestris*	Western Australia, Queensland	Spring-summer	19,100	>4 years	Medium	WA: 0% QLD: 49% in mungbean	High in mungbean
Doublegee/spiny emex/ three corner jack	*Rumex hypogaeus (syn. Emex australis)*	Western Australia	Winter-spring	429	>4 years	Medium	3 to 17%	Low
Feathertop Rhodes grass	*Chloris virgata*	Queensland	Summer	147,800	2 years	High in mungbean	73% in mungbean	High in mungbean
Indian hedge mustard	*Sisymbrium orientale*	South Australia, New South Wales	Winter	2600	3 years	Low to medium	Up to 15%	High
Liverseed grass	*Urochloa panicoides*	Queensland	Summer	39,400	3.5 years	High	66% in mungbean	High in mungbean
Marshmallow	*Malva parviflora*	South Australia, New South Wales	Winter	16,124	>4 years	Low (if killed before seeding)	Up to 11%	High
Mexican poppy	*Argemone mexicana*	Queensland	Winter	Data not collected	>3.5 years	Low	23%	High
Prickly lettuce	*Lactuca serriola*	South Australia	Spring-summer	Data not collected[1]	2 years	Low	0%	Low[1]
Roly poly	*Salsola australis*	Western Australia	All year	8303	1 to 2 years	Low	0%	Low
Sesbania pea	*Sesbania cannabina*	Queensland	Summer	17,200	>3.5 years	High in mungbean	60% in mungbean	High
Sowthistle/milk thistle	*Sonchus oleraceus*	Queensland, South Australia, Western Australia	All year	193,000	3 years	Medium	3 to 22%	Low
Statice	*Limonium lobatum*	South Australia	Winter-spring	Data not collected[1]	1 year	Low	0%	Low
Summer grass	*Eriochloa crebra*	Queensland	Summer	77,000	>3.5 years	High in mungbean	71% in mungbean	High
Turnip weed	*Rapistrum rugosum*	Queensland, South Australia	Winter	32,000	>3.5 years	QLD: high SA: low	QLD: 78% SA: <10%	High
Wild turnip	*Brassica tournefortii*	South Australia	Winter	Wheat: 6200 Lentil: 13,700	2 to 3 years	Medium	5 to 10%	High
Windmill grass	*Chloris truncata*	Western Australia, Queensland	Summer	88,200	2 to 3 years	Medium	WA: 0 to 25% QLD: 56% in mungbean	High in mungbean
Wireweed	*Polygonum aviculare*	Western Australia	All year	123,000	>4 years	Medium	2 to 21%	None

[1] Seed-set in prickly lettuce and statice in SA usually occurs after crop harvest.

A summer annual that emerges in spring and summer and matures in late summer or autumn.

Photo: Catherine Borger (DPIRD)

AFGHAN MELON

Citrullus amarus Schrad.

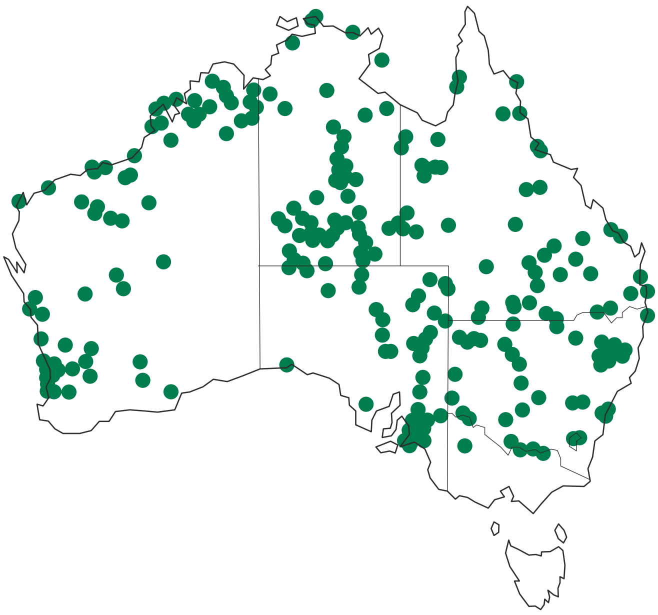
Other common names: bitter apple, bitter melon, bastard melon, pie melon, wild melon, paddy melon, wild watermelon.

Synonyms: *Citrullus lanatus* (Thunb.) Matsum. & Nakai, *Colocynthis citrullus* M.Roem., *Cucurbita citrullus* L.

KEY POINTS

- Afghan melon is a nationally distributed summer annual, costing Australian growers an estimated $89.6 million a year in lost revenue
- The seedbank lasts more than three years and melons just 3cm wide can hold mature seed to replenish the seedbank
- Most seeds emerge in the first year, but the seedbank will last longer when seeds are buried. Zero or no-tillage seeding systems, which leave seeds on the soil surface, will help reduce the seedbank more rapidly

Figure 1: *Citrullus amarus* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Afghan melon is a weed in the Cucurbitaceae family, which originated in sub-Saharan Africa. This species is found throughout Australia, with the exception of Tasmania (Figure 1). It is very similar to the perennial species colocynth (*Citrullus colocynthis* (L.) Schrad.), and the summer annual species prickly paddy melon (*Cucumis myriocarpus* E.Mey. ex Naud.).

Description

- A warm season, prostrate annual vine, with branches that may spread up to 3m and a stout taproot. Crushed plants release a strong odour.
- Cotyledons are oval and hairless, with round tips, on a short stalk with clearly visible, lighter-coloured veins.
- First true leaves are round, generally with three lobes, toothed edges, rounded tips and notched at the base.
- Leaves are alternate, up to 8cm long, with pale veins. Leaves are hairless on top with sparse hair underneath.
- Stems are usually branched with bristly hairs, often woolly towards the end of the stem and rough to touch.
- Flowers form on single, hairy stalks and are yellow, 3 to 4cm wide, with five petals. Flowers are either male or female, with both types on each plant.
- Fruit (melons) are green, with stripes of lighter-green patches, up to 15cm long. Young melons are hairy, but the mature melons are smooth.
- Seeds in the melon are 6 to 15mm long and about 6mm wide. Seeds are egg-shaped to oval with a narrow point at the base. They are initially white but mature to brown with black patches.
- Can be confused with colocynth, although this perennial species has smaller fruit and seeds, dark green leaves with nine lobes, and stems that do not branch. Further, the taproot is a swollen, bulbous shape.
- Can be confused with prickly paddy melon, although this species has cotyledons with less distinct veins, unbranched stems, smaller leaves that are usually a darker green with fewer lobes, and much smaller fruit with soft spines.

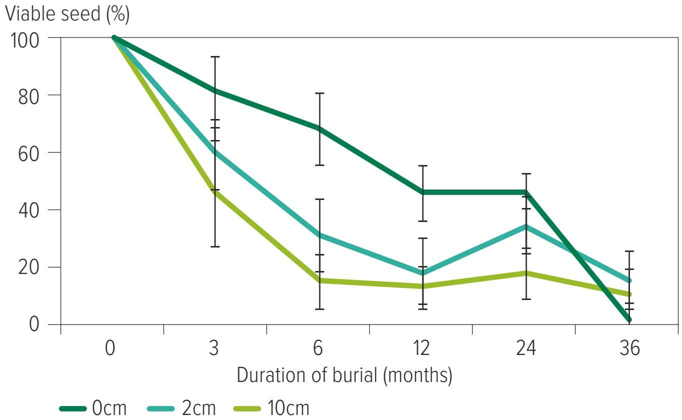
Figure 2: Top left: Afghan melon seeds. Top right: Seedling. Bottom left: Afghan melon vine with flowers. Bottom right: A mature plant with a melon.

Photos: DPIRD and Catherine Borger (DPIRD)

Figure 3: A 3cm-wide melon, dissected to show that nine of the seeds are already mature (brown) even though most seeds are still immature (white).

Photo: Catherine Borger (DPIRD)

Figure 4: Viability of Afghan melon seed on the soil surface or buried at a depth of 2 or 10 cm, over 3 to 36 months. Vertical bars indicate the standard error of the mean.



Why is it a weed?

Melons are nationally ranked as the most detrimental weed of the summer fallow, covering an area of 6,380,669ha and costing $90 million per year in lost revenue ($50 million from WA alone). Afghan melon is drought tolerant and is particularly common in semi-arid regions, but grows in many habitats across northern and southern Australia. Afghan melon is often the only plant surviving the summer drought. Like any weed of the summer fallow, it removes stored soil moisture and nutrients that would ordinarily be available to the subsequent winter crop. The vines can cause blockages in tynes at seeding.

Afghan melon is unpalatable to livestock due to the production of cucurbitacins, biochemical compounds produced by plants as a defence against herbivores. It may also be toxic to stock, but this is rarely a problem in the field due to low palatability. Stock in poor condition or stock without supplementary feed are more susceptible to toxicity from weeds over the summer fallow.

Seed

Dormancy and germination

Afghan melon seeds have initial dormancy (after-ripening requirements) that lasts for several months while the seeds mature. This ensures seeds remain dormant over autumn/winter and allows germination in the following spring. Germination is inhibited by light, particularly at low temperatures. The germination response to light and temperature has been attributed to day length and temperature during seed maturation. Inhibited germination at lower temperatures ensures the seeds do not emerge until spring and summer, even once seeds have finished after-ripening.

In laboratory trials at Northam, WA, Afghan melon seeds germinated in response to scarification (the seed coat was damaged) and gibberellic acid (the hormone associated with triggering germination). Scarification or gibberellic acid alone did not induce germination. This indicates that in the field, the correct temperature/moisture conditions need to be met for seedling emergence. Damage to the seed (from vehicles or livestock) is not enough to allow the seed to imbibe water and germinate, even after the seed has lost dormancy.

Annual emergence of Afghan melon seedlings (averaged over 12 populations) was monitored over three years (May 2016 to April 2019) in irrigated conditions at Northam. Emergence was 57 per cent in year one, 30 per cent in year two and eight per cent in year three. In every year, peak emergence occurred in October.

While Afghan melon is considered a summer weed, most summer species can emerge in spring. Summer weeds emerging in winter grain crops are becoming increasingly common. It is logistically difficult to control weeds directly prior to harvest, but to prevent seed-set, plants need to be sprayed before the production of any melons. Even a very small melon can hold multiple mature seeds (Figure 3).

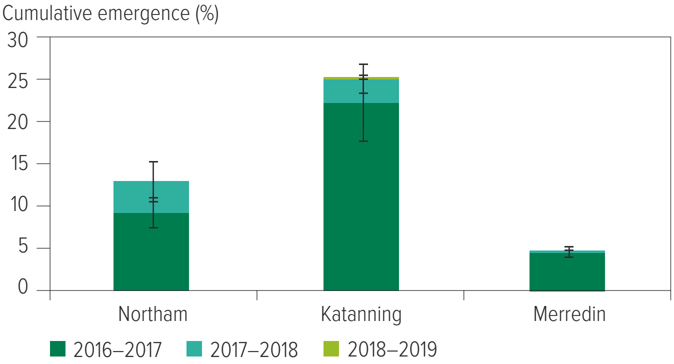
Seedbank persistence

In field conditions at Northam long-term dormancy of the seedbank of Afghan melon has been investigated by placing seeds on the soil surface, or at 2cm or 10cm depth for three years (Figure 4). Seeds on the soil surface lost viability (degraded or germinated) over three years, with only two per cent seed viability at the end of three years. By comparison, seed at 2cm or 10cm lost viability more rapidly, but retained 10 to 15 per cent viability at the end of three years. From a management perspective, seed may lose viability more rapidly if it gets buried by the seeding system, but burying the seed will create a long-term seedbank (more than three years).

Seeds on the surface have a long life span as they are not eaten by livestock, although the melons and seeds may be consumed by birds over summer. If seeds are buried, the hard, woody seed coat protects the seed from degradation or damage by soil organisms. Other research has shown that Afghan melon seed can remain viable for more than five years in storage. A long-term integrated weed management program would be needed to remove the dormant seedbank.

In field conditions, most emergence occurs in year one or two and the remaining seed degrades, or germinates after a very small rainfall event and subsequently dies without emerging. This was investigated by placing Afghan melon seed in micro-plots in the field for three years, with the soil agitated each year (May) to simulate crop seeding (Figure 5). Under these conditions, emergence in the first year was related to rainfall, with greatest emergence at Katanning (high rainfall) followed by Northam (medium rainfall) and Merredin (low rainfall). Katanning and Northam had emergence in the second year, but Merredin emergence in year two was 0.1 per cent. Seed (and soil) was retrieved after three years and sown in irrigated conditions, but emergence remained at less than one per cent. Therefore, soil agitation to bury some seed, and then potentially return it to a shallower depth or the soil surface in subsequent years (and expose it to light as the soil is moved), allows seeds to germinate or degrade more rapidly than seed in controlled conditions at a consistent depth (as in Figure 4).

Figure 5: Cumulative yearly emergence of Afghan melon (as a percent of the total weed seeds planted) at three locations in WA from 2016 to 2019. Vertical bars indicate the standard error of the mean.



Seed production and dispersal

Individual melons on an Afghan melon plant can contain up to 400 seeds at maturity. However, as discussed previously, seeds continue to form and mature as the melon increases in size, so a very small, hairy, immature melon will still contain mature seed. A single plant could produce up to 5000 seeds under favourable conditions. However, seed production is dependent on unpredictable summer rainfall. In a three-year trial conducted at Wongan Hills, WA, plant density ranged from zero to 11 plants/m^2, with a maximum seed production of 48 seeds/m^2. Dispersal of the seeds results from Afghan melon vines being dragged by tynes during the seeding process. Seeds are also dispersed by the bird species that eat them over summer.

Competition

Afghan melon seedlings are highly competitive against other weeds when establishing over the summer fallow due to their extensive root system and high drought tolerance. At Wongan Hills, three years of Afghan melon growth failed to impact on the following wheat yield in a site with sandy soil. In areas of soil with greater capacity to store moisture from summer rainfall, summer weed growth can have a much bigger impact on crop yield. Also, the impact of summer weed growth is greater in years with low winter rainfall, where the crop is highly dependent on stored soil moisture.

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dprid.wa.gov.au

African turnip weed grown in fallow. Photo: Bhagirath Chauhan

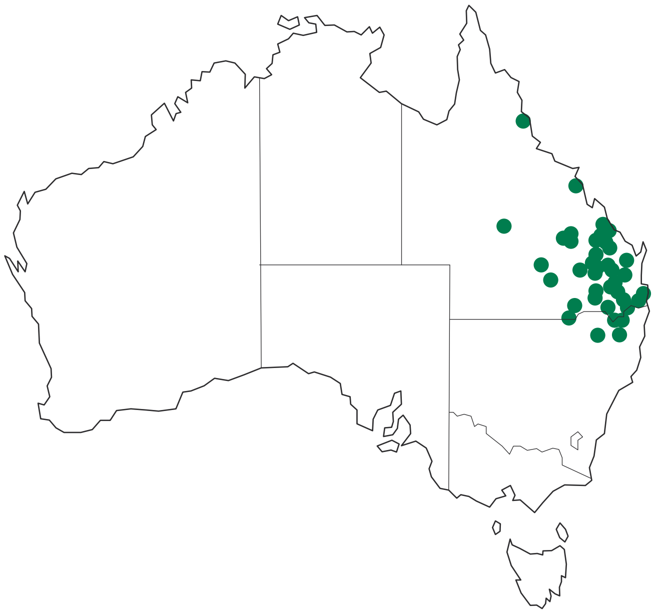
AFRICAN TURNIP WEED

Sisymbrium thellungii O.E. Schulz

KEY POINTS

- African turnip weed seeds exhibit low dormancy levels
- These seeds have a short lifespan, persisting for less than two years regardless of burial depths
- Seed persistence is notably higher at shallow depths (two centimetres) compared with the soil surface
- The emergence period is limited, occurring typically between May and June
- African turnip weed is a prolific seed producer, capable of producing more than 90,000 seeds per plant under fallow conditions
- While it is a weak competitor in wheat fields, it competes fiercely with chickpea crops and yields an abundance of seeds
- African turnip weed plants possess a high capacity for seed shattering

Figure 1: Distribution of African turnip weed in Australia.



Source: The Australasian Virtual Herbarium

Background

African turnip weed is a broadleaf weed in the Brassicaceae family. It is native to southern Africa and an emerging weed in Australia. Widespread infestation has been observed in Queensland and northern New South Wales (Figure 1).

Description

- It is an annual erect plant, scabrous, and about 60 centimetres tall.
- Its basal leaves are lyrate-pinnatisect (30cm long, with three to seven pairs of lobes).
- Mature plants produce bright yellow flowers.
- Pods are similar to that of wild turnip but do not have a 'beak'.
- Seeds are egg-shaped, brown in colour and small in size (1–1.5 millimetres in length).

Why is it a weed?

High seed production potential and adaptability to grow in water-stressed environments have made African turnip weed a concern in eastern Australia. The high shattering ability of this weed's seed pods in fallows and winter crops, such as chickpeas, allows high weed seedling recruitment in paddocks. It has evolved resistance to Group 2 herbicides (acetolactate synthase inhibitors) in Australia and is difficult to control in broadleaf crops, such as chickpeas, where herbicide options are limited.

Table 1: Effect of alternating day/night temperatures on the germination of African turnip weed under light/dark and complete dark.

Alternating temperature regimes (day/night °C)	Germination (%)	
	Light/dark	Dark
15/5	81	78
20/10	97	65
25/15	85	19
30/20	3	0.0
LSD (0.05)	7	

Table 2: Viable African turnip weed seed (%) in response to seed burial duration and depth (average of three locations).

Burial duration (months)	Viable seed (%)		
	Burial depth		
	0cm	2cm	10cm
0	100	100	100
3	78	82	75
6	47	77	64
12	15	56	41
18	0	21	5
24	0	0	0
30	0	0	0
36	0	0	0
LSD (0.05): Burial duration x burial depth = 12			

Seed

Dormancy and germination

African turnip weed possesses a low level of seed dormancy. Germination ranged between 41 and 100 per cent when fresh seeds of 18 populations collected from different agroecological conditions of eastern Australia were evaluated under ideal conditions in the laboratory. African turnip weed seeds were germinated over a wide range of day/night temperatures (15/5°C to 30/20°C) (Table 1). Germination was highest at 20/10°C (day/night temperature), suggesting the winter season (May and June) is a favourable environment for emergence.

Seed germination was higher (77 per cent) on the soil surface and a burial depth of even 1cm reduced its emergence. Gemination was inhibited in a dark environment and in crop residue, suggesting that conservation tillage with high residue cover may reduce its emergence. However, a no-till system with less residue cover could promote its germination.

Seed burial inhibited seedling emergence, suggesting that inversion tillage could reduce emergence if the paddock is infested with African turnip weed seedbanks. Under field conditions, emergence was observed only in May and June, suggesting that this weed requires particular temperature and moisture conditions.

Seedbank persistence

Nylon bags containing fresh African turnip weed seeds were placed at different depths at Gatton, St George and Narrabri to study seedbank persistence. After six months of seed placement, averaged over locations, seed decay was faster on the surface compared with burial depths of two and 10cm (Table 2). Averaged over locations, viable seeds on the surface after 12 months were 15 per cent. However, at the same time, viable seeds at two and 10cm soil depths were 56 and 41 per cent, respectively. After 24 months, seed decay was 100 per cent at each burial depth.

These results suggest that African turnip weed seeds are short-lived in no-till farming and adopting good management strategies for the initial two years could help in reducing the seedbank. After one year, viability was higher for buried seeds, suggesting that a tillage operation may bring these seeds back to the soil surface and reinfest the area.

Seed production and dispersal

The seed production potential (>90,000 per plant) was observed to be very high in May when grown without competition under field conditions (Table 3). African turnip weed produced only a small number of seeds in the late-planted (25 June) wheat crop. The growth of the late-planted wheat was slow during the initial phase, which allowed the weed to establish and produce some seeds.

Table 3: Seed production (number plant^{-1} ± standard error) of African turnip weed as affected by planting time and crop competition.

Planting time	Seed production (number plant^{-1})		
	No competition	Competition with chickpea	Competition with wheat
15 May	91,783 ± 28,953	75,871 ± 12,791	0
5 June	52,773 ± 12,975	34,659 ± 5300	0
25 June	17,639 ± 12,358	24,157 ± 9470	826 ± 662

Table 4: Growth response of African turnip weed to altered planting time.

Planting time	Seeds plant^{-1} (±SE)	Days to flowering (±SE)
4 May	67,885 (± 19610)	90 (± 3.7)
26 May	11,120 (± 725)	82 (± 2.3)
16 June	6475 (± 329)	71 (± 1.8)
7 July	4275 (± 137)	70 (± 1.3)

Table 5: Chickpea yield reduction in response to African turnip weed interference.

African turnip weed density (plants m^{-2})	Chickpea yield reduction (%)
0	0
5	18
14	29
25	51
38	71

In chickpeas, African turnip weed produced sufficient numbers of seeds for reinfestation in each planting date. However, delayed planting time reduced the seed number. It was observed that about 55 per cent of African turnip weed seeds shattered at chickpea maturity, suggesting a limited opportunity for harvest weed seed control.

Populations of African turnip weed differed in seed production potential when tested under a water-stressed environment in pot studies. The Dalby population (high-rainfall area) produced 4790 seeds plant^{-1} at 100 per cent water-holding capacity (WHC) and about 30 seeds plant^{-1} at 25 per cent WHC. However, the St George population (low-rainfall area) produced 4060 and 9830 seeds plant^{-1} at 25 per cent and 100 per cent WHC, respectively. These results suggest that the population collected from a low-rainfall area has the ability to produce enough seeds in a water-stressed environment.

In another study, African turnip weed produced 68,000 seeds plant^{-1} under fallow conditions when planted on 4 May (Table 4). However, seed production was reduced by 84 per cent for the 26 May planting time compared with the 4 May planting time. Minimum seed production was produced by the last cohort (that is, 7 July planting time). These results suggest that weeds in fallows may produce a significant number of seeds, especially from early cohorts. It was also observed that African turnip weed plants took 90 and 70 days to produce flowers in early and late cohorts, respectively.

Competition

African turnip weed is highly competitive in chickpeas. Under a weed-free situation in the field, chickpeas yielded 3600 kilograms a hectare^{-1} and the seed yield declined by 18, 29, 51 and 71 per cent at African turnip weed densities of 5, 14, 25 and 38 plants m^{-2}, respectively (Table 5). These observations suggest that early control of African turnip weed in chickpeas is necessary to increase yield and for reducing the weed seedbank in subsequent years. If African turnip weed plants are allowed to grow in chickpeas paddocks, they can produce an enormous number of seeds and the high shattering ability of these plants may increase seedbank replenishment.

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Chickpea paddock infested with African turnip weed. Photo: Bhagirath Chauhan

Awnless barnyard grass in wide rows in sorghum. Photo: Bhagirath Chauhan

AWNLESS BARNYARD GRASS

Echinochloa colona (L.) Link

Other common names: jungle rice, jungle grass, millet rice, pigeon millet.

KEY POINTS

- Fresh seeds of awnless barnyard grass exhibit moderate initial dormancy, a trait that varies among populations
- Seeds have the capacity to germinate within a temperature range of 20/10°C to 35/25°C (day/night)
- Germination rates are notably higher under light/dark compared with complete darkness
- Maximum seedling emergence (65 per cent) occurs at the soil surface, with seedlings unable to emerge from depths greater than eight centimetres
- The awnless barnyard grass seedbank is relatively short-lived, lasting less than three years. Therefore, implementing intensive control measures over a three-year period can significantly reduce infestation levels to a minimum
- The weed exhibits prolific seed production under fallow conditions, yet crop competition, such as with sorghum and mungbean, aids in diminishing its seed production.
- While it poses a high competitive threat in mungbean crops, more than 65 per cent seed retention at mungbean harvest presents an opportunity for harvest weed seed control

Background

Awnless barnyard grass is a warm-season weed and is widely distributed throughout the northern and eastern cropping regions of Australia. The adoption of the no-till system has increased its predominance in eastern Australia. In cotton, sorghum and mungbean crops, it has become a serious weed and causes a significant reduction in yield. The weed's infestation is also expanding in the Northern Territory and the Ord River irrigation area in Western Australia (Figure 1).

Description

- Seedlings are erect, which enables roots at a lower node.
- It is an annual plant and has short spikes in an alternate arrangement on the main axis.
- Spikelets are awnless and ligules are absent; therefore, it is also called awnless barnyard grass.
- Purple-red bands can be seen on the leaf sheath of awnless barnyard grass and become more prominent under water-stressed conditions.

Why is it a weed?

- A highly competitive weed across a range of environmental conditions and a problematic weed in summer crops of eastern Australia. It can germinate throughout the year in south-eastern Australia.
- Evolved resistance to multiple groups of herbicides in Australia; for example, Group 5 (atrazine) and Group 9 (glyphosate).
- A prolific seed producer and seeds are easily dispersed with water and wind.
- Life cycle is short and it produces multiple cohorts in a season.
- An alternate host for the virus that causes mosaic disease in many crops.

Seed

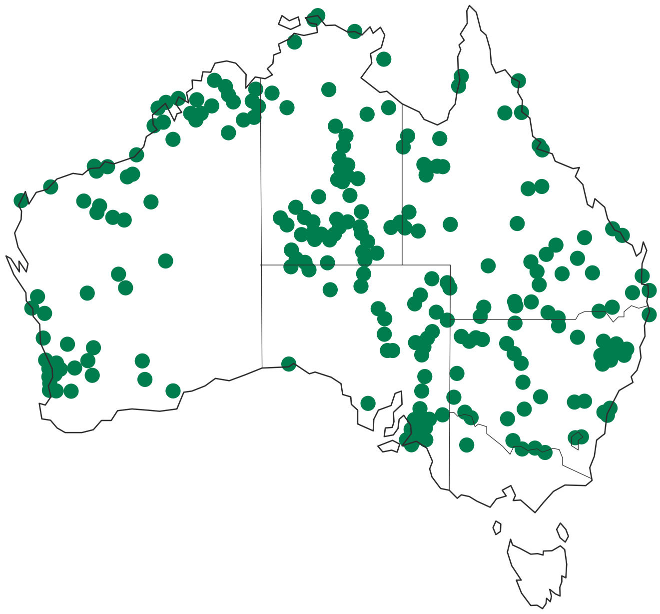
Dormancy and germination

Fresh seeds are dormant and dormancy varies with populations. The germination of fresh seeds varied from 15 to 60 per cent when tested in the laboratory using five populations of awnless barnyard grass collected from the northern grain region of Australia. A laboratory study revealed that seeds germinated at a wide range of alternating day/night temperatures (12h/12h) ranging from 20/10°C to 35/25°C (Table 1). This study suggests that awnless barnyard grass seeds in Australia can emerge in the spring, summer and autumn seasons.

Table 1: Effect of alternating day/night temperatures (15/5°C to 35/25°C) on the germination of awnless barnyard grass under light/dark and dark environments (lab study).

Alternating temperature regimes (day/night °C)	Germination (%) ± SE	
	Light/dark	Dark
15/5	0 ± 0	0 ± 0
20/10	27 ± 3.5	2 ± 0.9
25/15	87 ± 2.7	38 ± 15.3
30/20	89 ± 1.7	62 ± 25.1
35/25	88 ± 1.7	51 ± 20.9

Figure 1: ***Citrullus amarus*** **incidence in Australia.**



Source: The Australasian Virtual Herbarium (AVH 2020)

Awnless barnyard grass in narrow sorghum rows. Photo: Bhagirath Chauhan

Table 2: Viable seed (%) of awnless barnyard grass at Gatton and St George in response to seed burial duration and depth.

Burial duration (months)	Viable seed (%)					
	Gatton			St George		
	Burial depth					
	1cm	5cm	15cm	1cm	5cm	15cm
0	100.0	100.0	100.0	100.0	100.0	100.0
3	92	93	90	96	97	95
6	89	89	84	95	95	96
12	61	64	65	46	90	82
18	48	55	52	33	79	65
24	27	27	27	21	52	45
30	8	26	15	0	4	3

In the dark, seed germination increased with an increase in temperature from 20/10 to 35/25°C, suggesting that in the summer season seedlings may emerge from buried seeds. Seed germination was higher in light/dark environments compared with complete darkness, suggesting that germination may be stimulated under no-till farming situations.

Sorghum residue retention (eight tonnes per hectare^{-1}) reduced emergence from 70 to 47 per cent, suggesting that conservation tillage could help reduce emergence to some extent. Seedlings were unable to emerge from seeds buried at 8cm depth, suggesting that a deep tillage could be used to bury seeds below the maximum depth of emergence.

Under field conditions in eastern Australia, it was found that awnless barnyard grass had multiple cohorts starting from October to end of March and these cohorts appeared in response to rains. The cumulative emergence of different populations in a season varied from 38 to 84 per cent under field conditions, suggesting that populations varied in their dormancy behaviours.

Seedbank persistence

Nylon bags containing fresh seeds from three different populations were positioned at various depths at Gatton (with low clay content) and St George (with high clay content) sites, aiming to investigate the seedbank's longevity. The decay trend of the three populations was observed to be similar and rapid within the soil surface layer (1cm). After a 30-month period, the evaluation at Gatton revealed seed persistence levels of eight per cent, 26 per cent and 15 per cent at depths of one, five and 15cm, respectively (Table 2). Contrastingly, at St George, seed persistence was nearly negligible across all soil depths after the same 30-month burial period.

This study suggests that awnless barnyard grass seed persistence might be influenced by soil texture, indicating that a higher clay content can diminish seed longevity. These findings imply that seeds exhibit short life spans, especially in no-till farming scenarios. Employing effective management strategies during the initial three-year period could prove instrumental in reducing the seedbank.

Seed production and dispersal

Awnless barnyard grass produced 17,600 seeds plant^{-1} at 100 per cent water-holding capacity (WHC) of the soil and its seed production potential was 45, 43 and 11 per cent at 75, 50 and 25 per cent WHC of soil, respectively.

In another study, the seed production potential of different populations varied from 5380 to 10,240 seeds plant^{-1}. These results suggest that populations have different reproduction potentials and high moisture conditions in the soil increase its seed production potential. The capacity of awnless barnyard grass to produce >1000 seeds plant^{-1} under severe water stress conditions (25 per cent WHC of soil) makes it a serious weed for a build-up of seedbanks under fallow conditions.

A field study at Gatton revealed that the seed production potential under fallow conditions was highest (~24,000 seeds plant^{-1}) when planted in December compared with November, January and February planting (Table 3). Sorghum competition (planted at 50cm row spacing) in December-planted awnless barnyard grass reduced the seed production by >80 per cent compared with fallow situations.

Awnless barnyard grass plants grown in no competition/fallow (front), 1m row (middle) and 0.5m sorghum rows (back). Photo: Bhagirath Chauhan

Table 3: Seed production (number plant^{-1} ± standard error) of awnless barnyard grass as affected by planting time and crop competition.

Planting time	Seed production (number plant^{-1})		
	No competition	100cm rows	50cm rows
10 November 2017	9240 (56)	1213 (52)	773 (48)
10 December 2017	23,788 (52)	10,731 (51)	3513 (47)
10 January 2018	11,122 (48)	3193 (46)	1986 (42)
10 February 2018	1529 (40)	376 (41)	187 (41)
LSD (0.05)	Planting time x competition level = 3008		

Values in parentheses indicate maturity time (days).

In another study, awnless barnyard grass produced 4060 and 1090 seeds plant^{-1} when transplanted at the emergence and two weeks after the emergence of a sorghum crop, respectively. Seed retention in sorghum crops was found to be between 42 to 56 per cent, suggesting a limited opportunity for the use of harvest weed seed control tactics in sorghum crops, since most seeds dispersed before crop maturity. Awnless barnyard grass interference in mungbean at an infestation level of two plants m^{-2} produced 690 seeds m^{-2} and seed production increased by 3, 9, 15 and 26 times at weed infestation levels of 4, 8, 16 and 32 plants m^{-2}, respectively, compared with weed infestation level of two plants m^{-2}. It was also observed that the seed retention in mungbean was about 70 per cent, suggesting an opportunity for harvest weed seed control in mungbean.

Awnless barnyard grass-infested fields. Photo: Bhagirath Chauhan

Table 4: Mungbean yield reduction in response to awnless barnyard grass interference.

Weed density (plants m^{-2})	Mungbean yield reduction (%)
0	0
2	10
4	20
8	27
16	34
32	43

Competition

Awnless barnyard grass is highly competitive in mungbean. Under a weed-free situation in the paddock, mungbean resulted in a seed yield of 2800 kilograms per hectare^{-1} and the seed yield of mungbean declined by 20, 27, 34 and 43 per cent at weed densities of 4, 8, 16 and 32 plants m-2, respectively (Table 4). In another pot study, mungbean interference (4 to 8 plants pot^{-1}) reduced seed production by 85 to 95 per cent compared with weed-free conditions. These observations suggest that early control of awnless barnyard grass in mungbean paddocks could help in increasing mungbean yield.

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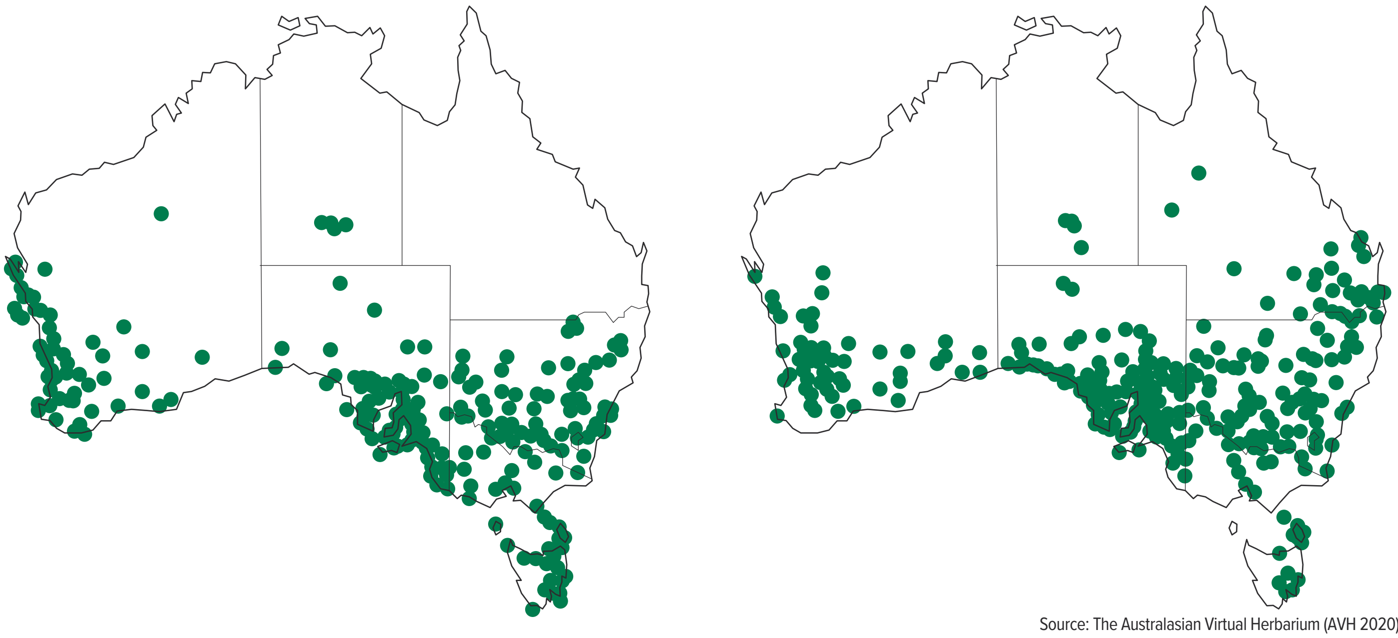
A winter annual that emerges in autumn and then has staggered emergence through winter and spring. Plants mature in late spring and summer.
Photo: Catherine Borger (DPIRD)

BARLEY GRASS

Hordeum leporinum Link or *H. glaucum* Steud.

Other common names: northern barley grass, smooth barley, hare barley, common foxtail.

Figure 1: *Hordeum leporinum* (left) and *Hordeum glaucum* (right) incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

KEY POINTS

- **The two common species of barley grass, *Hordeum leporinum* and *H. glaucum*, are not easy to distinguish, but they can usually be managed with similar weed control tactics**
- **Barley grass can have delayed, staggered emergence in autumn/winter. This makes it more difficult to control with non-selective or pre-seeding herbicides, but late weeds are less competitive in-crop**
- **While seed shedding is variable, barley grass retains enough seeds that harvest weed seed control is likely to be of some value as part of the integrated weed management program**

Background

Barley grass is a weed in the Gramineae family and is widely spread throughout south-eastern Queensland, NSW, Victoria, Tasmania, SA and southern WA. *Hordeum leporinum* is more common to the north of WA and Tasmania (Figure 1). *Hordeum glaucum* is more prevalent in SA and Queensland. However, both species grow in similar areas. In the following text, the scientific name will be used for information regarding a specific species and 'barley grass' will be used for information applicable to both species.

Description

- Barley grass is a winter annual that has peak emergence in autumn and then staggered emergence through winter and spring. Plants mature in late spring and summer.
- Plant height can vary from 12 to 50cm. Leaves are thin (1.5 to 2mm wide) and up to 20cm long, tapering to a point. They have sparse, soft hairs and are usually a paler green than other common grass species (Figure 2).

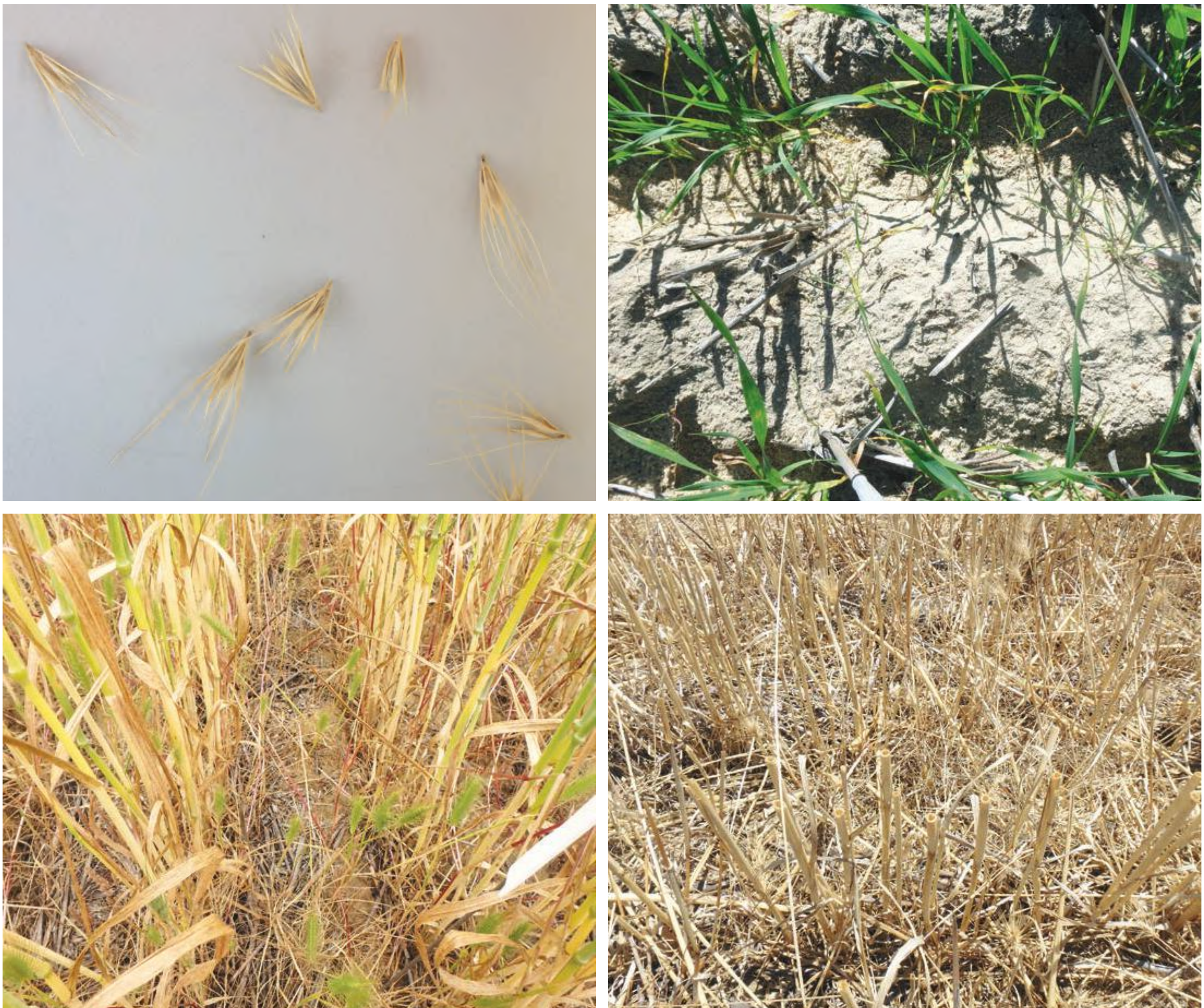
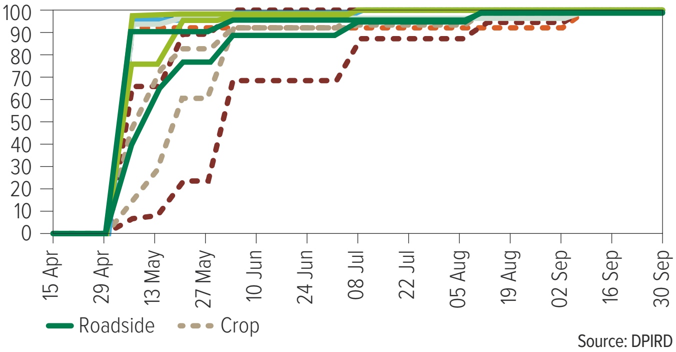


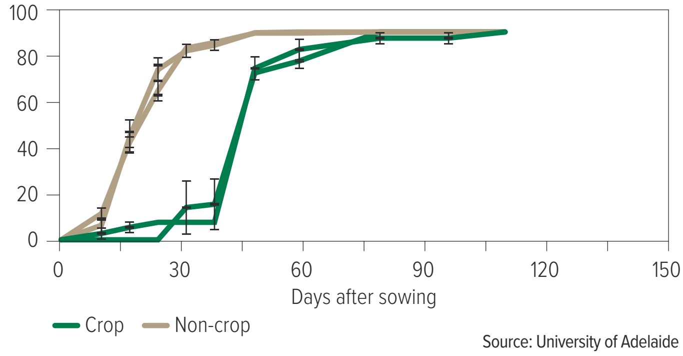
Figure 2: Top left: *Hordeum leporinum* seeds. Top right: *Hordeum leporinum* seedlings. Bottom left: *Hordeum leporinum* mature plants with seed heads in the inter-row of a wheat crop. Bottom right: *Hordeum leporinum* mature seed heads after harvest of the wheat crop. Photos: Catherine Borger (DPIRD)

Figure 4: Differences in seedling emergence patterns between cropped (broken lines) and adjacent fenceline (solid lines) populations of *Hordeum leporinum* collected in 2015 across southern WA and grown from April to September 2016.



Source: DPIRD

Figure 5: Differences in seedling emergence patterns between cropped (green lines) and non-crop (tan lines) populations of *Hordeum glaucum* collected in 2015 across South Australia and Victoria, and grown from April to September 2016. Vertical bars indicate the standard error of the mean.



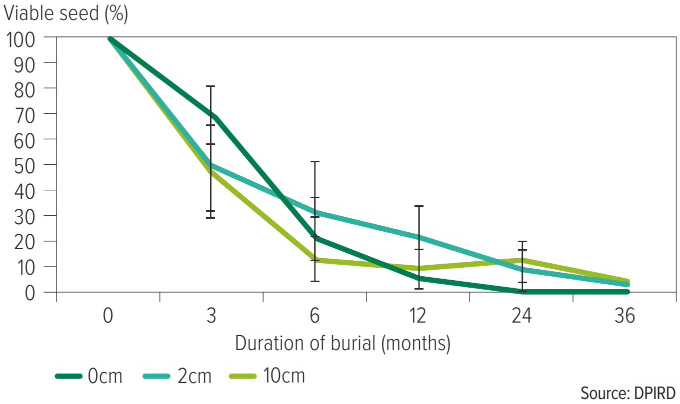
Source: University of Adelaide

- The leaves of barley grass have very prominent auricles (small projection at the base of the leaf) and a membranous ligule (thin outgrowth at the junction of leaf and leafstalk).
- The inflorescence (flower head that develops the seeds) is a cylindrical, spike-shaped panicle that may be partially enclosed by the flag leaf. The spikelet (individual seed-bearing unit on the inflorescence) is made up of three florets (flowers), but only the central one develops a fertile seed (Figure 2, top left). The florets on each side of the spikelet are sterile.
- Each spikelet has a bract on each side (glumes) and hair/bristles (awns) on the top that are rough and sharp. When the plant matures the spikelet sheds as a unit, meaning the single fertile floret and two sterile florets remain joined together.
- It is difficult to tell the difference between *H. leporinum* and *H. glaucum*. *H. leporinum* has larger anthers in the central floret and the anthers are projecting out at anthesis. Anthers are included within the floret in *H. glaucum*. *H. leporinum* also has a looser spikelet than *H. glaucum*. However, identifying these morphological differences requires a magnifying glass and taxonomic skills, and the morphological differences are not always consistent between species.
- The prominent auricles on these two species can be used to separate them from other species of barley grass such as *H. murinum* and *H. hystrix,* which have no auricles.
- Barley grass seedlings may be confused with other grass weeds. A simple way to distinguish seedlings is to pull them up. The seed is often still attached to the root, and on barley grass the distinctive three florets of the seed make it easy to identify.
- Many herbicide labels refer to 'barley grass' without specifying the species. It is common to find multiple barley grass species in the same field. So, from an agronomic point of view, 'barley grass' species need to be managed collectively. However, there are differences between the two species, so growers need to observe their own populations (in terms of emergence time, plant height, seed shedding time) to plan management strategies.
- *H. glaucum* plants are frequently taller than *H. leporinum*, with seed heads reaching the same height as the wheat canopy (Figure 3).
- *H. glaucum* plants may also shed earlier than *H. leporinum*, although there is considerable genetic and seasonal variation in shedding between barley grass populations.

Figure 3: Left: Mature *H. glaucum* plants growing to a similar height as wheat. Right: Plants that shed seed prior to crop harvest at Roseworthy, SA.

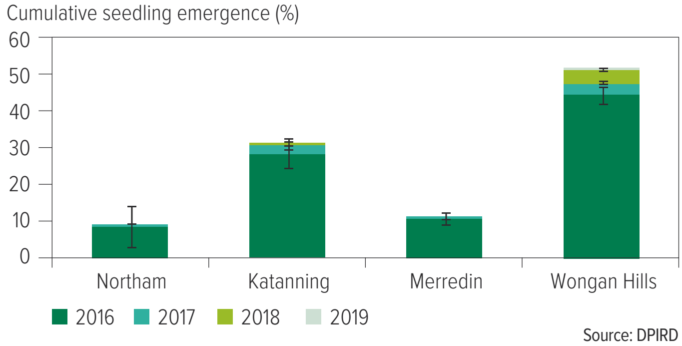
Photos: Gurjeet Gill (University of Adelaide)

Figure 6: Viability of *H. leporinum* seed at 0, 2 or 10cm depth, for 3–36 months. Vertical bars indicate the standard error of the mean.



Source: DPIRD

Figure 7: Cumulative emergence of *H. leporinum* seed placed in the field at various sites in Western Australia, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean.



Source: DPIRD

Why is it a weed?

Barley grass can be a beneficial stock feed early in the season but, as stated, the seeds are rough and can penetrate skin, eyes, mouth and intestinal tract, causing stress in stock. This reduces live-weight gains and carcass and wool quality. Seeds are easily dispersed by stock and are a contaminant of hay and grain.

Competition from barley grass in-crop reduces yield, and early shedding limits the effectiveness of harvest weed seed control. Further, barley grass hosts cereal diseases including take-all, stripe rust, scald and net blotch. There are few effective post-emergent herbicides for barley grass and resistance to herbicides mode of action groups 1 (A), 2 (B), 22 (L) and 9 (M) has been confirmed.

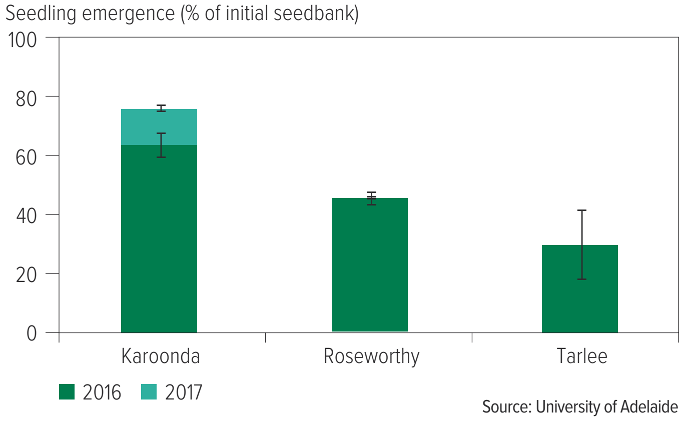
Seed

Dormancy and germination

Barley grass is traditionally considered an early germinating species, providing valuable early feed in pastures following the break of season in autumn. However, on-farm selection has led to later emergence in some areas. In WA, populations of *H. leporinum* seed collected from crop and the adjacent roadside in a range of locations generally had early emergence in April (Figure 4). However, two of the populations from crop had later emergence than matching roadside populations. Populations of *H. glaucum* collected from cropping paddocks and non-crop habitats on the same farms in SA also showed clear differences in seedling emergence pattern (Figure 5). These differences in seedling emergence pattern are related to the differences in seed dormancy and can be responsible for reduced effectiveness of the knockdown herbicides in cropping populations. However, if seedlings emerge late (in May–July), they are likely to be less competitive with the crop.

Cold stratification (chilling seeds to 4°C) led to earlier emergence of *H. leporinum* and *H. glaucum* seed collected from populations in WA and in *H. glaucum* populations from Victoria and SA. Cold conditions enhance the production of gibberellic acid within the seed, a hormone that simulates germination. As climate change increases average temperatures in autumn, emergence of barley grass will be increasingly common in winter rather than autumn.

Figure 8: Cumulative emergence of *Hordeum glaucum* seed placed in the field at three sites in South Australia, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Seedbank persistence

Emergence of multiple *H. leporinum* populations collected from WA and grown in controlled (ideal) conditions was monitored over three years. Seed had adequate moisture and all seeds were planted at 1cm depth. Emergence averaged 63 per cent in year one, 26 per cent in year two and two per cent in year three. Therefore, the seedbank lasted at least three years. By comparison, *H. leporinum* seed left on the soil surface over three years (36 months) had lost viability (germinated or degraded) after 24 months (Figure 6). Seed in the same experiment buried at 2 or 10cm depth retained four per cent viability at three years. Therefore, seedbank degradation is related to seed burial.

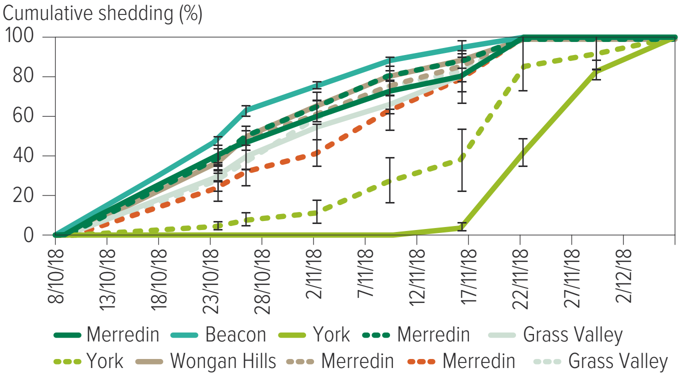
H. leporinum seeds were also placed in field conditions for four years, from April 2016 (Figure 7). In each May the crop seeding process was simulated, which would bury some seed and possibly return buried seed to the soil surface in subsequent years. Again, most emergence occurred in year one, with much lower emergence in year two. Katanning and Wongan Hills, WA, had emergence (0.4 per cent and 3.5 per cent) in year three and only Wongan Hills had emergence in year four (0.1 per cent). It is clear that in field conditions, seeds on the surface degrade more quickly

Table 1: Variation in growing-season rainfall (GSR), start of seed shed and final seed retention at the earliest opportunity of wheat harvest over multiple years at Roseworthy, SA and Wongan Hills, WA. The long-term average GSR is 287mm at Roseworthy and 314mm at Wongan Hills.

Year	Species	Location	GSR (mm)	Start of seed shed (days before harvest)	Seed retention (% of seed-set)
2016	*Hordeum glaucum*	Roseworthy	462	42	8
2017			311	43	7
2018			213	43	60
2019			242	49	13
2016	*Hordeum leporinum*	Wongan Hills	322	22	62
2017			222	17	96
2018			322	0	99

Source: DPIRD and University of Adelaide

Figure 9: Cumulative per cent shedding of barley grass populations from different regions of Western Australia, grown in micro-plots in Northam, Western Australia, in 2018. Populations include both *H. leporinum* and *H. glaucum*, but there was no significant difference between species. Vertical bars indicate the standard error of the mean.



Source: DPIRD

than buried seed. However, the process of crop seeding, where seeds are buried at a depth suitable for emergence and then possibly returned to the surface in subsequent seeding operations, causes the seedbank to decline in two or three years at most sites.

A similar study was undertaken with *H. glaucum* in SA at three field sites (Karoonda, Roseworthy and Tarlee). Consistent with the results from WA, most of the seedlings at these sites emerged in year one (Figure 8). At the site with the highest rainfall (Tarlee), there was no *H. glaucum* emergence in year two, three or four. This indicates that all *H. glaucum* seeds had emerged in year one and the remaining seed had decayed by the second growing season. At Roseworthy (medium rainfall), there was only 0.2 per cent emergence from the initial seedbank in year two and no emergence was observed in years three and four. Karoonda, which has the lowest rainfall out of the three SA sites, showed much greater seedling emergence in year two (12 per cent) than the other two sites. Even at Karoonda, there was no *H. glaucum* emergence observed in years three and four of this study. Therefore, *H. glaucum* seedbank in SA appears to be completely exhausted after two years.

Seed production and dispersal

H. leporinum plants produced eight to 67 seeds per plant, and in the field produced 66 to 877 seeds/m^2. Both *H. leporinum* and *H. glaucum* populations from WA, harvested in 2017 and grown in controlled conditions in 2018, commenced shedding in October. However, some populations did not begin shedding until November (Figure 9). While there were no consistent differences between shedding times of each species, there was considerable variation between individual populations of both species. This variation may result from genetic differences between populations, or from differences in the environments experienced by the maternal plants the seed populations were originally collected from. Clearly, timing of shedding is variable between populations. Further, average height of these populations ranged from 9 to 31cm, again without a consistent difference between the two barley grass species.

Single populations of both species had variable shedding times between years (Table 1). Retention of *H. leporinum* seed at the earliest possible date of harvest ranged from 62 to 99 per cent. However, seed rapidly shed during the harvest period, and seed retained in December ranged from zero per cent in 2016 (as seen for the populations grown at Northam in 2018, Figure 9) to 95 per cent in 2018. Clearly there is substantial environmental variation in shedding times, as well as genetic variation between populations. Studies at Roseworthy, SA, showed consistency in the start of seed shedding in *H. glaucum*. Each year seed shed started 42 to 49 days before the earliest possible crop harvest. However, there were considerable differences in the level of seed retention. In 2018, around 60 per cent of *H. glaucum* seeds were retained until crop harvest, whereas in the other three years seed retention was low and ranged from seven to 13 per cent (Table 1). The high level of pre-harvest seed shedding in *H. glaucum* in SA can also be seen in Figure 3.

Harvest weed seed control (HWSC) may be appropriate for barley grass in some areas. However, the wide variation in shedding times and plant height highlights that growers will need to inspect their own barley grass populations to determine the efficiency and practicality of HWSC. The effectiveness of HWSC may also be impacted by lodging. However, modelling has shown that HWSC can be an effective weed control tactic even for those weed species that shed seed. Capturing 20 to 40 per cent of barley grass seed at harvest is still worthwhile for long-term reduction in the weed seedbank.

Figure 10: Effect of *H. leporinum* density (nil, low, medium or high) on wheat yield at Wongan Hills, Western Australia. Weed density was 61, 112 and 209 plants/m^2 in 2017, 72, 338 and 326 plants/m^2 in 2018 and 78, 156 and 197 plants/m^2 in 2019. Vertical bars indicate the standard error of the mean.

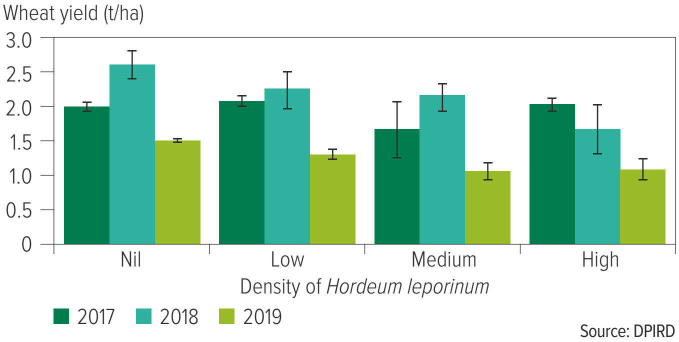
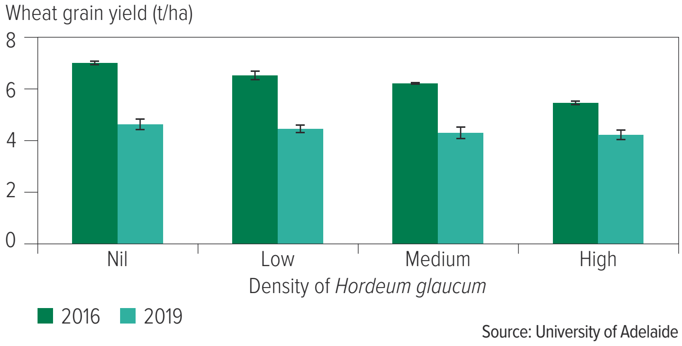


Figure 11: Effect of *Hordeum glaucum* density (nil, low, medium and high) on wheat yield at Roseworthy, South Australia. Weed density was 12, 65 and 285 plants/m^2 in 2016 and 13, 39 and 90 plants/m^2 in 2019. Vertical bars indicate the standard error of the mean.



Competition

The competitive ability of barley grass varied between years and species. *Hordeum leporinum* in WA reduced wheat yield by up to 36 per cent in 2018 and 30 per cent in 2019. By comparison, in 2017 the crop was dry sown into soil with subsoil moisture from summer rainfall. As a result, the crop emerged three weeks earlier than the weed seeds on the soil surface, and *H. leporinum* density of 209 plants/m^2 had no impact on yield (Figure 10). However, it is clear that under most seasonal conditions, high density of barley grass can substantially reduce crop yield.

Consistent with the results obtained in WA, there were clear differences in the yield loss caused by *H. glaucum* in different years in SA. In 2016, good rainfall at the start of the season resulted in rapid seedling emergence in barley grass, which caused a greater reduction in wheat yield than in 2019. The yield loss caused by the highest barley grass density was 22 per cent in 2016 and nine per cent in 2019 (Figure 11).

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

A winter annual that emerges in late autumn and winter and matures in summer.

Photo: Ben Fleet (University of Adelaide)

BEDSTRAW

Galium tricornutum Dandy.

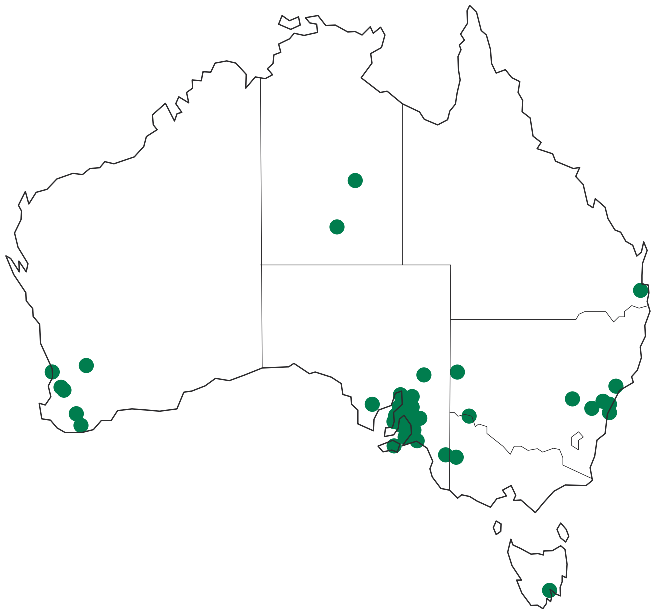
Other common names: three-horned bedstraw, cleavers, rough corn bedstraw.

Synonym: *Galium tricorne* Stokes.

KEY POINTS

- Bedstraw seeds have long-lived dormancy, which can be partially overcome by exposure to cold winter conditions. As a result, bedstraw seeds germinate after an extended exposure to low winter temperatures and seedlings usually emerge during July–August. Delayed seedling emergence in bedstraw allows plants to evade knockdown weed control and early pre-emergence herbicide activity
- The bedstraw seedbank was found to persist for longer than three years in mesh bags. This is consistent with field observations, with seedlings emerging in the fourth year after the placement of seeds in the field. Therefore, growers will need to implement a long-term management strategy to eliminate this species from their cropping fields
- Bedstraw was found to be a moderate competitor in wheat. Its impact on wheat yield appeared to be greater in a wetter growing season (15 per cent yield loss) than in a season with average rainfall (five per cent)
- Most of the seeds produced by bedstraw were retained on the plant until crop harvest (97 per cent). This makes bedstraw an excellent target for harvest weed seed control tactics

Figure 1: *Galium tricornutum* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

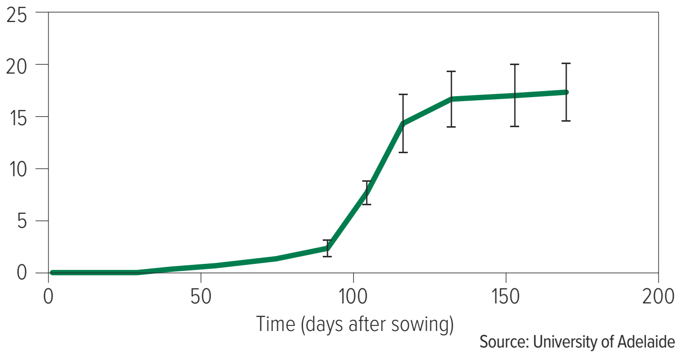
Bedstraw is commonly used as the shortened common name of three-horned bedstraw in Australia. It belongs to the family Rubiaceae and originated in Europe and central Asia. Three-horned bedstraw is present in SA and the Wimmera region of Victoria, where it can be a troublesome weed in crops (Figure 1). It has been a target of an eradication program in WA. A closely related species, cleavers (*Galium aparine*), which has a much larger stature than bedstraw, has been reported from ACT, NSW, SA, Tasmania, Victoria and WA.

Description

- Bedstraw is an annual herb with fine prickles on the stems and leaves that give it a sticky feel.
- It has rings of six to eight leaves that are hairless on the upper surface but have fine spines on the edges.
- It has small white flowers with four petals and flowering usually occurs from July to November.

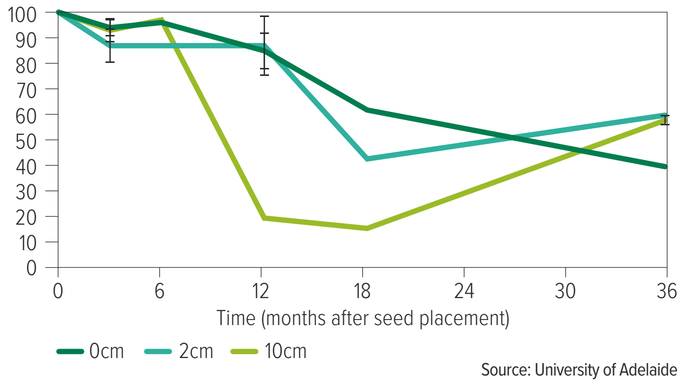
Figure 2: Top left: Bedstraw seeds. Top right: Seedlings with large fleshy cotyledons and first whirl of leaves.
Bottom left: Plants showing small white flowers. Bottom right: Plants growing to a similar height as a wheat crop at head emergence. Photos: Gurjeet Gill (University of Adelaide)

Figure 3: The pattern of seedling emergence of a bedstraw population sown in pots placed outdoors at Roseworthy, SA, in 2016. Seeds were sown on 1 May. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Figure 4: Viability of bedstraw seed at 0, 2 or 10cm depth after burial for up to 36 months. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

- Bedstraw produces paired, globular fruit that are usually in sets of three on short, curved stalks. The stems are prostrate or scrambling and climbing, and square in cross-section.

Why is it a weed?

Bedstraw can be present in field crops in southern Australia, usually at low to moderate densities. There are several effective herbicide options available for its control in cereal crops, but plants can establish over a long period and can be difficult to effectively control in pulse crops. It can spread easily within and between farms as a result of contaminated seed, hay, machinery and livestock. At present, there are no known cases of herbicide resistance in bedstraw. It is a declared plant in WA and subject to legislation.

Seed

Dormancy and germination

Studies undertaken in SA showed seed exposure to light has a strong inhibitory effect on its germination (Chauhan et al. 2006). Therefore, high soil disturbance seeding systems are likely to increase seed germination in bedstraw. Seed germination was also significantly increased by exposure to low soil temperature (5°C). These results help in explaining why seedling emergence is usually observed during the winter months of June–July (Figure 3). As can be clearly seen in Figure 3, bedstraw seedlings were first observed after 60 days. This timing of seedling emergence equates to July–August when night temperatures in winter can be frequently below 4°C. Such cold temperatures would provide the cold stratification stimulus required to break seed dormancy in this weed species. It should also be noted that the cumulative emergence from the seedbank was less than 20 per cent over six months, which fits well with bedstraw's reputation as a persistent weed species.

Seedbank persistence

A study of the seedbank persistence of bedstraw was conducted with a population collected from a cropping field in SA in 2016. Seeds were placed in nylon bags and buried at a depth of 0, 2 and 10cm in a field at Roseworthy. Nylon bags containing seeds were retrieved at different times after burial and assessed for weed seed viability. The overall trend indicated that bedstraw seeds can remain viable in the field for at least three years. At the last retrieval of the field-buried seeds after three years (36 months), 40 to 60 per cent of bedstraw seeds were viable at the three depths of burial (Figure 4).

Seedbank persistence of bedstraw was also investigated by placing them in field conditions at three sites of contrasting rainfall (Karoonda – low rainfall, Roseworthy – medium rainfall, Tarlee – high rainfall) in the cropping zone of SA for four years, from April 2016 (Figure 5). In May each year the crop seeding process was simulated, which would bury some seed, and possibly return buried seed to the soil surface in subsequent years. At all the sites, most seedling emergence occurred in year one (2016) and then steadily declined in subsequent years. More importantly, bedstraw seedlings emerged from the initial seedbank in all four years of this study. Seedling emergence across the sites in year four ranged from 0.2 per cent at Roseworthy to 0.8 per cent at Tarlee. These results clearly highlight the presence of long-term persistence (up to four years) of the seedbank of bedstraw. Clearly growers need to implement effective management tactics against this weed for a number of years to prevent a build-up of its resilient seedbank.

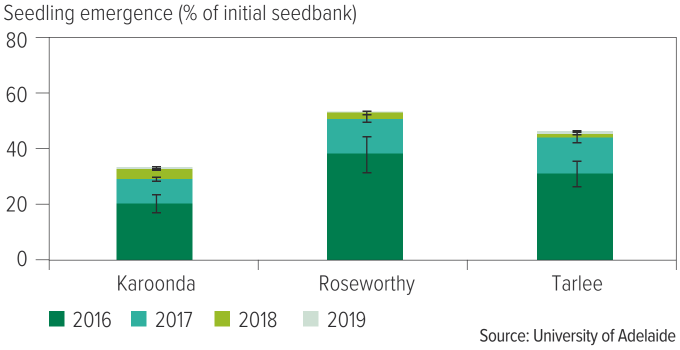
Seed production and dispersal

Like most weed species, bedstraw has the potential to set a large amount of seeds and, as seen earlier, some of these seeds can remain viable in soil for up to four years. Assessments of seed production at Roseworthy in an above-average rainfall season of 2016 showed that bedstraw competing with wheat can produce more than 14,000 seeds/m^2. Seed production averaged around 50 seeds per plant. Such a high seed-set potential in a weed species with long-lived seedbank is a cause for concern. Seed retention in bedstraw at crop harvest was investigated in two contrasting growing seasons at Roseworthy. Growing season rainfall at the site was 61 per cent higher than the long-term average in 2016, whereas rainfall received in 2018 was 26 per cent below the long-term average. However, seed retention in these two contrasting seasons remained high (91 to 99 per cent) and was unaffected by weed density (Figure 6). Therefore, bedstraw appears to be a good target for harvest weed seed control tactics, provided the harvester can separate the crop and weed seeds effectively.

Competition

Field studies in this project at Roseworthy showed bedstraw can grow as tall as wheat during spring, which allows it to intercept light for its growth (Figure 2). However, the negative effect of bedstraw infestation on wheat yield appears to vary considerably between growing seasons. In 2016, Roseworthy received 462mm of rainfall during the growing season, which

Figure 5: Cumulative seedling emergence from bedstraw seeds placed in the field at three sites in SA, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean.



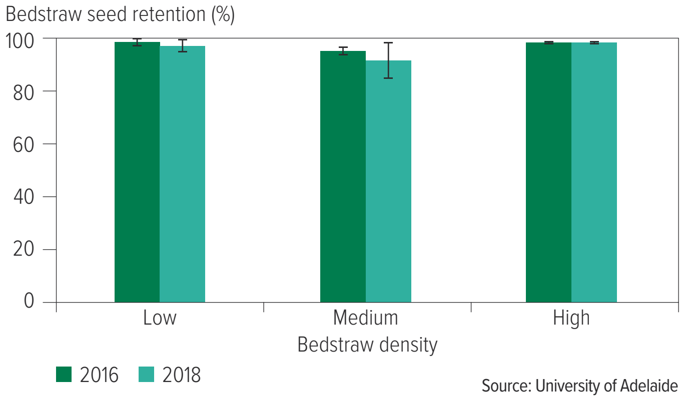
Source: University of Adelaide

was considerably greater than the long-term average of 288mm. In contrast, 2017 received 318mm, which is close to the average for the site. Field trials over these two years showed a much greater wheat yield loss due to bedstraw competition in 2016 than in 2017 (Figure 7). The highest bedstraw density of 170 plants/m^2 reduced wheat yield by more than 1t/ha in 2016 (15.3 per cent), whereas a similar weed density (180 plants/m^2) in 2017 reduced yield by only 0.3t/ha (5.6 per cent). It appears the wetter conditions allow this weed species to grow larger in stature and exert a stronger competitive effect on the crop. Bedstraw could be classified as a moderate competitor with wheat.

KEY CONTACTS

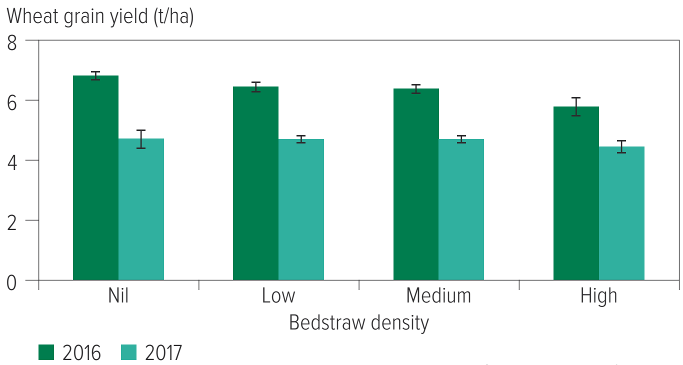
Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

Figure 6: Effect of growing season and bedstraw plant density on its seed retention at crop harvest. Vertical bars indicate the standard error of mean.



Source: University of Adelaide

Figure 7: Effect of bedstraw plant density (nil, low, medium and high) on wheat grain yield in 2016 and 2017 at Roseworthy, SA. Weed density was 14, 47 and 170 plants/m^2 in 2016 and 11, 50 and 180 plants/m^2 in 2017.



Source: University of Adelaide

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A winter annual that emerges in winter, grows throughout winter and spring, and matures in late spring and summer.

Photo: Gurjeet Gill (University of Adelaide)

BIFORA

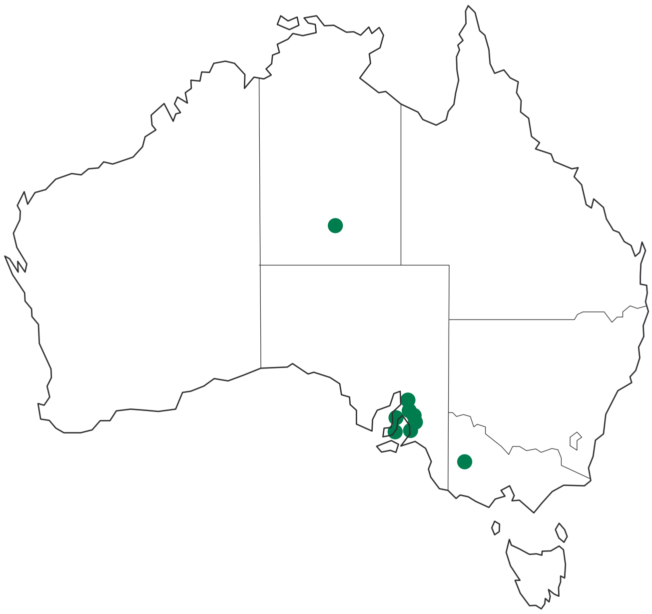
Bifora testiculata (L.) Sprengel.

Other common names: carrot weed, bird's eye.

KEY POINTS

- Bifora is an important weed of pulse crops in SA, where it can be highly competitive and reduce crop yields, as well as downgrade the grain due to seed contamination
- Bifora seeds have long-lived seed dormancy, which can be partially alleviated by exposure to cold winter conditions. Its seedbank was found to persist for four years after the placement of its seed in field soil. Therefore, a long-term management strategy is needed to eliminate this species
- Bifora was a moderate competitor in wheat where it reduced yield by around 10 per cent. In contrast, maximum yield loss in lentils was 25 per cent

Figure 1: *Bifora testiculata* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Bifora is used as the common name because there are no other species of bifora in Australia. Testiculata refers to the testicle-shaped seed capsules. It belongs to the family Apiaceae. Bifora originated in the Southern Europe and Mediterranean region. It is mainly a weed of cropping in SA (Figure 1), where it can be particularly difficult to control in pulse crops. Bifora is a declared pest plant in WA.

Description

- Bifora is an annual hairless herb, 20 to 30cm tall, with striped stems, finely divided leaves and strong smell similar to coriander. In field crops such as wheat, bifora plants can attain a similar height as the crop (Figure 2 bottom left).
- Bifora seedlings have two spear-shaped cotyledons (Figure 2 top right). Leaf blades are lobed almost to the midrib with three segments and angular lobes that are finely toothed.
- Flowers are white with five petals. Seeds remain enclosed in the skull-like capsule, cream or whitish yellow with three darker stripes on the back. Capsules are spherical to tear shaped, 4mm diameter with two holes near the beak (Figure 2 top left).

Why is it a weed?

In southern Australia bifora can be a persistent weed of crops and can constrain rotational options, particularly the use of pulse crops. It can spread easily within and between farms as a result of contaminated seed, hay, machinery and livestock. In cereals, there are several effective herbicide options available to control bifora but it is often able to produce some seed late in the growing season. This weed species is difficult to control in pulse crops, where herbicide options available are less effective than for cereals. At present, there are no known cases of herbicide resistance in bifora.

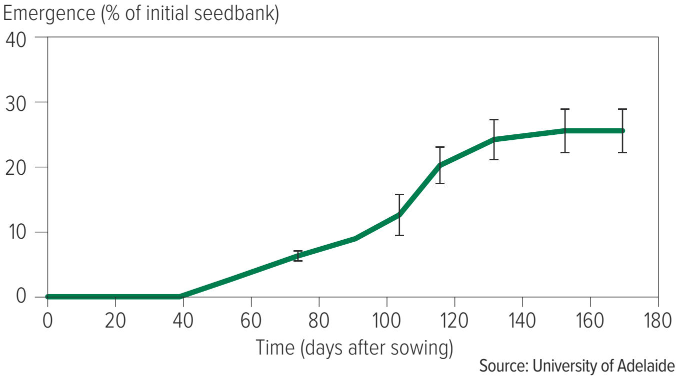
Seed

Dormancy and germination

Germination of bifora seeds is stimulated by the exposure to cold winter temperatures (cold stratification). Therefore, seedling emergence in bifora tends to start in late autumn and continue right through the winter months. In the example shown in Figure 3, seedling emergence in bifora was first observed at 54 days after sowing when ambient night temperatures had dropped to low levels in winter. Therefore, knockdown herbicide treatments before

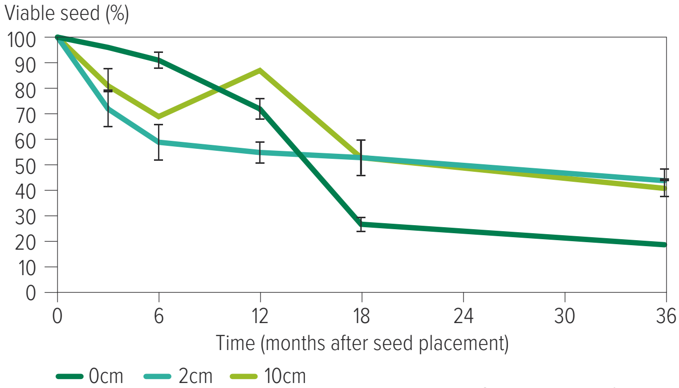
Figure 2: Top left: Bifora seeds. Top right: Seedlings. Bottom left: Plants standing tall in a wheat crop at head emergence. Bottom right: Bifora infestation in a faba bean crop at Riverton, SA. Photos: Gurjeet Gill (University of Adelaide)

Figure 3: The pattern of seedling emergence of a bifora population sown in pots placed outdoors at Roseworthy, SA, in 2016. Seeds were sown on 22 April. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Figure 4: Viability of bifora seed at 0, 2 or 10cm depth after burial for up to 36 months. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

crop sowing tend to provide little control of bifora populations. It should also be noted that only about 30 per cent of the bifora seed produced plants in year one, which means the remaining seedbank is likely to cause weed infestations in subsequent years.

Seedbank persistence

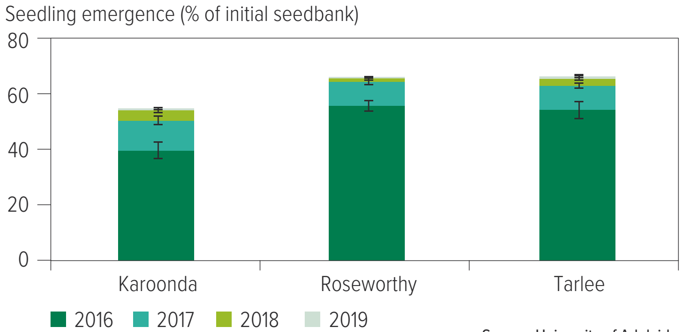
A study of seedbank persistence of bifora was conducted with a population collected from the Yorke Peninsula of SA. Seeds were collected in late 2016 and placed in nylon bags, which were placed at different depths in a field at Roseworthy in 2017. Sample bags were retrieved from the field and the viability of bifora seeds was assessed in the lab. There was a high level of seedbank persistence evident in this study (Figure 4). Seed viability at the soil surface (0cm) after 12 months was 72 per cent, which reduced to 27 per cent after 18 months and 19 per cent after 36 months. Viability of buried seeds was consistently greater than the surface seeds. Even after 36 months, 44 per cent of bifora seeds were viable at 2cm and 41 per cent at 10cm. These results suggest burial will increase the seedbank life of bifora and the seedbank of this species can easily persist for more than three years.

Persistence of bifora seeds was also investigated by placing them in field conditions at three sites for four years, from April 2016 (Figure 5). In each May the crop seeding process was simulated, which would bury some seed and possibly return buried seed to the soil surface in subsequent years. At all the sites, most seedling emergence occurred in year one (2016) and then steadily declined in subsequent years. More importantly, bifora seedlings emerged from the initial seedbank in all four years of this study. Seedling emergence across the sites in year four ranged from 0.3 per cent at Roseworthy to 0.8 per cent at Tarlee. These results clearly highlight the long-term persistence of the seedbank of bifora.

Seed production and dispersal

Bifora can be a prolific seed producer, especially in short-statured and less competitive crops such as lentils. In a field trial at Roseworthy in 2019, 40 plants/m^2 of bifora produced only 116 seeds/m^2 in wheat. In contrast, the similar plant density of bifora produced 4100 seeds/m^2 in a crop of lentils. These results highlight the large increase in bifora infestation after a crop of lentils or vetch where herbicide options available are less effective than those used in cereals. In contrast to the drier growing season of 2019 (242mm), bifora produced 4768 seeds/m^2 in wheat in 2016 (462mm), which had much higher growing season rainfall. Therefore, seed production in weeds is highly dependent on the growing season rainfall, as is the case with crop grain yields. Seed shedding in bifora was observed in late October and November each year. The level of seed retention varied considerably between the growing seasons. For example, in the high-rainfall year of 2016, 50 per cent of bifora seeds were retained on the plant until wheat harvest. In contrast, in the drier year of 2017 only 20 per cent of bifora seeds were retained until crop harvest. Therefore, the effectiveness of harvest weed seed control (HWSC) tactics is likely to vary considerably between the growing seasons. The effectiveness of HWSC will also be affected by the separation of bifora seed from crop grain. It can be quite difficult to separate bifora seeds from lentil grain, where it can be a regular contaminant in some areas in SA.

Figure 5: Cumulative emergence of bifora seeds placed in the field at three sites in SA, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean of six replicates.

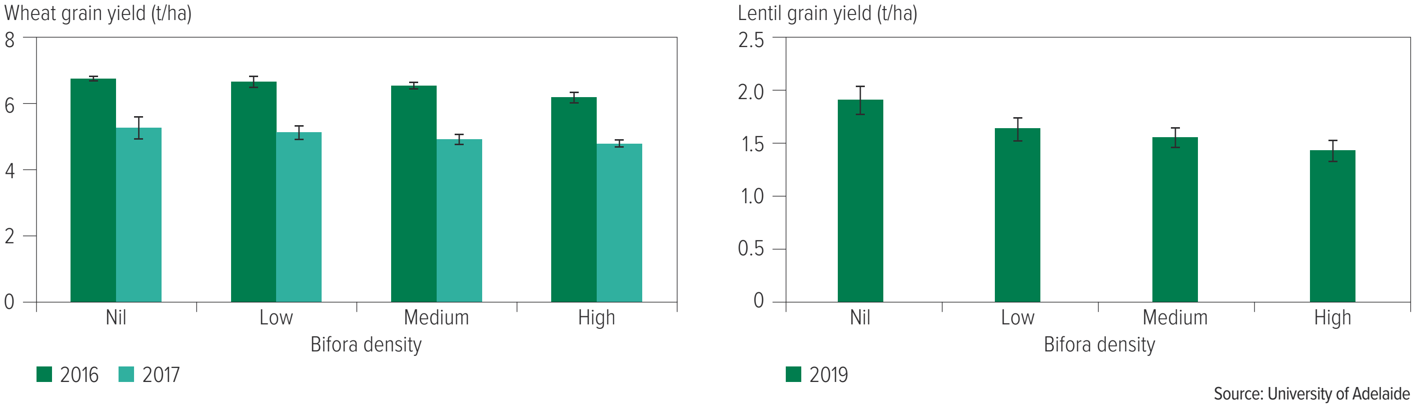


Source: University of Adelaide

Competition

Field studies at Roseworthy, SA, showed bifora could grow tall in a competitive wheat crop but the reduction in wheat grain yield was usually less than 10 per cent (Figure 6 left). Therefore, bifora appears to be a moderately effective competitor in wheat. However, bifora was more effective in competing with lentils, where similar weed densities reduced grain yield by 25 per cent (Figure 6 right). This difference in the competitive ability between wheat and lentils is consistent with the shorter stature and lower crop vigour of lentils than wheat.

Figure 6: Effect of bifora plant density (nil, low, medium and high) on wheat (left) and lentil (right) grain yield at Roseworthy, SA. Weed density was 16, 78 and 290 plants/m^2 in 2016, and 4, 22 and 47 plants/m^2 in 2017. Bifora density in lentils in 2019 was 4, 8 and 52 plants/m^2. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

Mature bladder ketmia plant in a mungbean crop.

Photo: Bhagirath Chauhan (University of Queensland)

BLADDER KETMIA

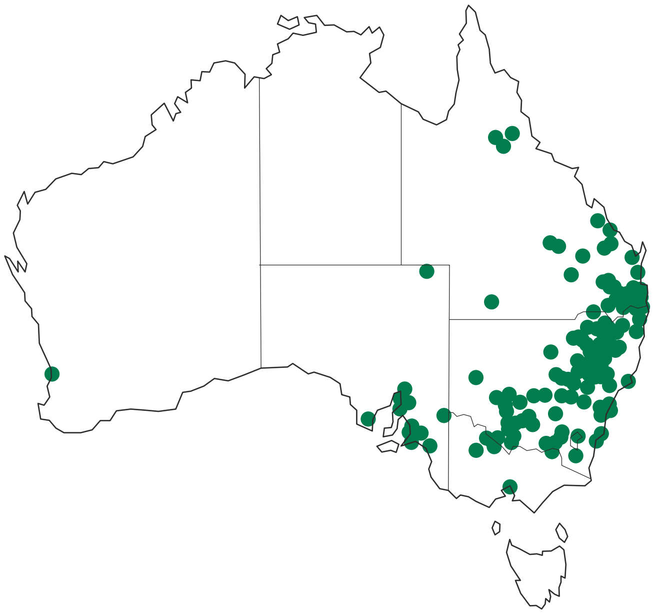
Hibiscus tridactylites L.

Other common name: flower-of-an-hour.

KEY POINTS

- Bladder ketmia seeds are highly dormant, which is mainly due to a hard seed coat
- The level of seedbank persistence is very high; 75 per cent of seeds were viable at 10cm after 3.5 years. Burial is likely to increase seedbank persistence
- Bladder ketmia at 43 to 52 plants/m^2 reduced mungbean yield by 65 per cent
- Seed production of bladder ketmia is high, with studies showing it produced up to 21,000 seeds/m^2
- Harvest weed seed control potential is moderate due to seed retention being just over 55 per cent

Figure 1: *Hibiscus tridactylites* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Bladder ketmia is an annual or biennial broadleaf weed of the Malvaceae family. It has established increasing levels of infestation across agricultural regions of Australia, particularly in Queensland and NSW (Figure 1).

Description

- A bladder-like calyx of 10 to 15mm in diameter contains an abundant number of dark brown, hairless and granular seeds of 2 to 3mm (Figure 2).
- Two smooth and thick cotyledons with round tips are covered in sparse hairs that are directed towards an indented base.
- At maturity, stems are broad and erect, branching between 300 and 1500mm in height. These feature glossy green palmate leaves of 20 to 75mm in length with narrow, deeply lobed tips and edges with a red trim.
- Solitary yellow to cream flowers of 15 to 25mm are purple at their base.
- Can be confused with prickly paddy melon, although this species has cotyledons with less distinct veins, unbranched stems, smaller leaves that are usually a darker green with fewer lobes, and much smaller fruit with soft spines.

Why is it a weed?

Adaptability to environmental conditions of temperature, salinity and water availability have made bladder ketmia an increasingly problematic weed in Australian summer crops. It is closely related to cotton, which makes it difficult to control in cotton cropping systems. Bladder ketmia is a prolific seed producer and a competitive weed in pulses, including soybeans and mungbeans. It has shown increasing levels of tolerance towards glyphosate.

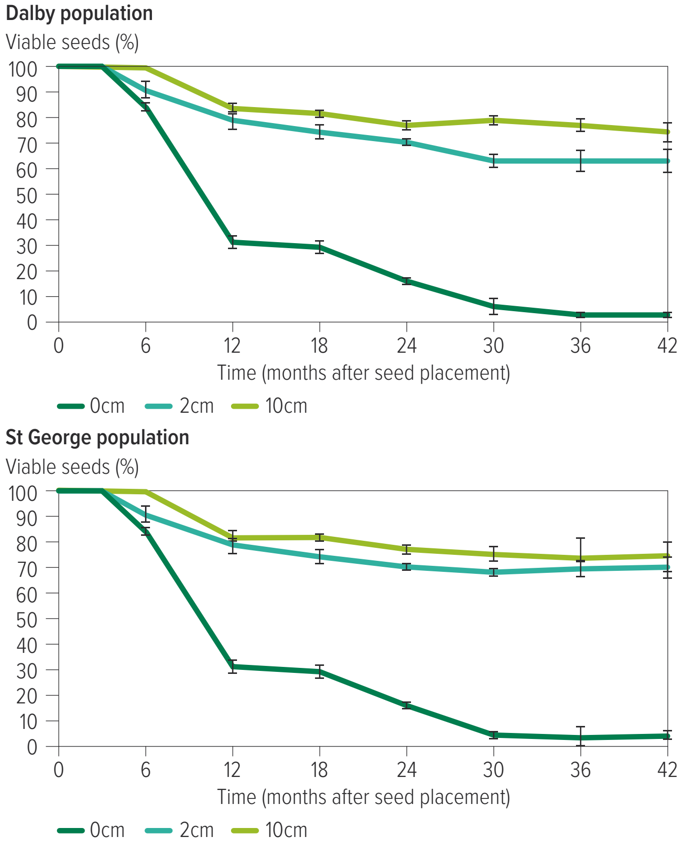
Seed

Dormancy and germination

Germination rates of fresh seeds of bladder ketmia were three to seven per cent; however, seed treatment with hot water resulted in up to 85 per cent germination, suggesting physical (hard seed

Figure 2: Top left: Bladder ketmia seeds. Top right: Bladder ketmia plants in a mungbean field. Bottom left: Bladder ketmia seedlings. Bottom right: Bladder ketmia flower. Photos: top left and top right: Bhagirath Chauhan (University of Queensland). Bottom left: Bruce Wilson. Bottom right: John Hosking.

Figure 3: Viability of two populations (Dalby and St George) of bladder ketmia seed on the soil surface or buried at a depth of 2 or 10cm over three to 42 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland

coat) dormancy in this species. A shallow burial (1 to 2cm) increases its seedling emergence and seedlings could emerge from seeds buried as deep as 8cm.

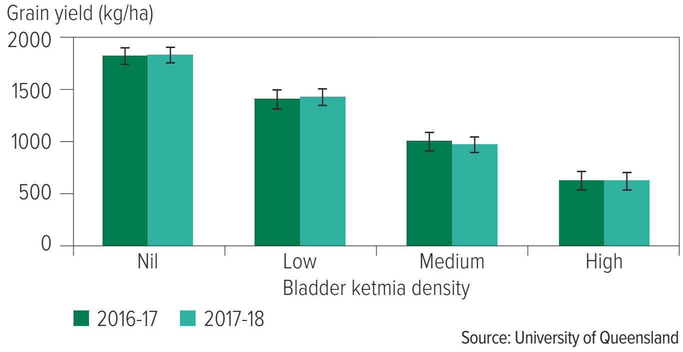
Seedbank persistence

A study on the seedbank persistence of bladder ketmia was conducted using two populations collected from Dalby (higher rainfall) and St George (lower rainfall) in Queensland. Seeds were collected in 2015 and placed in nylon bags, which were then placed at different depths in a field at Gatton, Queensland. For both populations, a high level of seedbank persistence was evident in this study (Figure 3). Persistence at the soil surface (0cm) after 12 months was 31 per cent, which reduced to 16 per cent after 24 months and three to four per cent after 36 months. Even after 42 months, three to five per cent of seeds were still viable on the soil surface. Viability for buried seeds was much greater than the surface seeds. Even after 42 months, 70 and 75 per cent of seeds were viable at 2 and 10cm, respectively. These results suggest burial will increase the seedbank life of bladder ketmia.

Seed production and dispersal

At 10 plants/m^2, bladder ketmia produced 6900 to 8420 seeds/m^2. At a higher density, it produced 17,800 and 21,200 seeds/m^2 in 2016-17 and 2017-18, respectively, with corresponding seed retention rates of 61 and 56 per cent. Despite this level of seed dispersal, harvest weed seed control for management in short-duration crops may be viable. High seed-set potential in a weed species with a long-lived seedbank contributes to its seriousness as a weed.

Figure 4: Effect of bladder ketmia density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high bladder ketmia density was 12, 30 and 43 plants/m^2 in 2016-17, and 15, 32 and 52 plants/m^2 in 2017-18.



Source: University of Queensland

Competition

Bladder ketmia is a strong competitor in mungbeans. Compared with the weed-free plots, a low bladder ketmia density resulted in a mungbean grain yield loss of 22 per cent (Figure 4). These losses increased to 65 to 66 per cent at high weed density (43 to 52 plants/m^2). Bladder ketmia emerged at 11 to 12 days after sowing (DAS) and mungbean emerged at seven to eight DAS.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A winter annual that emerges in autumn, grows throughout winter and spring, and matures in late spring and summer.

Photo: Catherine Borger (DPIRD)

BROME GRASS

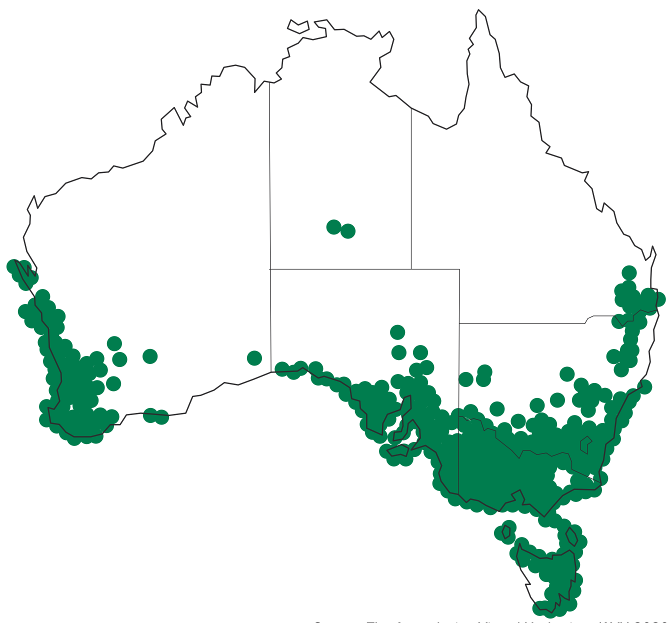
Bromus diandrus Roth

Other common names: great brome and ripbut brome (*Bromus diandrus*) are sometimes recognised as a separate species from rigid brome (*Bromus rigidus* Roth). However, some taxonomists refer to just the one species. It is not possible to tell them apart in the field. Brome grass has been used as the preferred common name here.

KEY POINTS

- Brome grass is widely distributed across southern Australia where it tends to prefer medium to lighter-textured soils. It is now ranked as the third most damaging weed to Australian grain producers in the southern region, with annual revenue loss estimated at $21 million
- The brome grass seedbank was found to persist for three years, which means growers need to develop multi-year management programs
- Brome grass can be highly competitive. At high weed densities in WA trials, brome grass reduced wheat yield by more than 50 per cent

Figure 1: *Bromus diandrus* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Brome grass (*Bromus diandrus* Roth) belongs to the Gramineae family and is widely naturalised in southern Australia (that is, in south-eastern Queensland, throughout NSW and Victoria, in the ACT and Tasmania, in large parts of SA, in the southern parts of the NT, and in the southern and western parts of WA). It is also known as ripgut brome.

Description

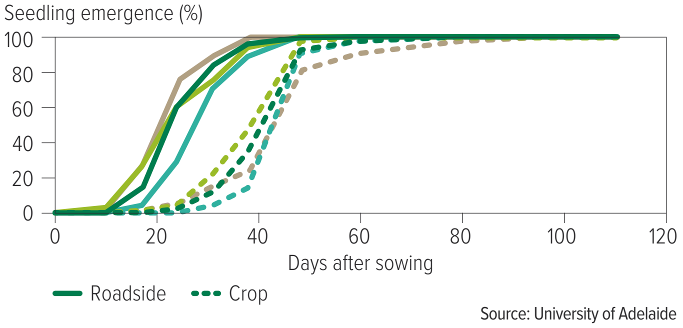
- A brome grass adult plant can grow up to 1m in height with hairy and rough leaves. The ligule (thin outgrowth at the junction of the leaf and leafstalk) is prominent, membranous, white, and with a fringe of hairs.
- The wide panicle (seed head) nods like that of an oat plant, and it bears a large, splayed spikelet with a very long awn that can exceed 5cm in length.
- The easiest way to tell brome grass from other grass species is the reddish colour or red-purple veins at the base of the seedlings. The mature leaves and seed heads also turn red as they senesce (see Figure 2), before turning a similar brown colour to the mature crop.

Why is it a weed?

Brome grass has increased in prevalence in the southern and western grain cropping regions of Australia, where it has been ranked as the third most important weed in terms of the economic impact (Llewellyn et al. 2016). Increased abundance partially results from the adoption of earlier sowing or even dry sowing. Increased prevalence in crops also results from the adoption of no-till seeding systems. Brome grass has developed delayed emergence, due to the strong inhibitory effect of light on seed germination. This means seeds on the soil surface remain ungerminated until after they are buried by crop sowing. This prevents seedlings from being killed by seed-bed preparation (that is, non-selective or knockdown

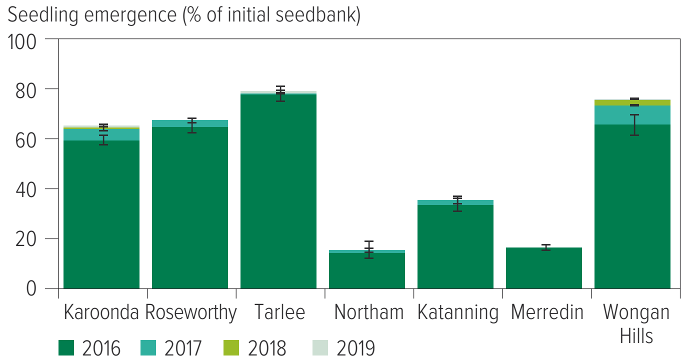
Figure 2: Top left: Brome grass seeds. Top right: Seedlings. Bottom left: Tillering plants in the inter-row of a wheat crop. Bottom right: Mature seed head above a wheat crop. Photos: Catherine Borger (DPIRD) and Ben Fleet (University of Adelaide)

Figure 3: Differences in seedling emergence pattern between cropped (broken lines) and adjacent fenceline (solid lines) populations of brome collected in 2015 across south-eastern Australia. Solid and dashed line of the same colour represent in-crop and non-crop brome grass populations collected from the same location.



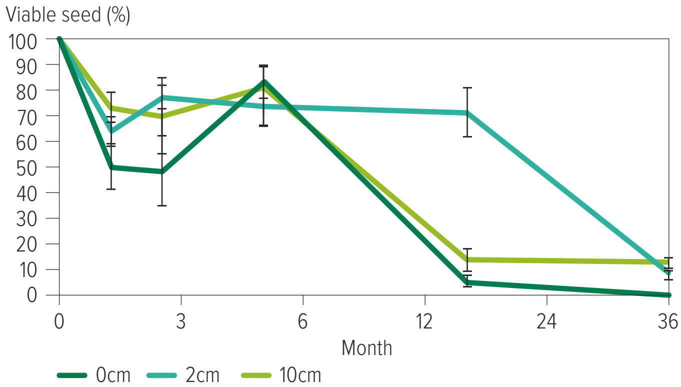
Source: University of Adelaide

Figure 4: Emergence of brome grass seedlings from the initial seedbank established in the field in the summer of 2015-16 at sites in SA (Karoonda, Roseworthy and Tarlee) and WA (Northam, Katanning, Merredin and Wongan Hills). Vertical bars indicate the standard error of the mean.



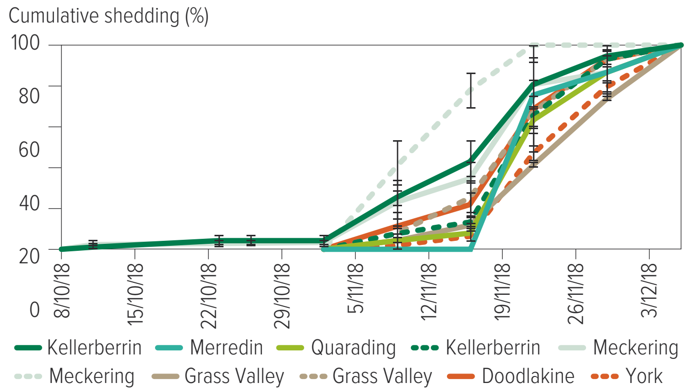
Source: University of Adelaide and DIPRD

Figure 5: Viability of brome seeds at 0, 2 or 10cm depth, for 3-36 months at Northam WA. Vertical bars indicate the standard error of the mean.



Source: DPIRD

Figure 6: Cumulative percentage shedding of brome grass populations from different regions of WA, grown in micro-plots in Northam in 2018. Vertical bars indicate the standard error of the mean.



Source: DIPRD

herbicides). This feature of brome grass ecology helps to explain why it has proliferated under no-till, where seeds remain on the soil surface until being buried by the sowing pass, which would remove the inhibitory effect of light.

Brome grass tends to contaminate crop grain at harvest and can lead to financial penalty if the level of contamination exceeds the prescribed limit. Grain contamination can also lead to reintroduction of brome grass into paddocks at seeding unless the grain used for seeding is professionally cleaned. Herbicide resistance has been confirmed to mode of action groups 1 (A), 2 (B) and 9 (M).

Seed

Dormancy and germination

On-farm selection for increased seed dormancy has also been responsible for increasing occurrence of this weed species in crops. Research undertaken has clearly shown higher levels of seed dormancy in brome grass populations collected from cropping fields than those from non-crop situations, such as fencelines or roadsides, in SA. As shown in Figure 3, brome populations collected from cropping fields established much later than their counterparts collected from non-crop habitats at the same location. This highlights the impact of management practices used in the cropping fields (for example, knockdown herbicides and tillage) on selecting for individuals with greater seed dormancy. By comparison, the same study in WA only identified one crop population with delayed emergence compared with the adjacent roadside population. Possibly as management intensifies in WA, more populations will develop delayed emergence as the SA populations have done.

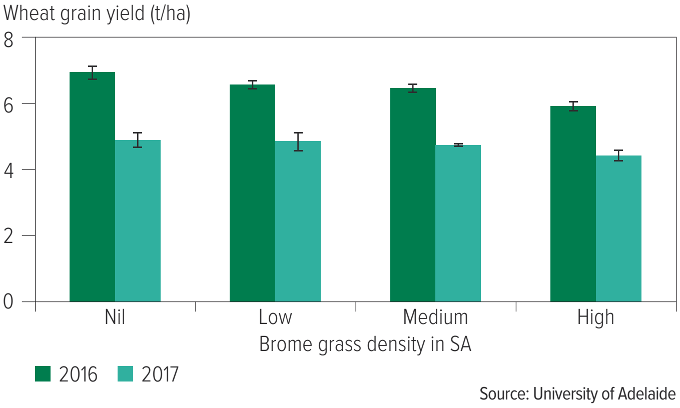
Seed of highly dormant populations of brome grass had increased germination after chilling (that is, exposure to 5°C). Cold temperatures have been shown to increase gibberellic acid production within the seed, a hormone known to stimulate germination. In the field, this means the dormant brome grass requires not only moisture, but also a period of colder temperatures to germinate. Therefore, germination of most of the seedbank of brome would not occur until cooler, moist conditions in late autumn–early winter, allowing it to evade early season weed control tactics (for example, knockdown herbicides).

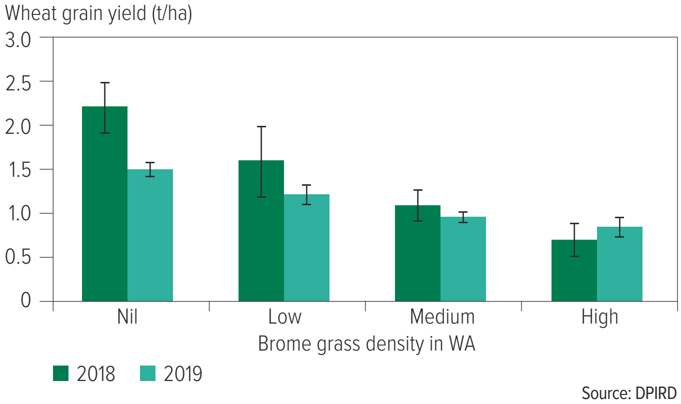
Seedbank persistence

Weed species that develop a long-lived seedbank are more difficult to manage and require implementation of effective weed control tactics throughout the rotation. Field studies at three different locations over four years showed that the brome grass seedbank can persist for three years, even though most of the seedling establishment occurs within the first year after seed dispersal (Figure 4). These results are consistent with previous studies, which showed that a three-year effective management program can deplete field populations of this weed species.

Research at Karoonda, SA, with sandier soils and a lower rainfall showed greater persistence of the initial seedbank into the second and third year than sites with greater rainfall and heavier-

Figure 7: Effect of brome grass density on wheat yield at Roseworthy, SA, in 2016 and 2017 (left). Low, medium and high brome density was 8, 62 and 195 plants/m² in 2016, and 6, 23 and 57 plants/m² in 2017. Effect of brome grass density on wheat yield at Wongan Hills, WA, in 2018 and 2019 (right). Low, medium and high brome density was 289, 438 and 446 plants/m² in 2018, and 53, 99 and 140 plants/m² in 2019. Vertical bars indicate the standard error of the mean.





textured soils (Roseworthy and Tarlee, SA). By comparison, sites in WA had variable emergence. Katanning and Wongan Hills, WA, had higher emergence in both year one and two. Merredin and Northam had high seed degradation and low emergence in all years. These results highlight the need for growers to implement multi-year weed management programs for brome grass. These results are consistent with previous findings, which indicated around 80 per cent depletion of the seedbank per year (Kleemann and Gill, 2009). Seed decay rate was somewhat faster in SA when seeds were buried in mesh bags, where all brome seeds had decayed within 18 months. In WA, seeds in mesh bags on the soil surface degraded after two years, but seed buried at 2 or 10cm remained viable over three years (Figure 5).

Seed production and dispersal

In 2019 at Roseworthy, SA, brome grass produced four times more seeds in lentils (8352 seeds/m^2) compared with wheat (2176 seeds/m^2) under similar infestations (70 to 72 plants/m^2). The number of seeds produced per panicle appeared most important to seed-set by brome grass, as significantly fewer seeds were produced in wheat (27 ± 4 seeds/panicle) than lentil (70 ± 6 seeds/panicle) under heavy brome infestation. In Wongan Hills, WA, brome grass in wheat produced two to 410 seeds/plant, and 3484 to 67,975 seeds/m^2, at a plant density of 60 to 1173/m^2. Seed production by brome grass varies considerably between growing seasons depending on the rainfall received and soil fertility.

The effectiveness of harvest weed seed control (HWSC) tactics is highly dependent on the level of weed seed retention on the plant until harvest. In WA, brome grass populations from different locations grown in micro-plots at Northam in 2018 had variable shedding, with some populations shedding as early as mid-October and some populations retaining seed until mid-November (Figure 6).

In field studies at Roseworthy, SA, brome grass plants started to shed seeds 14 to 26 days before wheat reached 12 per cent grain moisture content (that is, harvest ready) and at Wongan Hills, WA, plants started to shed seed eight to 17 days before the earliest possible harvest (Table 1). There was an extremely large seasonal variability in amount of seed retained up to crop harvest (20 to 91 per cent). Therefore, the effectiveness of HWSC on brome grass is likely to be quite variable between growing seasons. Lodging of brome grass panicles to below the header cutting height (15cm) was also observed in most seasons in SA, but in WA the crop was sufficient to hold the heads at canopy height. Lodging does often occur in brome grass and would also reduce the effectiveness of HWSC tactics.

Modelling of HWSC for brome grass indicates that even low levels of seed capture and destruction at harvest could substantially reduce the weed seedbank in the long term (Table 2). In a six-year modelled rotation of wheat/wheat/lentil/wheat/wheat/lentil at Wongan Hills, WA, no HWSC (normal harvest with one per cent of seed caught) allowed the soil seedbank to increase from 319 seeds/m^2 after harvest in 2011 to 10,954 seeds/m^2 in 2016. Removing as little as 20 per cent of the brome seed in the model through HWSC reduced the final weed seedbank to 5925 seeds/m^2 in 2016. If HWSC removed 60 per cent of the brome grass seeds, the seedbank declined over six years to 86 seeds/m^2. Since the field data show that brome grass seed retention ranges from 20 to 91 per cent at harvest (Table 1), it is likely that HWSC is a valuable weed management tactic for brome grass.

In the field trials in SA and WA, there was a large amount of wheat grain contamination with brome grass seed each year. Therefore, improvements in harvest technology are needed to separate brome grass seeds from the grain fraction. This is particularly important to stop the spread of potentially resistant brome grass populations, if growers seed fields with contaminated grain. Improved separation of brome grass seed from crop grain would also minimise financial penalties for growers from violating the grain contamination standards.

Competition

Studies in this project showed the highest density of brome grass reduced wheat yield by more than 1t/ha in 2016 and around 0.5t/ha in 2017 (Figure 7). The lower crop yield loss in 2017 was associated with the presence of a lower weed density (195 plants/m^2 in 2016 compared with 57 plants/m^2 in 2017). In WA, brome grass at increasing densities caused large reductions in wheat yield at Wongan Hills. Much greater wheat yield reductions by brome grass at Wongan Hills than at Roseworthy may be related to the higher weed densities and the presence of lighter soil texture at Wongan Hills, which is the preferred soil type for this weed species.

Table 1: Variation in growing-season rainfall (GSR), start of seed shed and final seed retention at the earliest opportunity of wheat harvest over multiple years at Roseworthy, SA and Wongan Hills, WA. The long-term average GSR is 287mm at Roseworthy and 314mm at Wongan Hills.

Year	Location	GSR (mm)	Start of seed shed (days before harvest)	Seed retention (% of seed-set)
2016	Roseworthy	462	14	70
2017		311	21	20
2018		213	26	91
2019		242	26	40
2016	Wongan Hills	322	8	37
2017		222	17	72
2018		322	12	54

Source: University of Adelaide and DPIRD

Table 2: The total number of brome seeds/m^2 in the soil seedbank on 1 December of each year (that is, the day after crop harvest in each year of the six-year wheat/wheat/lentil/wheat/wheat/lentil scenario), following harvest weed seed control of 1%, 20%, 40%, 60%, 80% and 100% of the seed. The starting density of the weed seedbank was 100 seeds/m^2. Harvest weed seed control of one per cent is a normal harvest.

Year	1%	20%	40%	60%	80%	100%
2011	319	266	210	143	125	42
2012	2709	1890	1179	309	247	13
2013	1831	1197	692	209	168	5.2
2014	5611	3279	1593	487	350	1.4
2015	18,210	9997	4204	266	191	0.7
2016	10,954	5925	2378	86	59	0.1

Source: DPIRD

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

A summer annual weed species that continues to grow and set seed as long as summer moisture is available.

Photo: Catherine Borger (DPIRD)

BUTTON GRASS

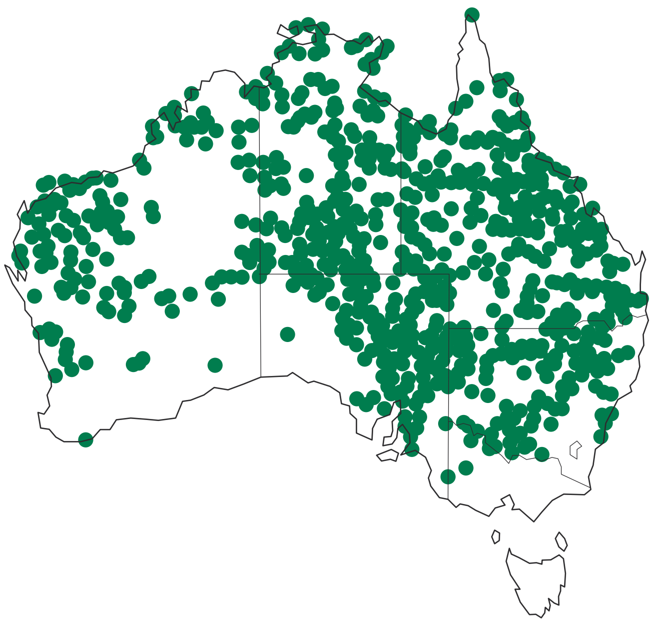
Dactyloctenium radulans (R.Br.) P.Beauv.

Other common name: finger grass.

KEY POINTS

- This nationally distributed native grass has a short-lived seedbank where adequate moisture allows seed germination
- In summer crops, this species has a consistently high impact on crop yield
- In the summer/autumn fallow of southern Australia, this summer annual has a smaller impact on yield, and in some regions may be a beneficial pasture forage species

Figure 1: *Dactyloctenium radulans* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Button grass is a weed in the Poaceae family. This native species is found throughout Australia, with the exception of Tasmania (Figure 1).

Description

- Button grass grows semi-erect, up to 40cm tall, with spreading branches forming leafy tufts.
- The grass-like leaves are approximately 8cm long and 2 to 6mm wide at the base, tapering to a point. Leaves are flat and may be covered in hairs. The leaf edges are often wrinkled or fringed, with 1.5 to 2mm long hairs.
- A single plant can form up to 45 primary tillers. The tiller stems are slender, smooth, hairless, and often bend at the nodes. Plants have both prostrate and erect tillers.
- The prostrate tillers develop roots at the node and branch into seven to eight secondary tillers; this allows a single plant to spread over an area of several metres, like a lawn.
- The plant develops two to three seed heads on the end of each tiller, whereas other weedy grass species have one seed head per tiller.
- The seed head has two to 11 compact spikes in a finger-like arrangement. Each spike is 5 to 13mm long and holds multiple spikelets with five to 11 seeds, and each spike falls intact from the plant.
- Seeds are like small brown grains of sand less than 1mm long and hard.
- Button grass can be confused with other summer grasses (*Digitaria* species).

Why is it a weed?

Button grass can tolerate a wide range of climates and soil types, as indicated by the very broad incidence highlighted in Figure 1. It is favoured by no-till farming systems, so has become increasingly prevalent. In eastern and northern Australia button grass competes directly with summer annual crops to reduce yield. Summer weeds in southern and western Australia can use

Figure 2: Top left: Button grass seeds. Top right: A young plant. Bottom left: Seed heads with spikes. Bottom right: Button grass infesting a mungbean crop. Photos: Catherine Borger and Abul Hashem (DPIRD) and Bhagirath Chauhan (University of Queensland)

Figure 3: Button grass emergence over five months at Merredin, WA, from seed on the soil surface or buried to a depth of 2cm. Vertical bars indicate the standard error of the mean.

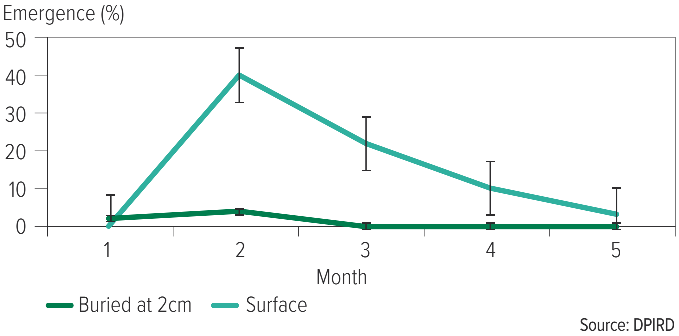


Figure 4: Cumulative emergence of button grass (as a percentage of total weed seeds planted) at three locations in WA from 2016 to 2019. Vertical bars indicate the standard error for the mean.

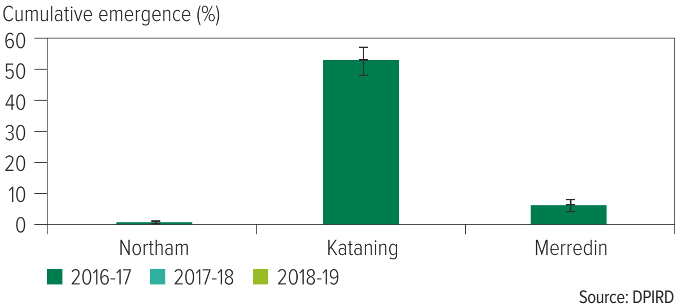
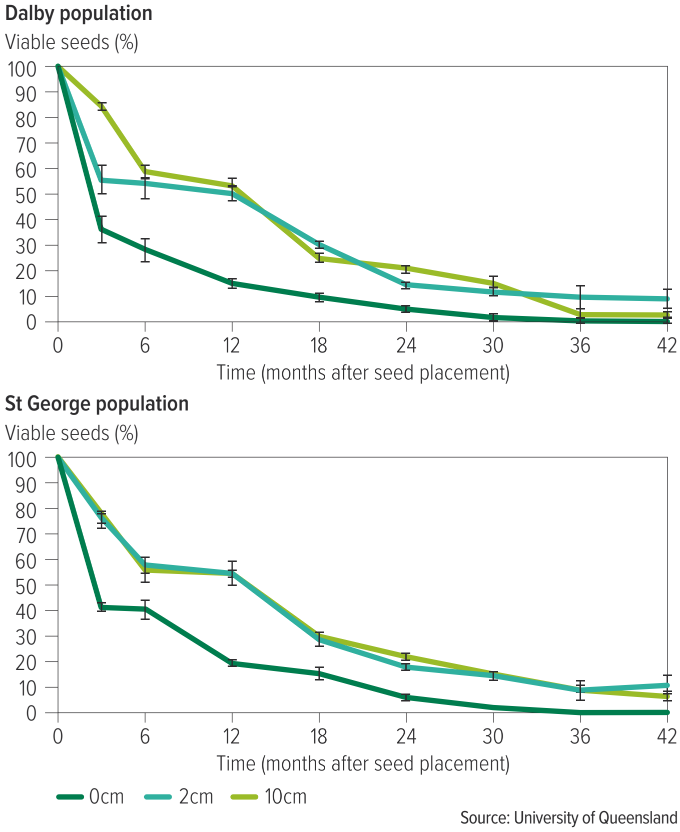


Figure 5: Effect of burial depth and duration on seedbank persistence of two populations of button grass. Vertical bars indicate the standard error of the mean.



stored soil moisture and nutrients, reducing the yield potential of the subsequent winter crop. Button grass can also act as a green bridge for crop pests and diseases.

Alternatively, button grass can be a valuable pasture species in arid areas, although overgrazing of button grass (green or dry plants) in stockyards can result in nitrate–nitrite toxicity in sheep and cattle. Further, toxicity from prussic acid can result in the field when hungry livestock are exposed to lush growth. Dry plants are rarely toxic in the field. Livestock in poor condition or which have no other source of feed are more likely to experience toxicity from button grass.

Button grass emerges more rapidly after summer rainfall than other summer weed species, which makes it particularly adept at supporting Australian plague locust. Further, early emergence means plants are rarely sprayed at the seedling stage, as growers often wait for other summer weed species to emerge. The early emergence means button grass plants are also the first summer weed to experience heat or moisture stress. As a result, button grass at the time of spraying is often more mature, stressed and dusty than other weed species, and may be poorly responsive to herbicides.

Seed

Dormancy and germination

Button grass seeds in WA have initial dormancy (after-ripening requirements) to prevent emergence in the autumn and winter following seed production. Emergence in autumn and winter in southern Australia is further restricted as the optimal temperature for germination is 30°C. In a laboratory experiment, germination of WA populations immediately following seed production in summer was zero per cent. However, initial viability was very high. Scarification (damaging the seed coat) allowed more than 90 per cent germination for all populations. Once seed had three to four months to complete after-ripening, germination was 52 per cent in light and 15 per cent in dark conditions. In Queensland, germination of fresh seeds varied from 33 to 43 per cent, but increased to more than 80 per cent after four months of after-ripening at room temperature (25°C). There are clearly some ecotypic differences in initial dormancy levels of button grass populations.

The light requirement for germination indicates seeds on the soil surface will have higher emergence than seed buried by the crop seeding operation. Button grass seeds are very small and, if seeds germinated at depth, the cotyledon may fail to emerge. This was confirmed in the field, as seeds on the soil surface at Merredin, WA, increased emergence from zero per cent in the first month to 40 per cent germination in the second month. However, emergence of seed buried at 2cm remained low (Figure 3).

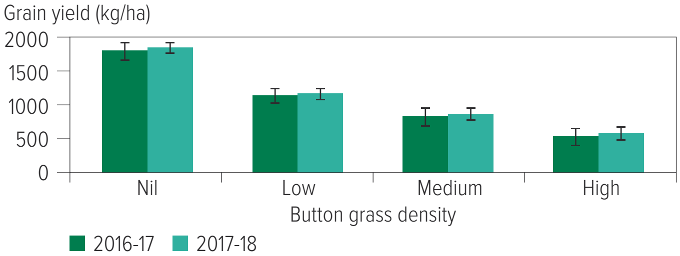
It is clear seed emergence will be greatest when seeds are left on the soil surface in a zero or no-tillage seeding system, rather than minimum tillage with increased soil disturbance. This explains why button grass is a common weed in systems with conservation tillage. Seeds on the soil surface are also more likely to have their seed coat degrade (enabling the entry of water) than seeds buried at depth, as they are exposed to weather, erosion and animals.

Seed germination also increased from 52 per cent to 85 per cent following exposure to water for 10 days, although 30 days exposure to water reduced germination to less than 10 per cent. This confirmed the tendency of button grass to emerge rapidly after heavy rainfall and favour environments that are subject to temporary flooding, such as creek lines.

Seedbank persistence

In irrigated field conditions at Northam, WA, button grass seed had 98 per cent emergence in year one, followed by 0.4 per cent emergence and 0.1 per cent emergence in years two and three. In year one, the 98 per cent emergence occurred in a

Figure 6: Effect of button grass density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high button grass density was 10, 26 and 43 plants/m² in 2016-17, and 15, 30 and 47 plants/m² in 2017-18.



Source: University of Queensland

single cohort in November. This highlights that once seed has lost dormancy, seeds emerge easily once the temperature is sufficiently high (for example, at or close to 30°C). Increased average spring temperatures are going to exacerbate emergence of summer weeds during spring in mature winter annual crops, when it is logistically difficult to control weeds.

These findings were confirmed in the field. Button grass was sown in the field at Katanning (high rainfall), Northam (medium rainfall) and Merredin (low rainfall) in WA, where soil was disturbed manually to simulate the seeding system (Figure 4). In all three sites, emergence occurred in year one. In year two emergence was less than 0.2 per cent at all sites and in year three emergence was zero per cent. Emergence was greatest in the higher rainfall site at Katanning; as discussed, button grass emergence increases following prolonged exposure to moisture. However, emergence at all sites was lower than in the controlled conditions at Northam. This was probably because simulating the crop sowing process buried some seed. As discussed, button grass emergence is much higher from the soil surface than when seed is placed at depth.

In Queensland, the depletion of seedbank of two populations of button grass (Dalby – higher rainfall, St George – lower rainfall) was rapid at the soil surface; 15 to 19 per cent of seeds remained after 12 months, five to six per cent after 24 months and no seeds persisted at 36 months (Figure 5). Persistence at depths of 2cm and 10cm were 14 to 22 per cent of seeds at 24 months and three to nine per cent of seeds at 36 months. Seed persistence at 42 months at a depth of 2cm remained at nine to 11 per cent, while three to seven per cent of seeds buried at 10cm remained viable, suggesting buried seeds may survive more than 3.5 years. It is clear that undisturbed seeds last longer than those subject to annual disturbance from a crop sowing event, where there is more opportunity for the seed coat to be damaged due to movement through the soil.

Seed production and dispersal

In an irrigated trial in Queensland, the high density of button grass (43 to 47 plants/m²) produced between 204,000 to 219,000 seeds/m². These plants retained 58 to 67 per cent of their seeds at mungbean harvest, suggesting the potential use of harvest weed seed control to minimise further infestation from this weed. However, over three years at Wongan Hills, WA, with a weed density of a maximum of eight plants/m², seed production was a maximum of 1214 seeds/m². Seed production in southern Australia is highly dependent on unpredictable summer rainfall. Seeds from plants growing in the summer fallow of the southern region may disperse if mature plants at the end of autumn are dragged by seeding equipment, or through water movement. Button grass seeds are a favourite food for ants; granivores (seed eaters) may disperse the seeds or consume them.

Competition

In Queensland under irrigated conditions, button grass emerged at a similar time to the crop (button grass emergence two to three days after mungbean emergence). Compared with the weed-free plots, a low density (10 to 15 plants/m²) of button grass reduced mungbean yield by 36 per cent (Figure 6), demonstrating its high competitiveness in a mungbean crop. A high density of button grass (43 to 47 plants/m²) reduced yield by 68 to 69 per cent.

Button grass in southern farming systems, growing as a summer annual, may reduce yield of the subsequent winter crop by removing soil moisture and nutrients. In three years at Wongan Hills, WA, button grass in the summer fallow had no impact on crop yield. However, this site had sandy soil with poor water-holding capacity. APSIM (Agricultural Production Systems sIMulator, www.apsim.info) modelling indicates that controlling summer weeds may increase crop water use efficiency by two per cent in Wongan Hills compared with 65 per cent at Salmon Gums, WA, 33 per cent at Waikerie, SA, 202 per cent at Tottenham, Victoria, or 172 per cent at Condobolin, NSW. Clearly, the impact of weeds in the summer fallow for winter annual crops in southern Australia varies widely between soil types.

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A summer-growing annual weed that emerges throughout summer and autumn following summer rainfall.

Photo: Catherine Borger (DPIRD)

CALTROP

Tribulus terrestris L.

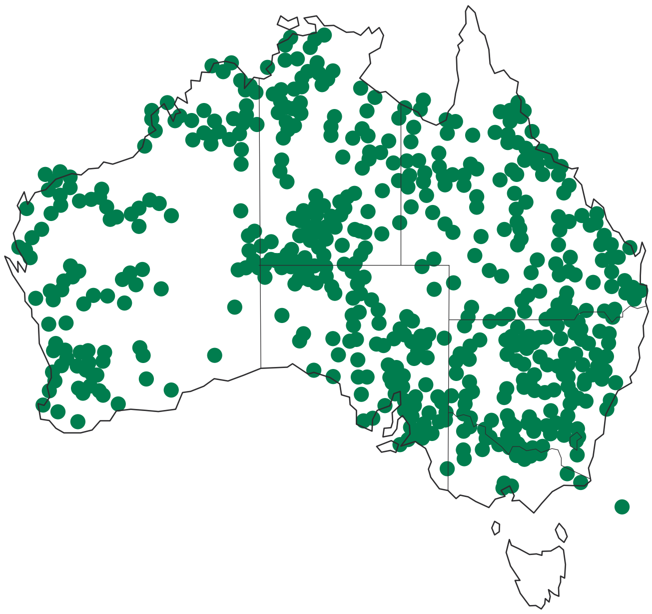
Other common names: bindii, bindyi, cat's head, goat's head burr, yellow vine, bendy-eye, bull head, ground bur-nut.

Synonyms: *Tribulus hispidulus* Presl, *T. lanuginosus* L.

KEY POINTS

- Caltrop is a summer annual, but may emerge in winter crops in late spring
- It takes less than a month for a caltrop seedling to grow and develop fully mature seed; early control is vital to prevent seed-set
- The caltrop seedbank can last more than three years, with burial increasing seedbank persistence
- Caltrop reduces mungbean yield in Queensland. In southern Australia, the impact of this summer weed on yield of the subsequent winter crop is less consistent

Figure 1: *Tribulus terrestris* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Caltrop is a weed of the Zygophyllaceae family. Caltrop is found throughout Australia, with the exception of Tasmania (Figure 1).

Description

- Caltrop is a summer annual, prostrate, sprawling weed, although it may grow as a perennial in northern Australia where winter temperatures are higher.
- The intertwined plants form a matt over the ground. It has numerous green to reddish-brown stems up to 3m long, covered in fine hair, radiating from a woody taproot (Figure 2).
- The leaves are darker on the upper surface than the lower surface. They are hairy, more so on the lower surface, which gives a silvery appearance. Leaves are arranged in opposite pairs, with each leaf consisting of three to 14 leaflets (5 to 15mm long and 3 to 5mm wide), either with no stalk or a very short stalk.
- Flowers are yellow with five to six petals each. They may be very short-lived, opening in the morning and closing or shedding petals in the afternoon.
- The seed of caltrop is a woody burr about 1cm in diameter, with rigid spines about 6mm long protruding from it. The mature burr splits into five wedge-shaped segments, with each segment containing two unequal pairs of spines. Each burr segment may contain up to four seeds.
- The spines on the burrs are arranged so that at least one spine is always pointing upward no matter how the burrs fall from the plant. This allows burrs to easily penetrate shoes, hooves or tyres. Burrs near the centre of the plant mature and shed while the plant remains green and new burrs develop on the ends of the branches.

Why is it a weed?

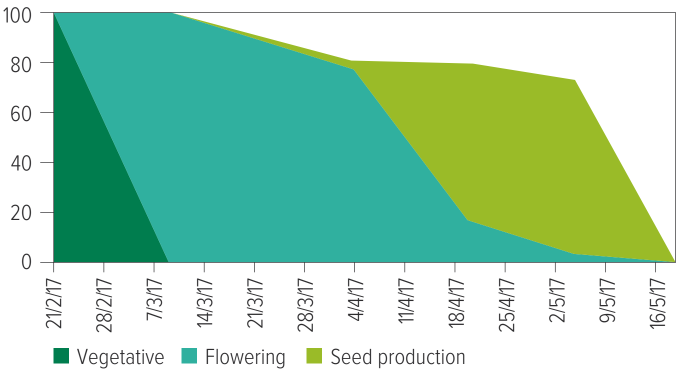
In northern and eastern regions of Australia with summer cropping, caltrop competes directly with the crop. This plant is normally prostrate, but stems shaded by the crop may become more erect and grow up into the crop canopy. This may hinder harvest and caltrop seeds will contaminate the grain. In the winter cropping areas of southern Australia, caltrop grows over the summer/autumn fallow. The long, vine-like branches can block or tangle in seeding machinery and, like other summer fallow weeds, caltrop

Figure 2: Top left: Caltrop burr segments. Top right: Caltrop seedling. Bottom left: A mature plant with flowers and seeds. Bottom right: Mature plants growing in crop residue over summer. Photos: Catherine Borger (DPIRD)

depletes soil moisture and nutrients that would otherwise be available to the following crop.

Caltrop burr injures livestock and dogs, and contaminates wool. Caltrop is also potentially toxic to sheep and goats as it causes photosensitisation. It may accumulate toxic nitrites under conditions of high nitrogen availability in the soil (for example, growing in stockyards), or toxic harmala alkaloids. However, livestock poisonings are very rare. It also causes punctures in tyres.

Figure 3: The percentage of caltrop plants at each growth stage, from a cohort that emerged on 21 February 2017 at Wongan Hills, WA.



Plant survival was 100 per cent when the cohort first emerged, and then was reduced as some plants in the cohort died over the summer/autumn. Plants stayed in the seedling/vegetative stage for a few days, but many plants were flowering by 9 March 2017, and some plants had also started producing seed by this date. By 20 April 2017 most plants were producing seed. While a few plants died over summer, many plants continued to produce and shed seed until May 2017, when they were killed by pre-seeding herbicides.

Source: DPIRD

Seed

Dormancy and germination

While each burr segment can hold up to four seeds, only one of the seeds in each burr segment germinates. Caltrop germinates most readily at 24° to 27°C and germination is inhibited by low temperatures and dark conditions. This indicates that seed emerges most easily from the soil surface (high temperatures and light availability). However, seed will emerge from a depth of up to 5cm. Germination and establishment are favoured by light-textured, sandy soils, and rainfall as low as 5mm may be sufficient to allow caltrop emergence.

Most newly matured seeds (approximately 90 per cent) are dormant and require an after-ripening period of approximately six to 12 months. The after-ripening requirement and germination inhibition at cold temperatures allow caltrop seeds produced in the summer/autumn fallow to remain in the soil until the following spring/summer. However, the 10 per cent of seeds with no innate (initial) dormancy assist caltrop populations to produce several cohorts of plants over summer/autumn, if the initial seed is produced at the beginning of summer.

Seed germination occurs when average soil temperatures reach 15° to 20°C for at least two weeks. As average spring temperatures increase, emergence in October or November has become increasingly common. In field trials at Wongan Hills, WA, initial emergence over three summers occurred in February 2017, November 2017 and November 2018. In irrigated conditions at Northam, WA, emergence of 12 populations consistently occurred in October over the three-year span, although small cohorts also emerged in August in 2018. Therefore, depending on rainfall and temperature, this weed may emerge at any time of year, and most commonly emerges in spring.

Figure 4: Effect of burial depth and duration on seedbank persistence of two populations of caltrop from Queensland (left) and seedbank persistence averaged over two populations from WA (right). Vertical error bars indicate the standard error of the mean.

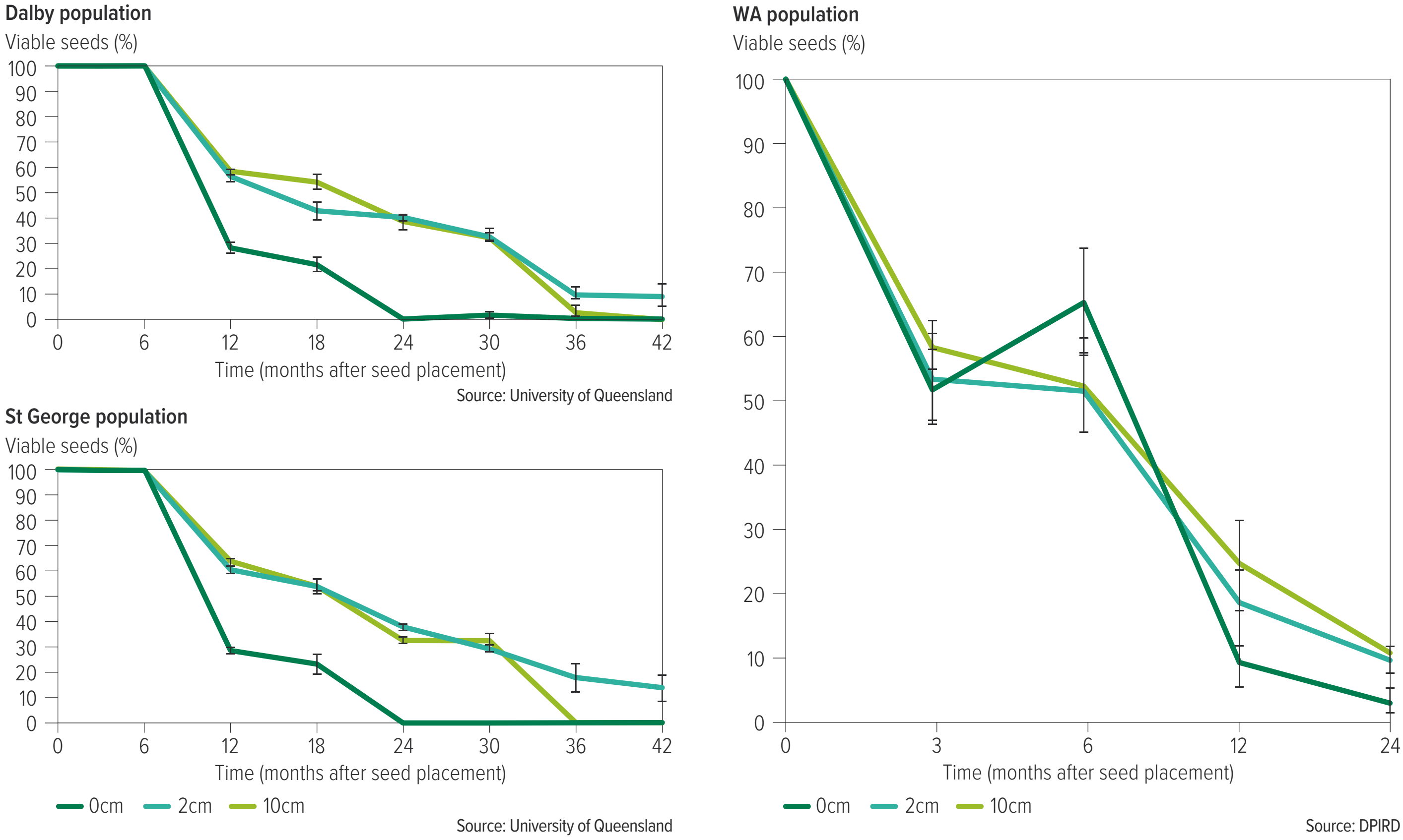


Figure 5: Movement of seeds on vehicles is a major source of caltrop dispersal; brush tyres down when new machinery enters the farm.

Photo: Catherine Borger (DPIRD)

Caltrop plants can produce viable seed in less than a month, although on average there are 17 days from emergence to flowering and 10 days from flowering to viable seed production (Figure 3). This means plants emerging in October or November can set seed at or prior to crop harvest in December. The short life span and staggered germination through spring and summer make it difficult to spray all plants prior to seed production, especially in-crop during spring prior to harvest.

Seedbank persistence

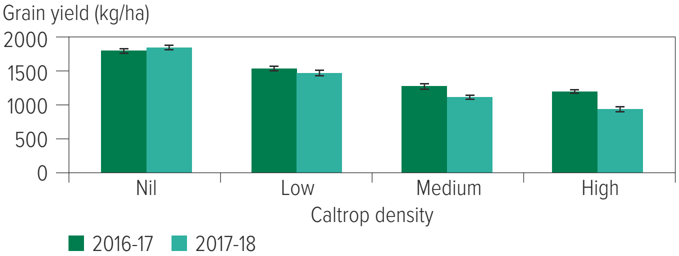
In dryland conditions at Gatton, Queensland, seed persistence at the soil surface (0cm) after 12 months was about 30 per cent, which reduced to one per cent after 36 months and no seeds survived 42 months (Figure 4). Viability for buried seeds was much greater than the surface seeds. After 24 months, about 40 per cent of seeds were viable at 10cm depth but no seeds survived after 42 months. Similarly, shallow burial (2cm) resulted in 40 per cent seed viability after 24 months. However, about 15 per cent of seeds were still viable after 42 months.

In irrigated conditions at Northam, WA, with seed buried at 1cm depth, emergence was 56 per cent in year one, 21 per cent in year two and 10 per cent in year three. This suggests the seedbank can last more than three years, even in ideal (non-moisture limited) conditions. This was confirmed by a seed burial trial at Northam, with two populations of caltrop seed at 0, 2 or 10cm depth in the soil over two years. Surface seed viability reduced to three per cent after two years, and seed buried (at 2 or 10cm) had 10 to 11 per cent viability (Figure 4).

Seed production and dispersal

Caltrop plants at Wongan Hills, WA, produced zero to 708 seeds/plant, with a maximum of 1524 seeds/m^2. In mungbeans at Gatton (irrigated), high-density caltrop produced 11,400 and 19,100 seeds/m^2 in 2016-17 and 2017-18, respectively, with all seeds retained at mungbean harvest. Caltrop in ideal conditions can produce more than 20,000 seeds per plant. Caltrop growing in the summer/autumn fallow in southern Australia can be dispersed when the vines are dragged by seeding implements, or on livestock or vehicles for long-distance dispersal (Figure 5).

Figure 6: Effect of caltrop density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high caltrop density was 5, 8 and 15 plants/m^2 in 2016-17, and 8, 12 and 21 plants/m^2 in 2017-18.



Source: University of Queensland

Competition

A competition trial was conducted in irrigated conditions at Gatton, Queensland, in 2016-17 and 2017-18. Compared with the weed-free plots, low density (five to eight plants/m^2) of caltrop resulted in a mungbean grain yield loss of 14 to 20 per cent (Figure 6). These losses increased to 29 to 39 per cent at medium weed density and 33 to 49 per cent at high weed density.

At Wongan Hills, WA, caltrop growing over the summer fallow had no impact on the yield of the subsequent crop over three years. However, summer rainfall was below average. In soil with greater water-holding capacity and years with high summer rainfall, caltrop is likely to reduce yield of winter crops. At Merredin, WA, caltrop over the summer consistently reduced wheat yield due to removal of nitrogen from the soil.

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A winter annual that emerges in autumn to spring and matures in spring and early summer.

Photo: Catherine Borger (DPIRD)

DOUBLEGEE

Rumex hypogaeus T.M.Schust & Reveal.

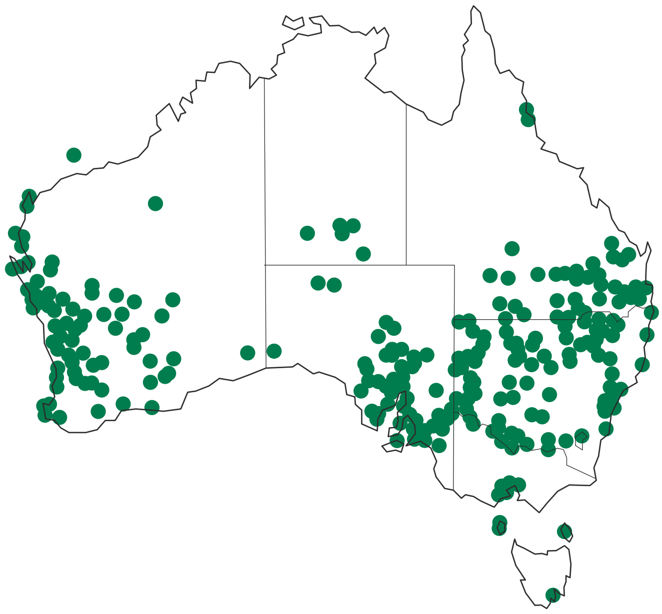
Other common names: bindii, bull head, cape spinach, cathead, cat's head, devil's thorn, goat head, prickly jack, three corner jack, spiny emex.

Synonym: *Emex australis* Steinh.

KEY POINTS

- The doublegee seedbank can last more than three years, and the spiny seeds are particularly problematic as they will puncture tyres or shoes and injure animals
- Doublegee plants produce both aerial seeds along the branches and subterranean seeds at the base of the crown. Plants as young as four to five leaves can have multiple, fully mature, subterranean seeds
- As a prostrate species, the impact on crop yield is low compared with other weed species and inconsistent between years, but dense doublegee can reduce cereal yield

Figure 1: *Rumex hypogaeus* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Doublegee is a weed in the Polygonaceae family and is naturalised in southern Australia and occasionally found in Tasmania and northern Australia (Figure 1).

Description

- Vigorous annual herb with a strong taproot and a long, fleshy, hairless stem with a prostrate growth habit. However, in competition with a crop, plants may be more erect.
- Cotyledons are hairless, elongated and club-shaped with a round apex. Subsequent leaves are alternate, hairless and triangular with undulating margins.
- Young plants have ovate leaves in a prostrate rosette.
- Mature plants can remain prostrate or assume a semi-erect habit in a dense crop or pasture.
- Round, ribbed stems branching from the centre of the rosette may grow up to 60cm long.
- Clusters of very small, inconspicuous white flowers form in the centre of the plant and along the branches.
- Male and female flowers are separate, with the male flowers in clusters on small stalks and the female flowers almost without a stalk, in the leaf axils.
- Seeds are hard and woody, 7 to 11mm long and triangular. Each angle extends to a rigid sharp spine arranged in such a way that one spine is always pointing upward. The seed changes from green to brown when mature.
- The senesced plant turns a reddish-brown colour, much darker than the dry crop residue.
- This species is sometimes confused with caltrop (*Tribulus terrestris* L). However, caltrop has fine fern-like greyish leaves and small yellow flowers (up to 10mm across) with five to six petals.

Figure 2: Top left: Doublegee seeds. Top right: Doublegee seedlings. Bottom left: Mature plants in crop residue. Bottom right: Senesced plants are a darker red/brown than the crop residue. Photos: Catherine Borger (DPIRD)

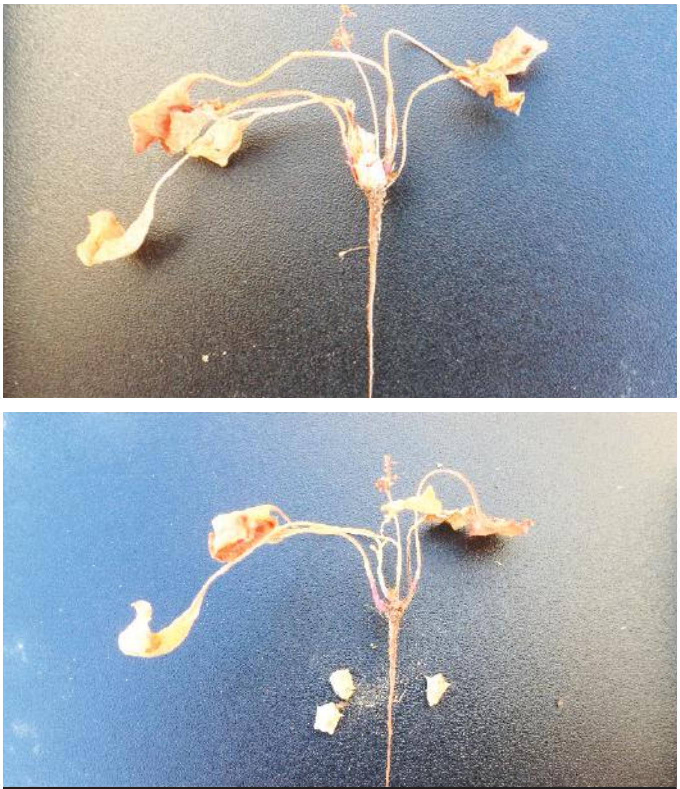


Figure 3: A senesced doublegee plant at the five-leaf stage with no branches or seeds above ground, but three fully mature subterranean seeds at the base of the crown. Photos: Catherine Borger (DPIRD)

Why is it a weed?

Doublegee is a significant weed of agriculture in southern Australia. Nationally it causes an estimated revenue loss of $1.4 million annually and covers 177,880ha, making it Australia's 11th most widespread cropping weed. A density of eight to nine plants/m^2 can reduce wheat yield by up to 50 per cent. It can contaminate grain, leading to a rejection of grain deliveries. It is very difficult to separate doublegee seeds from the grain of pulse crops. Although it is relatively easy to separate the seeds from cereal and canola, additional cleaning post-harvest may be required.

The plants contain oxalate at levels that are not usually toxic, but may poison sheep if eaten in large quantities. The spiny fruits of doublegee can injure animals and people and are robust enough to puncture shoes.

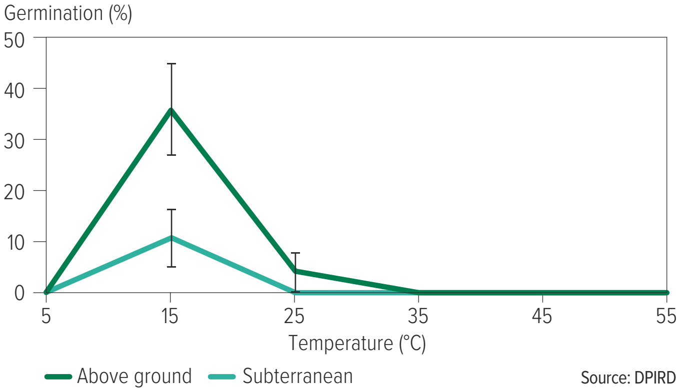
Seed

Dormancy and germination

Doublegee seeds have an after-ripening period of two to six months, so 80 to 95 per cent of seed produced in spring and summer can germinate by the following autumn. If seeds lose dormancy over summer and conditions are not optimal for germination, 60 to 90 per cent of these seeds reacquire dormancy (that is, seeds can cycle in and out of dormancy) to ensure most emergence occurs in autumn and winter. Approximately five to 20 per cent of seed has long-term dormancy and will not germinate for at least two years.

While seedlings predominantly emerge in autumn and winter, small cohorts may emerge throughout the year. Seed germination occurs at temperatures ranging from 5° to 35°C, but optimal germination occurs at 15° to 20°C. Optimal emergence occurs from seed buried at 1cm, and seeds at 1 to 5cm are more likely to establish than seeds on the soil surface or seeds at a depth of 10cm or more. On undisturbed agricultural sites (such as pasture) where seed-set is prevented, the dormant seedbank lasts about two to three years. In a cropped field, cultivation and burial of seed induces dormancy and allows the seedbank to last longer than three years.

Figure 4: Germination of above-ground and subterranean seeds of doublegee plants at range of temperatures. Vertical bars indicate the standard error of the mean.



Source: DPIRD

Doublegee plants can produce seed above ground on the branches or subterranean seeds at the base of the crown. Plants as young as five to six leaves can have fully mature subterranean seeds before any seeds are set above ground (Figure 3). The subterranean seeds have a lower initial germination rate than the above-ground seeds, indicating they potentially have higher dormancy (Figure 4).

Seedbank persistence

In field conditions at Northam, WA, viability of doublegee seed was investigated by placing seeds on the soil surface or at 2cm or 10cm depth for three years (Figure 5). Seeds on the soil surface lost viability (degraded or germinated) over three years (zero per cent at the end of three years). By comparison, seeds at 2cm or 10cm were slower to lose viability, and retained more than two per cent viability at the end of three years. From a management perspective, a seeding system that buries a greater percentage of the seed (that is, minimum tillage compared with no-tillage) will create a larger dormant seedbank.

In irrigated conditions at Northam, emergence (averaged over 12 populations) was 59 per cent in year one, 23 per cent in year two and nine per cent in year three. This indicates the seedbank lasts more than three years.

Doublegee seeds were placed in micro-plots in the field for three years, with the soil agitated each year (May) to simulate crop seeding (Figure 6). Under these conditions, emergence in the first year was related to rainfall, with greatest emergence at Katanning (higher rainfall) followed by Northam (medium rainfall) and Merredin (lower rainfall). Katanning and Northam had emergence in the first year of 17.5 per cent and 6.1 per cent respectively, but at Merredin emergence in year one was 1.1 per cent. Only Merredin had emergence in the third year (0.5 per cent). Seed (and soil) was retrieved after three years and sown in irrigated conditions, but emergence remained at less than one per cent. Therefore, in field conditions, most emergence occurs in year one to two, and the remaining seed degrades or germinates after a very small rainfall event and subsequently dies without emerging. Clearly, soil agitation to bury some seed and then potentially return it to a shallower depth or the soil surface in subsequent years (and expose it to light as the soil is moved) allows seeds to germinate or degrade more rapidly than seed in controlled conditions at a consistent depth (as in Figure 5).

Figure 5: Viability of doublegee seed on the soil surface or buried at depth of 2cm and 10cm, over zero to 36 months. Vertical bars indicate the standard error of the mean.

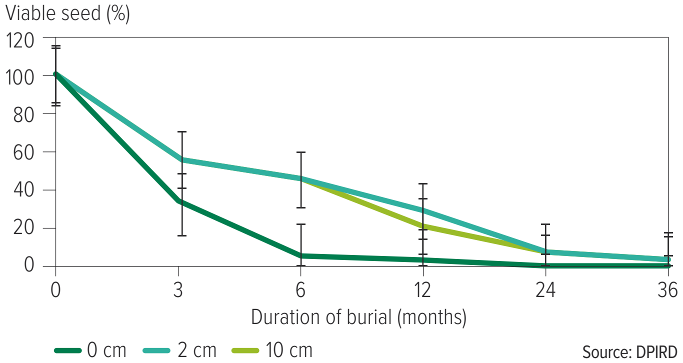


Figure 6: Cumulative annual emergence of doublegee (as a percentage of total weed seeds planted) from 2016 to 2019. Vertical bars indicate the standard error of the mean.

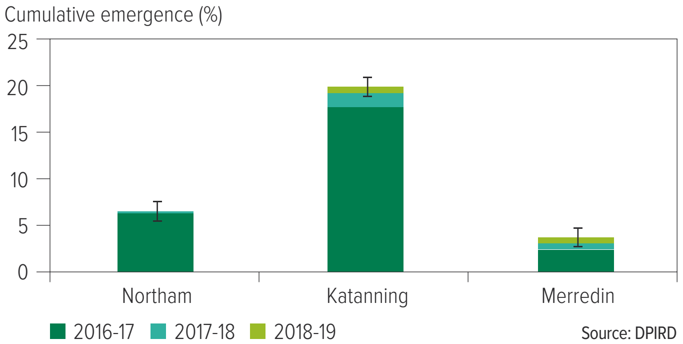


Figure 7: Doublegee seed shedding from 2 October to 1 December in a wheat crop at Wongan Hills, WA, in 2016, 2017 and 2018. Vertical bars indicate the standard error of the mean.

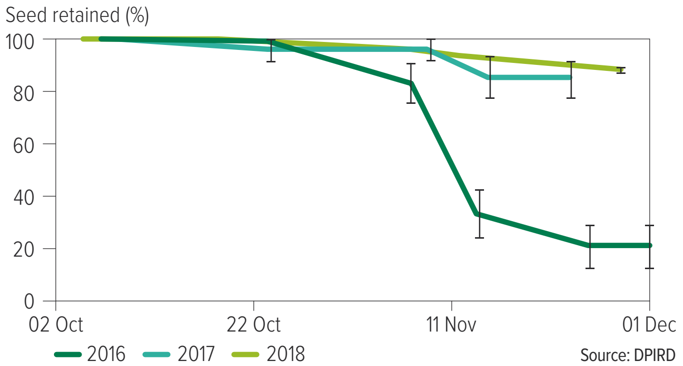
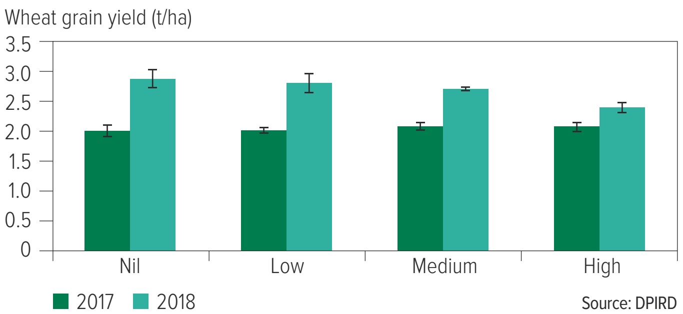


Figure 8: Effect of doublegee density on wheat yield at Wongan Hills, WA, in 2017 and 2018. Low, medium and high doublegee density was 3.5, 5 and 20 plants/m^2 in 2017, and 64, 183 and 164 plants/m^2 in 2018. Vertical bars indicate the standard error of the mean.



Seed production and dispersal

Doublegee plants in wheat in WA produced up to 450 seeds/plant, depending on seasonal conditions, or 268 to 429 seeds/m^2. The main source of long-distance seed dispersal is via livestock or vehicles. As stated, the spines on the seeds are arranged so one spine is always pointing upwards. This allows the seeds to lodge in stock (in the feet or wool) or in the tyres of vehicles. Many growers prevent the spread of this weed by manually removing the seeds from their tyres at paddock gates.

Seeds are also dispersed through movement of contaminated hay or grain. While seed is more common in hay, doublegee seeds are found in two per cent of grain deliveries in WA. As stated, doublegee growth may be erect when competing in crop (that is, the stems grow up the crop plants into the canopy). The rate of seed shedding is highly variable, depending on seasonal conditions (Figure 7). However, there is usually some seed retained in November or December to potentially be captured at harvest, although this may be close to the ground if growth is prostrate.

Competition

Doublegee is a comparatively poor competitor compared with other weeds due to its late emergence in some seasons and prostrate growth habit. However, it may still significantly reduce yield. In Wongan Hills, WA, a doublegee density of 164 plants/m^2 in a wheat crop reduced yield by 17 per cent (Figure 8). By comparison, a density of 20 plants/m^2 in 2017 had no impact on crop yield.

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

A warm-season annual grass.

Photo: Bhagirath Chauhan (University of Queensland)

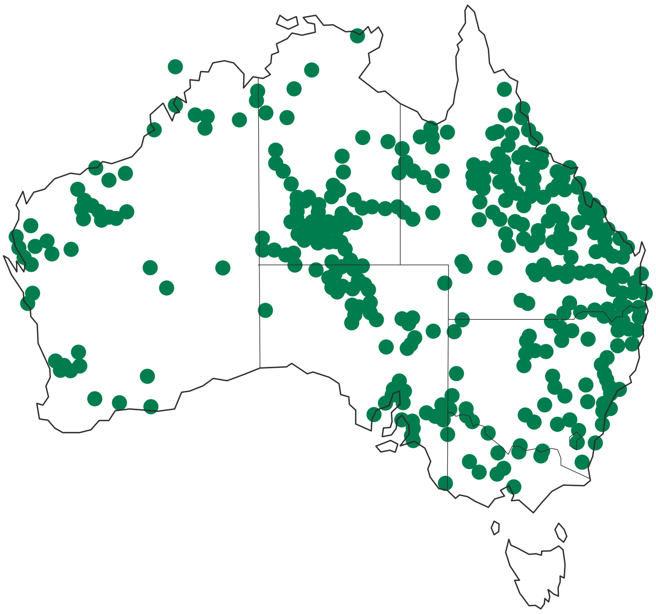
FEATHERTOP RHODES GRASS

Chloris virgata Sw.

KEY POINTS

- Feathertop Rhodes grass seeds generally have moderate initial dormancy, but the actual level can be highly variable
- Feathertop Rhodes grass can germinate over a wide temperature range, but maximum germination occurs at alternating day/night temperatures of 30°/20°C
- Seedling emergence and viability decreases with increasing burial depth
- Regardless of seed position in the soil, the seedbank is short-lived (less than two years), indicating that intensive control for 12 to 18 months will reduce the infestation to very low levels
- Seed production can be extremely high, especially from plants in fallow with little other competition. Control of isolated plants can significantly reduce additions to the seedbank
- Feathertop Rhodes grass is highly competitive in mungbean crops but more than 90 per cent seed retention at mungbean harvest presents a favourable opportunity to utilise harvest weed seed control practices as part of an integrated management strategy

Figure 1: *Chloris virgata* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

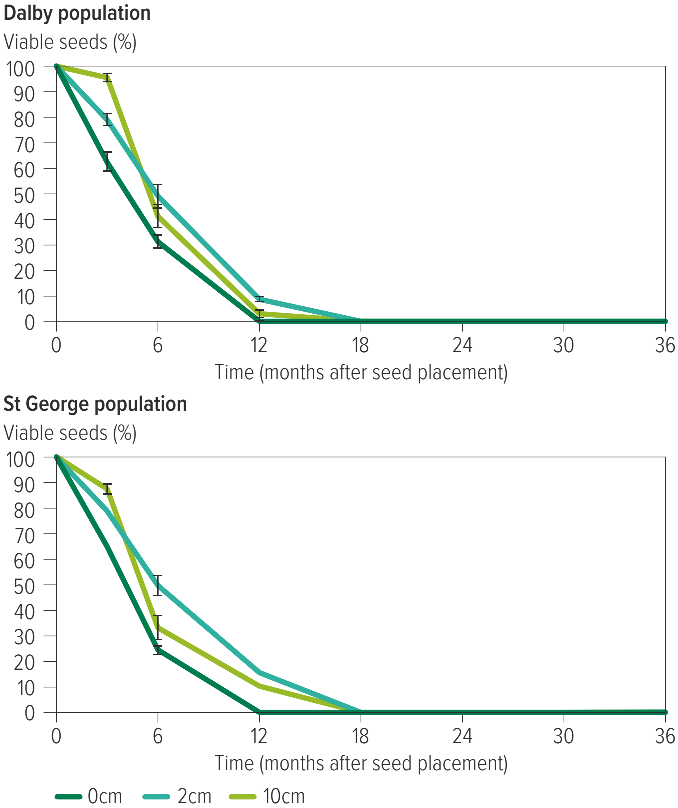
Feathertop Rhodes grass is an exotic warm-season weed with an expanding distribution across Australia (Figure 1). It has become a serious cropping weed in the northern region, which is correlated with the predominance of no-till cropping systems. The prevalence of feathertop Rhodes grass is now spreading further south.

Description

- Seedlings are erect with stems having a flattened appearance.
- Stems are hollow, hairless and branched. They are capable of rooting at the nodes.
- Leaves of 50 to 250mm are flat and drooping, their parallel sides tapering to a fine point.
- Capable of producing high tiller numbers.
- Seed heads comprise bundled spikes that have the appearance of an upright feather, with each spike containing two rows of oval seeds featuring surface grooves and hairs (Figure 2).
- At maturity, these seed heads appear on erect stems of 150 to 1000mm in height (Figure 2).

Figure 2: Top left: Feathertop Rhodes grass seeds. Top right: Seedlings. Bottom left: A seed head. Bottom right: Matured plants in sorghum.
Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of feathertop Rhodes grass seed on the soil surface or buried at a depth of 2 or 10cm, over three to 36 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland

Figure 4: Effect of alternating day/night temperature on germination of different populations of feathertop Rhodes grass. Lines represent different populations.

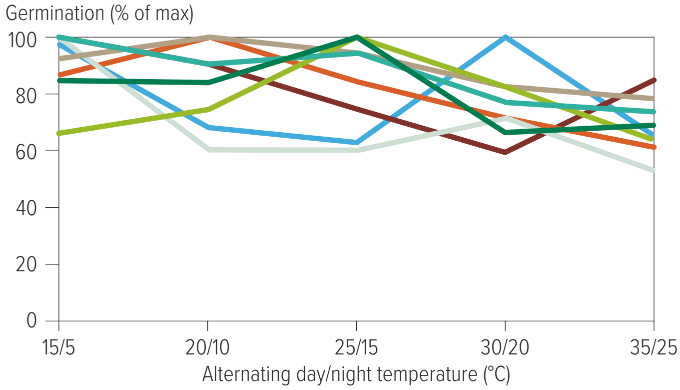
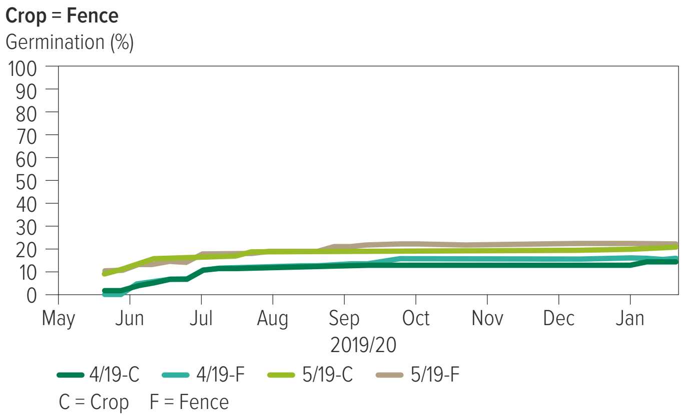


Figure 5: Germination pattern of two populations of FTR collected from fenced and crop areas. Germination was similar between populations from fences and crops.



Why is it a weed?

Feathertop Rhodes grass is competitive across a range of environmental conditions and is a dominant weed in cropping and fallow situations and unmanaged areas throughout Australia. Its abundant seed production and high dispersal rate are enhanced by its ability to grow under harsh conditions of salinity, temperature and water stress. Although a summer weed, feathertop Rhodes grass has also been observed in winter crops. Multiple cases of herbicide resistance have been observed, including to glyphosate.

Seed

Dormancy and germination

Fresh seeds of feathertop Rhodes grass germinated at 39 to 51 per cent, and after four months germination increased to between 85 and 89 per cent, suggesting seeds generally have a moderate level of dormancy. However, considerable variation exists in these initial dormancy levels depending on population. Seeds germinated at a wide range of alternating day/night (12h/12h) temperatures ranging from 15°/5°C (typical of winter months) to 35°/25°C (Figure 4). Maximum germination was observed at 30°/20°C alternating day/night temperature; however, some seeds germinated at 15°/5°C (typical of winter months). Therefore, germination is possible over a very wide window throughout the year. Light is not an absolute requirement for germination, but it enhances germination. For example, germination in dark was 30 per cent, which reached 90 per cent in the light/dark regime. These results suggest that germination and emergence of feathertop Rhodes grass in the field will be favoured by the presence of seeds at or near the soil surface, such as in no-till farming systems.

Seed germination of fence and crop populations of feathertop Rhodes grass revealed great variation across populations. While a few populations demonstrated a similar germination pattern (Figure 5), some fence populations demonstrated high germination rates as compared with their crop pairing (Figure 6). Conversely, the germination of in-crop feathertop Rhodes grass exceeded 40 to 75 per cent at six months in another five populations, while their fence counterparts remained at less than 20 to 50 per cent (Figure 7). These inconsistent patterns of germination require management practices specific to a location and the populations present.

Although it is a summer weed, feathertop Rhodes grass managed to germinate across winter months, presenting the potential for further crop interference in late winter and spring. Furthermore, variation in dormancy across populations further impacts decision-making in weed management and tillage operations. This adaptability across a range of temperatures and growing conditions presents the potential for further infestation and damage under increasing annual temperatures.

Seedbank persistence

In 2016, seeds of two feathertop Rhodes grass populations in Queensland (Dalby – higher rainfall, St George – lower rainfall) were collected and placed in nylon bags, which were placed at different depths at a single site to study seedbank persistence. For both populations, the depletion of the seedbank was rapid at the soil surface, with total depletion at 12 months (Figure 3). At 12 months, persistence at 2 and 10cm burial was nine to

Figure 6: Germination pattern of five populations of FTR collected from fenced and crop areas. Germination was greater for the populations collected from fences.

Fence > Crop

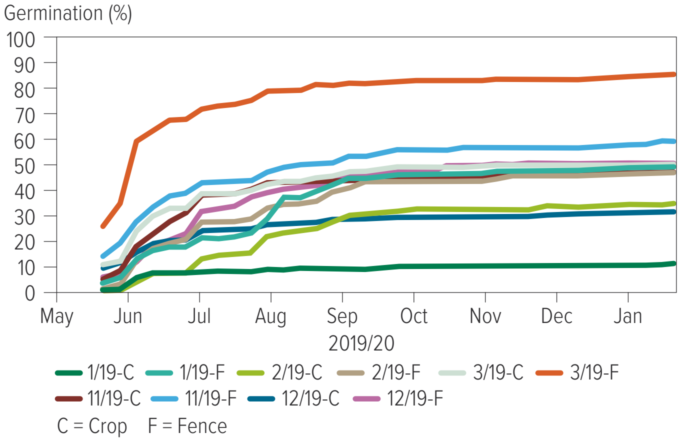


Figure 7: Germination pattern of five populations of FTR collected from fenced and crop areas. Germination was greater for the populations collected from crops.

Crop > Fence

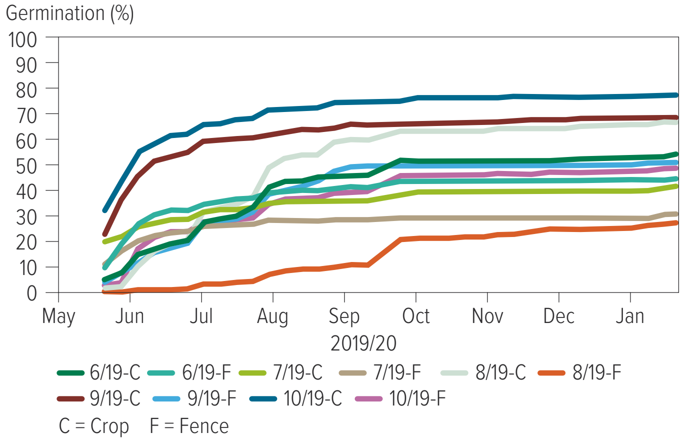
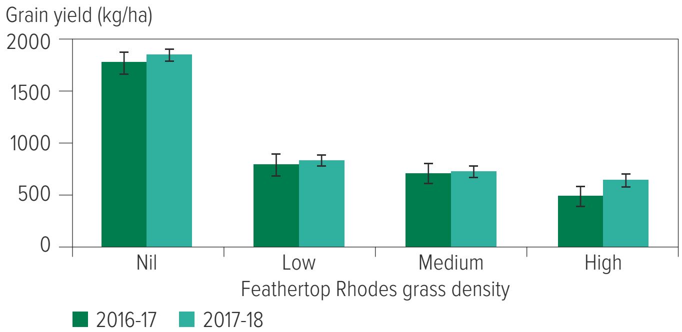


Figure 8: Effect of feathertop Rhodes grass density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high FTR grass density was 15, 31 and 49 plants/m² in 2016-17, and 18, 34 and 45 plants/m² in 2017-18.



Source: University of Queensland

16 per cent and three to 10 per cent, respectively. Regardless of burial depth, there was no viable seed remaining 18 months after seed placement. Similarly, seed persistence was also investigated by placing them in field conditions for four years. No seeds had successfully germinated in this study after 36 months. Both studies indicate feathertop Rhodes grass seeds are short-lived. This allows an opportunity to exhaust the seedbank through a considered management strategy within a relatively short period.

Seed production and dispersal

At a weed density of 45 to 49 plants/m², feathertop Rhodes grass seed production growing in mungbeans was 120,000 and 147,800 seeds/m² in 2016-17 and 2017-18, respectively. The corresponding seed retention rates were 97 and 93 per cent, respectively, at mungbean harvest. This high level of seed retention presents a favourable opportunity to utilise harvest weed seed control as part of a suite of control tactics, but delaying harvest will result in more shedding of seed. Seed production can be even higher when irrigated or when growing without competition. Feathertop Rhodes grass has the potential to set mature seed very quickly, especially when stressed.

Competition

Studies over two seasons have shown Feathertop Rhodes grass to be highly competitive in mungbeans, even at the lowest weed density (15 to 18 plants/m²). Compared with the weed-free plots, the low-density plot resulted in a mungbean grain yield loss of 55 per cent (Figure 8). These losses increased to between 65 and 73 per cent at high weed density (45 to 49 plants/m²). Where the emergence of the weed is delayed relative to crop emergence (for example, by using residual herbicides), the impact on yield is not as significant. Other studies have shown even low densities of feathertop Rhodes grass can have a significant detrimental effect on sorghum yield.

References and further reading

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A winter annual that emerges in autumn and winter and matures in late spring or summer.

Photo: Ben Fleet (University of Adelaide)

INDIAN HEDGE MUSTARD

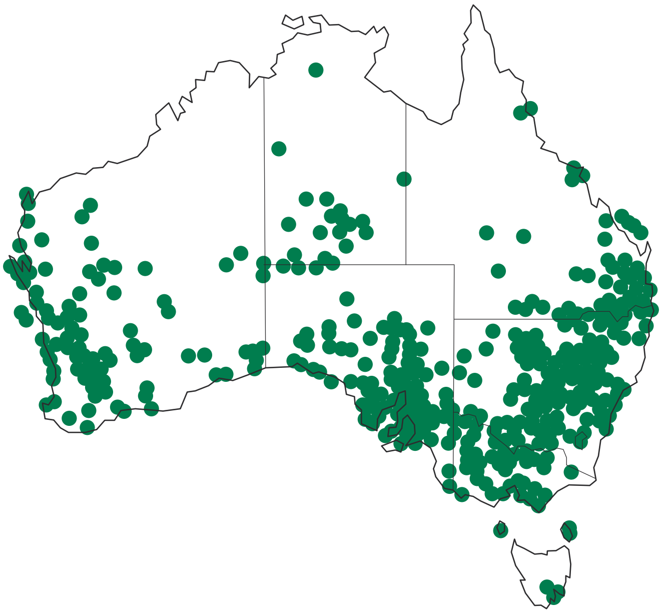
Sisymbrium orientale L.

Other common names: eastern rocket, hedge mustard, mustard, wild mustard.

KEY POINTS

- Seed dormancy in Indian hedge mustard tends to be short-lived, but its seedlings can establish over a period of two to three months during the growing season. Therefore, growers should expect to use post-emergence herbicide options where a large seedbank of this weed species is present
- Indian hedge mustard seedbank was found to persist for three years. Therefore, growers need to develop an effective multi-year management program for this weed. Populations with multiple herbicide resistance are known to be present in the southern region and could pose serious challenges
- Indian hedge mustard is a moderate competitor with grain crops; yield losses of up to 15 per cent were recorded in wheat and lentils
- Indian hedge mustard is a prolific seed producer. In a field trial at Roseworthy, SA, in 2017, Indian hedge mustard had an average seed set of 2594 seeds/m^2 in a wheat crop and 51,239 seeds/m^2 in lentils. Therefore, wheat is a much stronger competitor against this weed than pulse crops such as lentils. However, Indian hedge mustard seed capsules remained intact and retained their seeds until crop harvest. Therefore, this weed species is an excellent target for harvest weed seed control in cropping systems

Figure 1: *Sisymbrium orientale* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

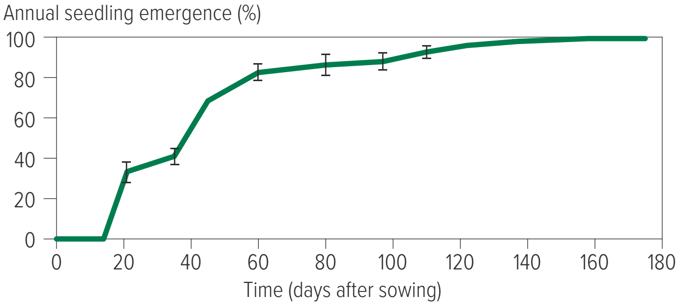
Indian hedge mustard is commonly referred to as hedge mustard, mustard or wild mustard. It belongs to the family Brassicaceae and originated in southern Europe, the Mediterranean, North Africa and Western Asia. It is known to be present in all Australian states and territories (Figure 1). In *Impact of weeds on Australian grain production*, Llewellyn et al. (2016), Indian hedge mustard or wild mustard was ranked in the top 10 weeds in the SA Mid North, Lower Yorke and Eyre Peninsula regions.

Description

- A grey-green, annual bushy plant that can sometimes exhibit biennial growth habit, but behaves mainly as an annual weed.
- Plants form a short-lived basal rosette of leaves, 200 to 300mm in diameter, that wither or are carried up the stem as it elongates. The middle stem leaves are usually arrow-shaped (Figure 2 bottom left).
- Develops four-petalled, yellow flowers (Figure 2 bottom right).

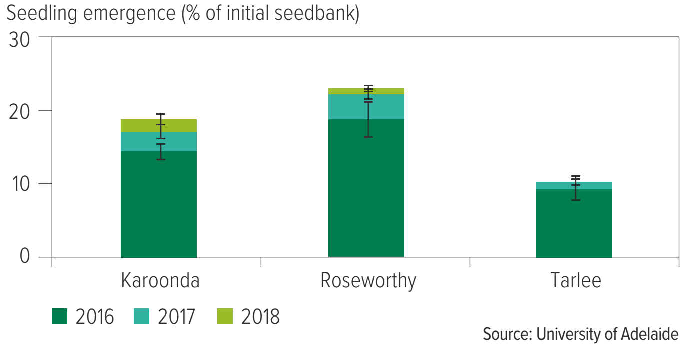
Figure 2: Top left: Indian hedge mustard seeds. Top right: Seedlings with first whirl of leaves. Bottom left: Plants showing arrow-shaped middle stem leaves. Bottom right: Flowers are yellow, four-petalled with long cylindrical seed capsules. Photos: Gurjeet Gill (University of Adelaide)

Figure 3: Annual seedling emergence pattern of an Indian hedge mustard population at Roseworthy, SA, in 2016. The seeds were sown in trays in April and seedling emergence was recorded regularly. The trays were watered to prevent water stress during the dry periods of the growing season. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Figure 4: Cumulative emergence of Indian hedge mustard seeds placed in the field at three sites in SA. Soil in each quadrat was agitated each May to simulate the crop seeding operation and bury the weed seeds. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

- Fruits are 40 to 120mm long and 1 to 1.5mm wide, cylindrical, slender, rigid, two-celled capsule, curved or straight on 3 to 10mm long stalks (pedicels) that are almost as thick as the fruit. Fruits have a single row of seeds with about 60 seeds per cell or 120 per seed capsule, which open from the base to release seed when ripe (Figure 2 bottom right).
- Seeds are small, brown, narrowly egg-shaped to oblong and not flattened, 1mm long and 0.6mm wide (Figure 2 top left).
- It is an indeterminate plant and produces many flowers and seeds in the late winter and spring.

Why is it a weed?

Indian hedge mustard is a moderately competitive weed with crops, but its strength lies in being able to produce a large amount of seeds when control tactics fail. Resistance to Group B (ALS inhibitors) herbicides was first reported in this species in 1990 and became widespread over time. More recently, resistance has also been reported to herbicide mode of action groups 4 (I), 5 (C) and 12 (F). Populations with multiple herbicide resistance have been identified and can be difficult to manage.

Seed

Dormancy and germination

Seeds of Indian hedge mustard are mostly dormant at maturity, but its dormancy is overcome by after-ripening under field conditions by late autumn (Chauhan et al. 2006). Therefore, seed dormancy in this weed species tends to be relatively short. Seed germination is strongly stimulated by exposure to light. Seedling emergence of seeds from the previous growing season was highest when present on the soil surface (70 per cent) but declined with depth, and no seedlings emerged from a soil depth of 10mm. This observed response to seed burial is consistent with the requirement for light for seed germination in Indian hedge mustard. In the field, seedling emergence was greater under no-till than minimum tillage systems (Chauhan et al. 2006). Widespread adoption of no-till systems in Australia is likely to have contributed to the increasing incidence of this weed species since the 1980s.

Annual seedling emergence pattern of Indian hedge mustard populations was investigated during the autumn to spring period in 2016 (Figure 3). The results showed that about 40 per cent of the annual seedling emergence occurred within 35 days after sowing. This component of the seedbank could be controlled by the application of the knockdown herbicides. However, 60 per cent of the seasonal emergence occurred later in the growing season and would require the use of selective herbicides. Knowledge of the resistance status of the populations of this weed would be important to select suitable herbicide options for its control.

Seedbank persistence

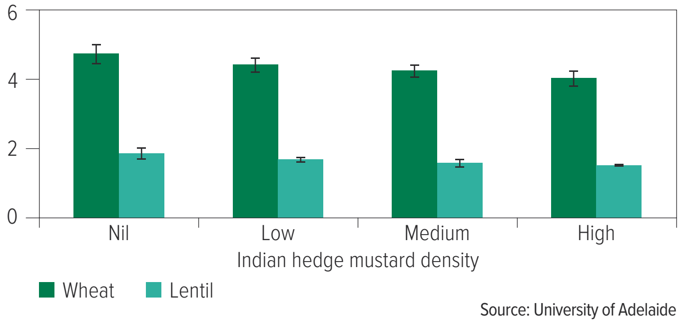
Seed persistence of Indian hedge mustard seeds was investigated by placing them in field conditions at three sites in SA for four years, from April 2016 (Figure 4). In each May the crop seeding process was simulated, which would bury some seed, and possibly return buried seed to the soil surface in subsequent years. As expected, most seedling emergence occurred in year one (2016) and then steadily declined in subsequent years. At Karoonda and Roseworthy, Indian hedge mustard seedlings were observed for three growing seasons after the initial seed placement. At Tarlee, which was the site with the highest average growing season rainfall, weed seedlings were only observed for the first two years. It appears greater seasonal rainfall may have contributed to the faster seed decay, which was reflected in lower total seedling emergence and a faster decay of the seedbank. It should also be noted that the total seedling emergence over the three years ranged from 10 per cent at Tarlee to 25 per cent at Roseworthy. Therefore, a large proportion of the seedbank of Indian hedge mustard appears to decay without producing plants. The results of this research showed this small-seeded species can persist in the seedbank for up to three years.

In contrast, seeds of Indian hedge mustard placed in nylon bags had completely decayed within two years of burial in the field. Faster decay of small-seeded species enclosed in nylon bags rather than in soil has been reported in previous studies. The seedling emergence pattern of Indian hedge mustard populations was monitored over three years at Roseworthy and this also provided useful information about the persistence of its seedbank. When averaged across 12 Indian hedge mustard populations, 76 per cent of the total emergence occurred in year one, 23 per cent in year two and 0.5 per cent in year three. These results are in agreement with the seedling establishment in the field, which also showed Indian hedge mustard emergence in three years at two out of the three field sites.

Seed production and dispersal

Indian hedge mustard is an indeterminate plant that has the ability to produce a huge amount of seeds depending on the growing season rainfall and competitive effects of the crop. In seed production assessments at Roseworthy in 2017, Indian hedge mustard produced 2594 ± 374 seeds/m^2 in a wheat crop. In contrast, it produced 51,239 ± 11,358 seeds/m^2 in lentils, which is known to be a much weaker competitor than wheat.

Figure 5: Effect of Indian hedge mustard plant density (nil, low, medium and high) on wheat and lentil grain yield at Roseworthy, SA in 2019. Weed density was 15, 69 and 120 plants/m^2 in wheat, and 3, 7 and 60 plants/m^2 in lentils. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Furthermore, all seed capsules remained intact until the harvest of wheat and lentils. Therefore, Indian hedge mustard is an excellent target for harvest weed seed control tactics.

Competition

Competitive effects of Indian hedge mustard on wheat and lentils was investigated in the field at Roseworthy, SA, in each year of the project. Crop grain yield decreased with increasing weed density. At the highest weed density, Indian hedge mustard reduced grain yield of wheat and lentils by 15 per cent. It should be noted, however, that the weed density in wheat (120 plants/m^2) was double that in lentils (60 plants/m^2). The results clearly show that even though Indian hedge mustard has a very small seed and seedlings, it can still cause economic yield losses in the absence of effective control measures.

References and further reading

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Chauhan BS, Gill G and Preston C (2006) Influence of environmental factors on seed germination and seedling emergence of Oriental mustard (*Sisymbrium orientale*). *Weed Science* 54, 1025-1031.

Llewellyn RS, Ronning D, Ouzman J, Walker S, Mayfield A and Clarke M (2016) *Impact of weeds on Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices*. Report for GRDC. CSIRO, Australia.

KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

An annual warm season grass.

Photo: Bhagirath Chauhan (University of Queensland)

LIVERSEED GRASS

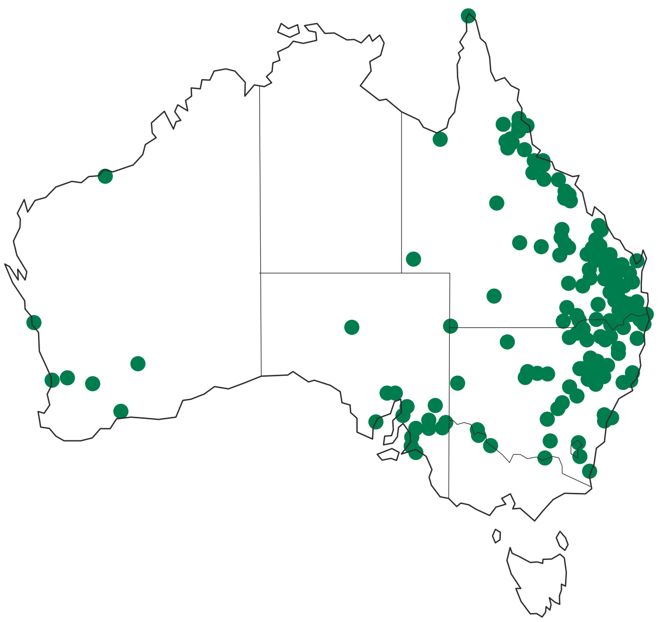
Urochloa panicoides P.Beauv.

Other common name: urochloa.

KEY POINTS

- Liverseed grass seeds have a moderate level of dormancy, suggesting some seeds will germinate immediately after shedding and others will remain dormant until subsequent seasons
- Seeds can remain viable for three years in the soil, suggesting management practices that will not allow further seed production will deplete its seedbank in three years
- It is a highly competitive weed in mungbeans; seven to 12 plants/m^2 caused 23 to 26 per cent loss of grain yield
- Liverseed grass produced 34,000 to 39,000 seeds/m^2 and 26 to 32 per cent of these seeds had dispersed at crop harvest time

Figure 1: *Urochloa panicoides* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Liverseed grass is an annual summer grass of the Poaceae family. It is an emerging weed in Australian cropping systems, proliferating in crops and in fallows in Queensland and NSW (Figure 1). It occurs to a very limited extent in SA and WA.

Description

- Liverseed grass is a tufted annual grass, sometimes rooting from the lower nodes.
- It can grow up to 1m tall.
- Seedlings are yellowish-green, with hairs on the leaf sheaths and margins.
- Leaves are hairy, up to 11mm wide and their margins crinkled. Ligule is a rim of hairs about 2mm long.
- The inflorescence comprises two to seven racemes.
- Seed heads have two to seven spikes up to 5cm long.
- Seeds occur in two rows on one side of the spike.
- Flowers during summer and autumn.

Why is it a weed?

Liverseed grass has thrived under conservation agricultural systems, causing a significant yield loss in summer crops as well as depleting soil moisture and nutrients for winter crops. It is a prolific seeder and a highly competitive weed. Resistance to herbicides from mode of action group 5 (C) and 9 (M) have been documented in Australia.

Seed

Dormancy and germination

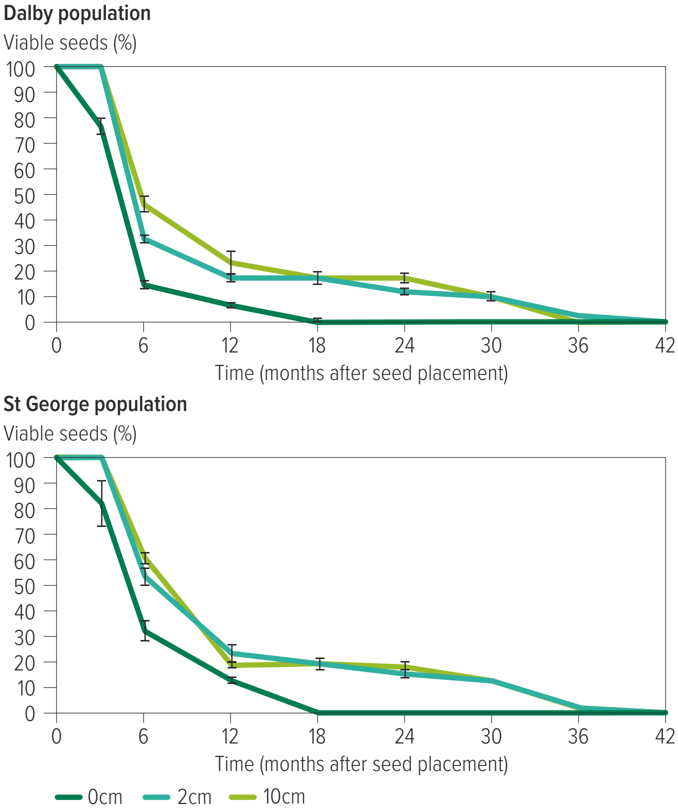
Liverseed grass seeds have a moderate level of dormancy. Fresh seeds had 40 per cent germination, which increased to 87 per cent after four months. In a recent study, seed dormancy of liverseed grass was not affected by location (high and low-rainfall regions) or management (fence versus cropped).

Seedbank persistence

A study was carried out for the seedbank persistence of two Queensland populations (Dalby – higher rainfall, St George – lower rainfall) of liverseed grass. For both populations, the depletion of the seedbank at the soil surface in a mesh bag

Figure 2: Top left: Liverseed grass seeds. Top right: Seedlings. Bottom left: Large plants. Bottom right: Infestation in mungbean.
Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of liverseed grass seed on the soil surface or buried at a depth of 2 or 10cm, over three to 42 months. Vertical bars indicate the standard error of the mean.



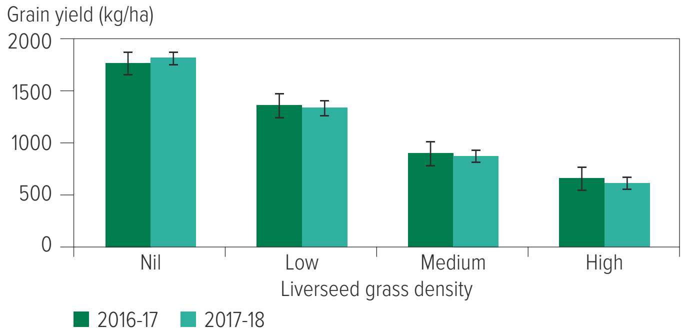
Source: University of Queensland

study was significant, with less than one per cent of seeds remaining viable after 18 months and no viable seeds remaining at 24 months (Figure 3). In this study, with seeds buried at 2 and 10cm, 17 to 23 per cent of seeds remained at 24 months. About one to three per cent of seeds were viable at these depths after 36 months, but no seeds remained viable after 42 months. In another field study, zero to three per cent of liverseed grass seedlings emerged after 18 months of seed placement and no seedlings were observed after 30 months.

Seed production and dispersal

High seed production in liverseed grass is coupled with significant dispersal rates. Maximum counts of 34,400 and 39,400 seeds/m^2 were recorded in mungbean field trials in 2016-17 and 2017-18, respectively. About 30 per cent of these seeds had dispersed at mungbean harvest. Despite this high dispersal rate for a summer grass, opportunities for destroying the seedbank through harvest weed seed control remains a potentially viable option.

Figure 4: Effect of liverseed grass density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high density of liverseed grass was 7, 18 and 35 plants/m^2 in 2016-17, and 12, 23 and 39 plants/m^2 in 2017-18.



Source: University of Queensland

Competition

Competitive effects of liverseed grass on mungbeans were investigated in the field over two seasons. Liverseed grass emerged three to four days after mungbeans. Crop grain yield decreased significantly with increasing liverseed density. At low liverseed grass density (seven to 12 plants/m^2) mungbean grain yield loss was 23 to 26 per cent (Figure 4). These losses increased to 52 per cent at medium weed density and 66 per cent at high weed density.

References and further reading

AVH (2020) The Australasian Virtual Herbarium, Council of Heads of Australasian Herbaria, https://avh.ala.org.au/occurrences/search?taxa=Urochloa+panicoides+var.+panicoides#tab_mapView, accessed 23 April 2020.

KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A winter annual that emerges in autumn and winter and matures in summer.

Photo: Gurjeet Gill (University of Adelaide)

MARSHMALLOW

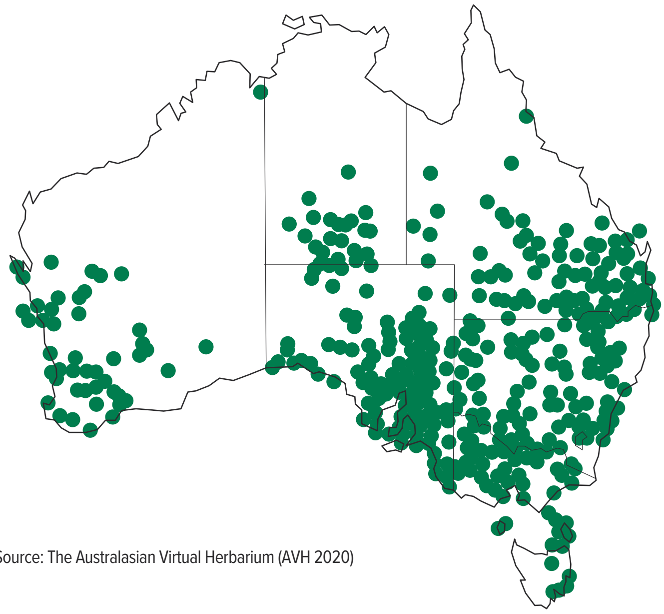
Malva parviflora L.

Other common name: small-flowered mallow.

KEY POINTS

- Marshmallow can be found in all Australian states and territories. It is inherently more tolerant to glyphosate than most other weeds of cropping systems in Australia
- Marshmallow seeds are highly dormant at the time of production and dormancy is associated with a hard seed coat. Therefore, the seedbank of this species can persist for at least four years. The results obtained indicate buried seeds are likely to persist for longer than seeds present on the soil surface
- Marshmallow is a low to moderate competitor with wheat; even at an extremely high density (139 plants/m^2), wheat yield was only reduced by 11 per cent. Care should be taken to control marshmallow plants that can establish over the summer–autumn period as they can be hard to control and are also highly competitive with crops
- Our studies confirmed previous reports that marshmallow produces around 10 seeds per flower head. However, each plant can produce many more heads in lentils than in wheat. Therefore, seed production ranged from two to 65 seeds/plant in wheat compared with 60 to 1140 seeds/plant in lentils
- Marshmallow seeds are retained effectively in the flower heads until maturity, which makes this species a good target for harvest weed seed control tactics

Figure 1: *Malva parviflora* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

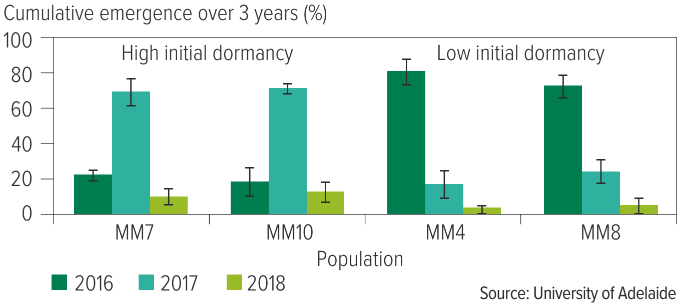
Small-flowered mallow or marshmallow are the names most commonly used to describe this weed species, which belongs to the Malvaceae family. Marshmallow originated in the Mediterranean or south western Europe and was introduced into Australia. It can be found in all Australian states and territories (Figure 1).

Description

- Marshmallow is an erect or sprawling, annual or biennial herb, which can grow up to 1.5m tall.
- It has characteristic heart-shaped cotyledons, which makes it easy to identify soon after seedling emergence.
- The leaves are round and lobed and quite distinct from other species (Figure 2 right).

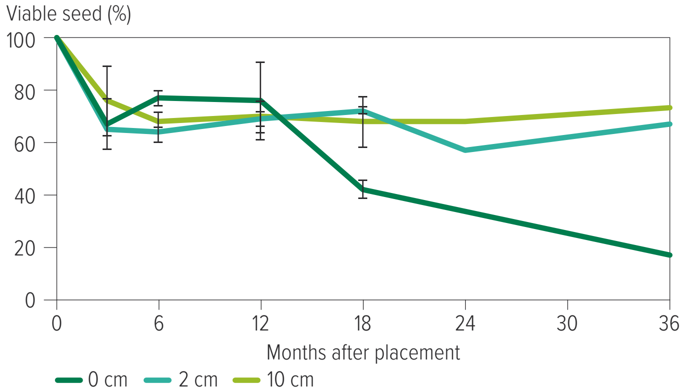
Figure 2: Top left: Marshmallow fruits, which have an appearance of tiny pumpkins, and small fruit segments that contain individual seeds. Sepals are large and remain attached to the fruit right up to maturity. Top right: Small marshmallow seedlings with heart-shaped cotyledons in the field in February 2017, at Roseworthy, SA. Bottom left: Round and lobed leaves of marshmallow are very distinct from other weed species. Bottom right: Marshmallow plants setting large amounts of seed in a lentil crop. Photos: Ben Fleet (University of Adelaide)

Figure 3: Differences in seed dormancy in marshmallow populations can lead to large differences in seedling emergence pattern. Note the large differences in seedling emergence between the low and high initial dormancy populations in 2016 and 2017. Vertical bars indicate the standard error of mean.



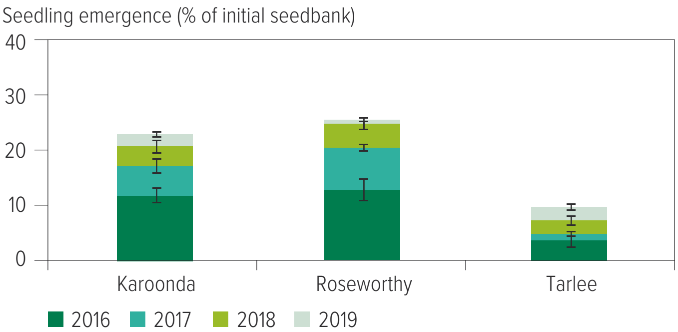
Source: University of Adelaide

Figure 4: Viability of marshmallow seed at 0, 2 or 10cm depth after burial for up to 36 months. Vertical bars indicate the standard error of the mean.



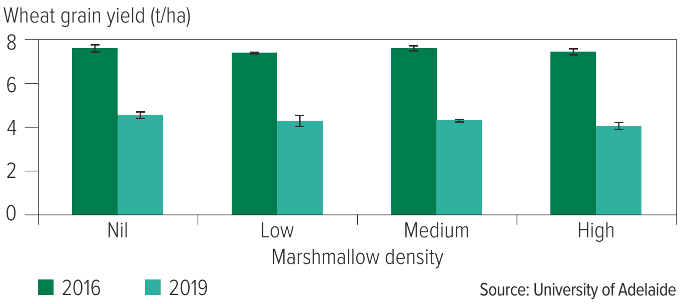
Source: University of Adelaide

Figure 5: Cumulative emergence of marshmallow seeds placed in the field at three sites in SA. Soil in these quadrats was agitated each May to simulate the crop seeding operation, which is likely to cause some seed burial. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Figure 6: Effect of marshmallow plant density (nil, low, medium and high) on wheat grain yield at Roseworthy, SA, in 2016 and 2019. As a result of seed dormancy in the seedbank, weed density was 1, 5 and 16 plants/m² in 2016. Marshmallow seed dormancy was overcome by pre-treatment with hot water in 2019, which increased its plant density to 5, 34 and 139 plants/m². Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

- Marshmallow produces small, five-petalled white or pink flowers, which swell into 10mm fruits that look like tiny pumpkins (Figure 2 left).
- Its seeds are small (1 to 2mm wide), red-brown in colour, smooth and kidney-shaped. Marshmallow produces approximately 10 seeds per flower (Michael et al. 2007).

Why is it a weed?

Marshmallow has a reputation for having a persistent seedbank, which enables it to establish plant populations even after effective management practices have been used. Grazing animals such as sheep are known to readily graze this weed and are a major vector for spreading its seeds. Hard-seeded viable seeds (approximately 20 per cent of total consumed) can be passed intact through sheep, with the majority being excreted within three days, although some seeds can still be dispersed up to seven days after initial seed digestion (Michael et al. 2006b). Even though herbicide-resistant populations have not been identified yet, marshmallow is inherently more tolerant to glyphosate than most other weeds. Therefore, plants can survive knockdown weed control unless suitable rates are used and effective mixing partners are added to glyphosate.

Seed

Dormancy and germination

In previous studies, it has been reported that freshly harvested seeds of marshmallow have high levels of innate dormancy (Chauhan et al. 2006), which is mainly associated with its hard seed coat. Michael et al. (2006a) reported that manual scarification or a period of fluctuating summer temperature (50/20°C) was required to release seed dormancy.

Marshmallow populations collected from the field can vary considerably in seed dormancy expression. As shown in the example (Figure 3), two populations (MM7 and MM10) had a higher level of initial seed dormancy and showed a much lower level of seedling establishment. In contrast, the other two populations (MM4 and MM8) had a higher component of 'soft seed' and germinated more readily in the first year after seed-set. These large differences in seed dormancy in marshmallow could be associated with spring rainfall. In seasons with good spring rainfall, seeds are likely to develop harder and thicker seed coats and express a greater level of seed dormancy than seeds produced in dry springs. It is important to note that the seedbank of even the low dormancy populations was able to persist into the third growing season.

Seedbank persistence

The effect of seed burial on the persistence of a marshmallow seedbank was investigated at Roseworthy, SA. Seeds were collected in 2016 and placed in nylon bags, which were then placed at different depths in a field at Roseworthy in 2017. Sample bags were retrieved from the field and the viability of marshmallow seeds was assessed in the lab.

Seeds of marshmallow were found to persist for 36 months at the three burial depths investigated (Figure 4). There was a clear trend for a faster decay or loss of viability in the seeds placed on the soil surface than those buried at 2cm or 10cm. Previous studies have shown lower diurnal fluctuation in soil temperature at depth than on or close to the soil surface. As marshmallow seeds have an impermeable hard seed coat, greater soil temperature fluctuation on the soil surface is likely to promote softening of the seed coat and a resultant breaking of seed dormancy. Results also show that even when seeds are present on the soil surface, they can remain viable for at least three years.

Seed persistence of marshmallow seeds was also investigated by placing them in field soil in April 2016 at three sites of contrasting rainfall (Figure 5). In each May the crop seeding process was simulated, which would be expected to bury some seed and possibly return buried seed to the soil surface in subsequent years. At all the sites, most seedling emergence occurred in year one (2016) and then steadily declined in subsequent years. From a seedbank persistence viewpoint, marshmallow seedlings emerged from the initial seedbank in all four years of this study. Seedling emergence as a percentage of the initial seedbank in year four ranged from 0.7 per cent at Roseworthy to 2.3 per cent at Tarlee, SA. These results clearly highlight that the marshmallow seedbank can persist for at least four years in field conditions in SA. The lower seedling establishment at Tarlee than the other two sites is most likely due to a higher level of seed decay at this higher-rainfall site.

Seed production and dispersal

Previous research in WA showed that marshmallow produces approximately 10 seeds per flower head (Michael et al. 2007). In studies at Roseworthy in 2019, seed production in marshmallow ranged from nine to 12 seeds/flower head in wheat and nine to 11 seeds/flower head in lentils. Of course, flower heads produced per plant can be highly variable depending on the timing of weed emergence and competitive effects of the crop. In the Roseworthy studies, seed production of two to 65 seeds/plant in wheat and 60 to 1140 seeds/plant in lentils was recorded. These results suggest poorly weed-competitive crops, such as lentils, could lead to a massive build-up in the marshmallow seedbank, which should be a cause for concern because of the long seedbank life of this species. Seeds were retained in the flower heads until crop harvest, which makes this species a good target for harvest weed seed control.

Competition

Field studies were undertaken in this project at Roseworthy to determine the competitive effect of marshmallow on wheat. In 2016, seed dormancy in marshmallow seed reduced weed establishment to levels well below the target densities. At the highest weed density in 2016 (16 plants/m^2), marshmallow competition reduced wheat yield by two per cent. In order to achieve higher weed densities in 2019, marshmallow seeds used in the trial were exposed to a pre-sowing heat treatment. This heat treatment was highly effective in breaking seed dormancy and target weed densities of more than 100 plants/m^2 were achieved. Even at the highest weed density of 139 plants/m^2, marshmallow reduced wheat yield by only 11 per cent in 2019 (Figure 6). Based on these results, marshmallow is a moderate competitor with wheat, provided weeds that establish during the summer–autumn period are effectively controlled before sowing the crop. Marshmallow plants that emerge with or after the crop appear to be weak competitors with wheat.

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

An erect-growing annual herb.

Photo: Bhagirath Chauhan (University of Queensland)

MEXICAN POPPY

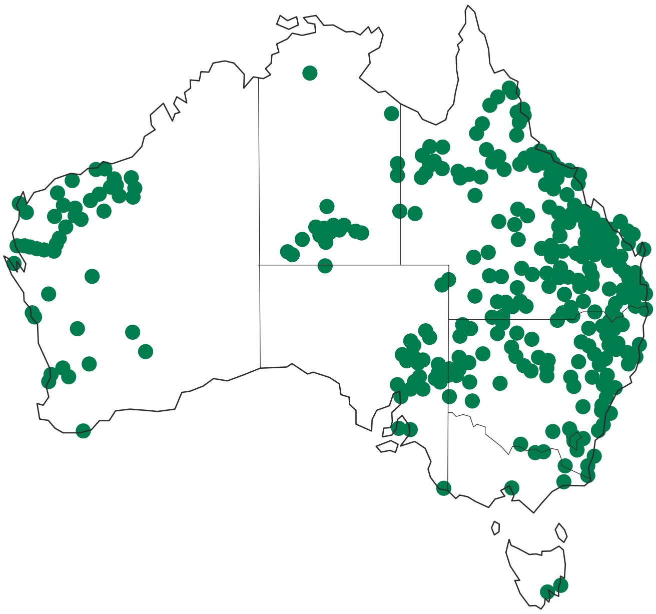
Argemone mexicana L.

Other common name: Mexican prickly poppy.

KEY POINTS

- Mexican poppy seeds are highly dormant, which allows its seedbank to potentially persist over a number of years
- Surface seeds deplete much faster than buried seeds, suggesting no-till farming systems should help to manage its seedbank
- Mexican poppy is a poorly competitive weed in wheat, suggesting the utilisation of crop competition can be a useful practice to aid in its management

Figure 1: *Argemone mexicana* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Mexican poppy is an annual broadleaf weed of the Papaveraceae family, frequently confused with *Argemone ochroleuca* L. It is an emerging weed in Queensland and NSW, particularly in crop fallows (Figure 1). Mexican poppy is a problematic weed in chickpeas and wheat cropping systems, thriving under conditions of increased moisture and low-density crops as well as in fallow periods.

Description

- Dark brown globular seeds of 1 to 2mm are present in spiked and ribbed oblong fruit of 15 to 50mm in length and 20mm in diameter (Figure 2).
- Mature stems are blue-green, grow up to 90cm and secrete a yellow sap when damaged.
- In between the yellow prickles that feature on the stem are clustered rosettes of prickly, deeply-lobed leaves. These leaves are 50 to 100mm in length and are blue-green with white veins.
- At maturity, a solitary yellow flower will develop. The weed features a lengthy taproot.

Why is it a weed?

Mexican poppy is ranked in the top 20 most costly weeds of crops in the northern region. The yellow sap present in Mexican poppy plants is poisonous to cattle. Seeds may contaminate hay, chaff or grains, which interfere with market access and make grain unsuitable for stock feed. Its very prickly nature also means it can cause injury to humans and livestock. In the soil, seeds may remain dormant for several years, making its control difficult. Mexican poppy has allelopathic properties that reduce germination of other plants.

Seed

Dormancy and germination

Mexican poppy has a high level of seed dormancy, with no germination of fresh seeds. After six months, in light/dark conditions at 20/10°C day/night temperature, its germination reached only one to four per cent across eight populations collected from high and low-rainfall regions. The mechanism responsible for dormancy in this species is not well understood, but visual observations suggest dark and/or cold stratification may increase germination.

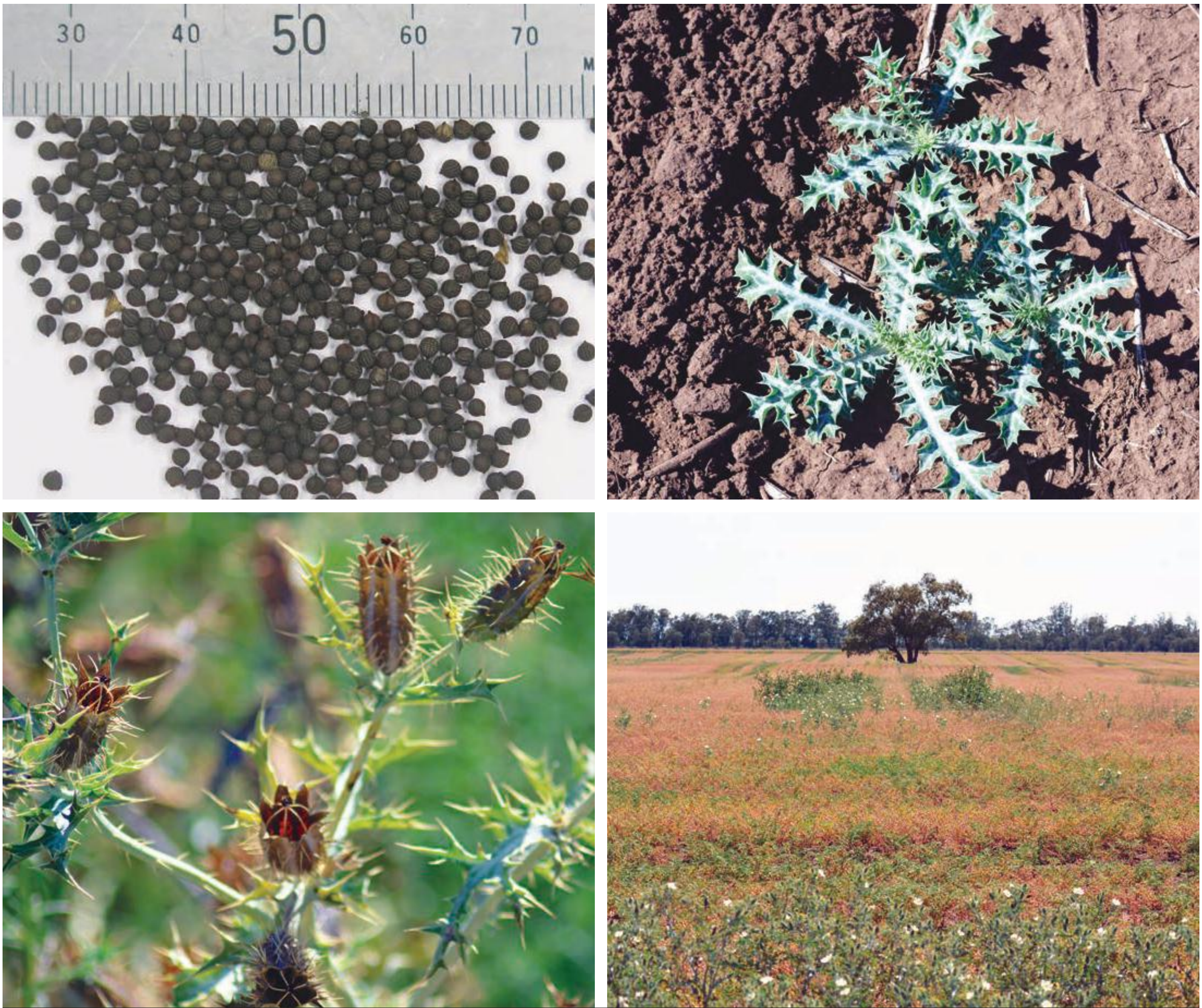
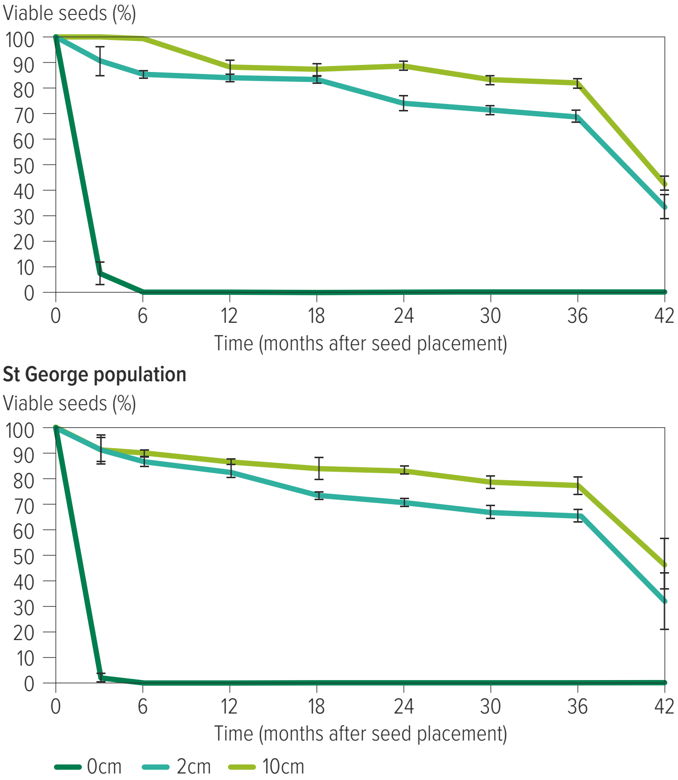


Figure 2: Top left: Mexican poppy seeds. Top right: Seedlings. Bottom left: Matured fruits. Bottom right: Infestation in chickpeas.

Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of two populations of Mexican poppy seeds on the soil surface or buried at a depth of 2 or 10cm, over three to 42 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland

Seedbank persistence

In 2015, seeds of two Mexican poppy populations in Queensland (Gatton – higher rainfall, St George – lower rainfall) were collected and studies carried out to determine the persistence of the Mexican poppy seedbank.

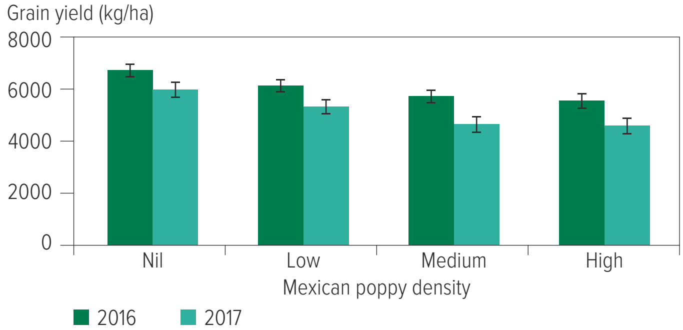
Mexican poppy seeds at the soil surface depleted rapidly with only seven per cent viable seeds after three months (Figure 3). About one per cent of seeds were viable after 12 months, but none after that. In contrast, Mexican poppy demonstrated high persistence levels when buried. After 24 months, persistence was more than 70 per cent at a depth of 2cm and 90 per cent at 10cm (Figure 3). After 42 months (last date in the study), up to 33 per cent of seeds were still viable at 2cm and 47 per cent at 10cm.

These results suggest the use of minimal or no-till systems will help in managing this weed by enabling fast decay on the soil surface. Burial is likely to increase the seedbank life of Mexican poppy.

Seed production and dispersal

In research studies, Mexican poppy failed to set seed in competition with wheat over two years.

Figure 4: Effect of Mexican poppy density on wheat grain yield at Gatton in 2016 and 2017. Error bars are least significant difference at the five per cent level of significance. Low, medium and high Mexican poppy density was 15, 44 and 74 plants/m² in 2016, and 24, 69 and 94 plants/m² in 2017.



Source: University of Queensland

Competition

In competition with wheat, Mexican poppy did not produce a high amount of biomass and yield loss was low. Compared with the weed-free plots, the low density of Mexican poppy reduced wheat yield by 10 per cent (Figure 4). The highest weed density resulted in yield reductions of 23 per cent, demonstrating its poor competitiveness in a wheat crop.

Therefore, the utilisation of narrow row spacing and high seeding rate for increased crop competition presents an effective management strategy for Mexican poppy.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

A winter annual that emerges in winter and matures in late summer, often after crop harvest.

Photo: Alicia Merriam (University of Adelaide)

PRICKLY LETTUCE

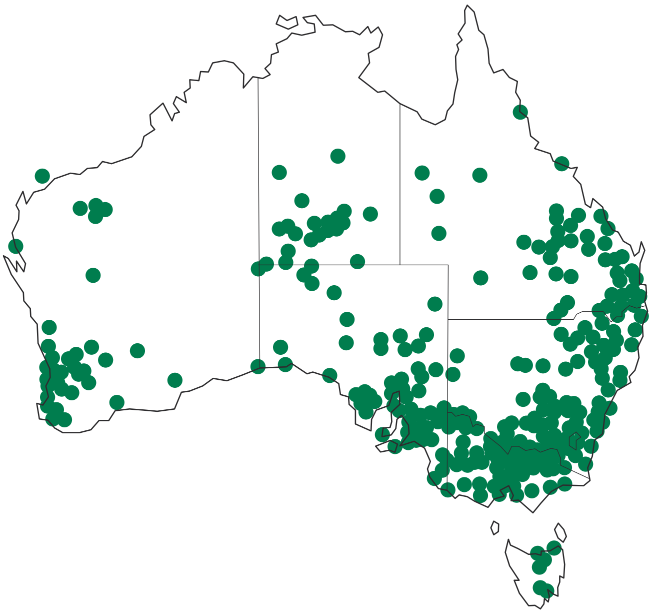
Lactuca serriola L.

Other common names: milk thistle, whip thistle, wild lettuce.

KEY POINTS

- The optimum temperatures for germination of prickly lettuce seeds ranged from 15 to 25°C and light exposure stimulated germination which is consistent with its greater infestation in no-till systems. Therefore, even shallow soil burial at 2cm depth caused a large reduction in seed germination
- Most of the seedbank of prickly lettuce emerged in the first year and the seedbank in this species did not persist for more than two years. Therefore, implementation of effective management tactics for two years should be able to exhaust the prickly lettuce seedbank. However, this is a wind-dispersed species and it is possible for its seeds to blow in from non-crop areas or other infested paddocks nearby
- At prickly lettuce plant densities of 20 plants/m^2 in wheat, it was unable to cause any crop yield loss. Low weed densities established are likely to be associated with seed burial by the seeding operation
- In the field trials at Roseworthy, SA, prickly lettuce seed production occurred after the harvest of wheat. Therefore, harvest weed seed control tactics are unsuitable for this weed species. Care should be taken to use effective herbicide treatments to prevent weed regrowth and seed-set, which tend to occur regularly in prickly lettuce

Figure 1: *Lactuca serriola* incidence in Australia



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

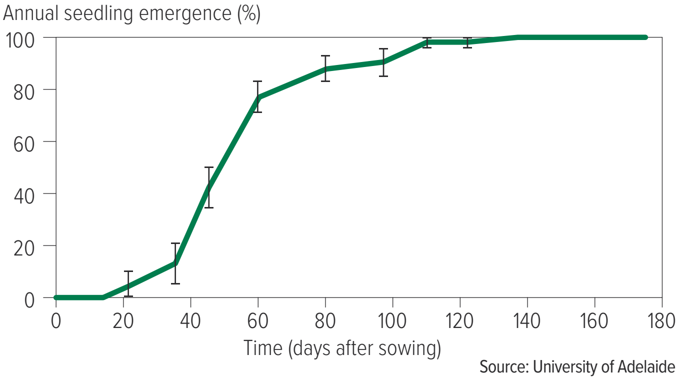
Lactuca is from the Latin *lac* or *lactis* meaning milk and refers to the milky sap. Leaves are prickly in nature, hence the name prickly lettuce. It belongs to the family Asteraceae and is believed to have originated in southern Europe, north Africa and western Asia. The cultivated lettuce (*L. sativa*) was probably derived from this species. It has been reported to occur in all Australian states and territories (Figure 1). In some areas of Australia, it is commonly referred to as whip thistle.

Description

- A tall, prickly stemmed, annual or biennial plant that has lobed and prickly leaves. The spines are mainly confined to the underside midrib and edges of the leaves. It usually has a single stem that is much branched near the top.
- Plants form a short-lived basal rosette prior to stem elongation and flowering.
- Plants exude white sticky sap when broken.

Figure 2: Top left: Seeds of prickly lettuce. Top right: Seedling at four-leaf stage. Bottom left: Prickly lettuce infestation in lentils. Bottom right: Prickly lettuce plants setting seed in a mature crop of chickpeas. Photos: Alicia Merriam (University of Adelaide) and Ben Fleet (University of Adelaide)

Figure 3: The pattern of seedling emergence of prickly lettuce populations sown in pots placed outdoors at Roseworthy, SA, in 2016. Seeds were sown on 22 April. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

- Loose, pyramidal, spike-like panicle at the end of the stem with stiff spineless branches with many flower heads.
- Flowers are pale yellow to blue 7 to 15mm long. Fruit (seed) is a pappus of many silky, barbed hairs, 3 to 6mm long, that fall off easily and assist in the wind dispersal.

Why is it a weed?

No-till and zero-till systems are known to concentrate weed seeds on or near the soil surface, which favours weed species that require light exposure for seed germination. No yield losses of cereals or grain legumes due to prickly lettuce have been reported in Australia, but grain quality and harvesting efficiency can be severely compromised (Amor 1986). Flowering buds are cut together with grain during harvest, resulting in grain contamination and reductions in value. In addition, cut stems release a milky sap that can clog harvesting machinery and increase the moisture content of the grain (Amor 1986).

Evolution of herbicide resistance has also played an important role in increasing the incidence of prickly lettuce in Australia. Resistance to ALS inhibiting herbicides was first reported in 1994 and in Victoria in 2009. Since then, resistance to group 2 (B) herbicides has become widespread in this weed species. Growers often encounter difficulties in controlling prickly lettuce in lentils, even though they have grown imidazoline herbicide-tolerant lentil varieties and used the recommended herbicides.

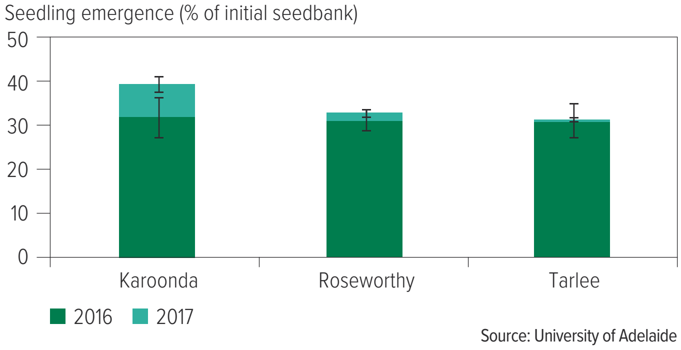
Seed

Dormancy and germination

The optimum temperatures for germination of prickly lettuce seeds ranged from 15 to 25°C (Wu et al. 2019). Light stimulated the germination of prickly lettuce seeds, which is consistent with its greater infestation in no-till systems. Therefore, it was not surprising that seed germination declined dramatically even with shallow burial in soil at 2cm depth (Wu et al. 2019). Studies undertaken at Wagga Wagga, NSW, showed prickly lettuce populations behaved similarly with 69 per cent of seedling emergence occurring in late autumn and early winter, 22 per cent in late winter and 1.4 per cent in spring of the first year. These results indicate seed dormancy in prickly lettuce is short-lived and most seedlings emerge in large cohorts in late autumn to early winter.

The seedling emergence pattern observed at Wagga Wagga by Wu et al. (2019) was similar to that seen at Roseworthy, SA, in 2016 (Figure 3). Prickly lettuce seeds were sown in trays and watered regularly to prevent water stress. Seedling emergence started at 20 days after sowing in mid-May but most seedlings established in June–July. As prickly lettuce plants spend many weeks of their lifecycle as a rosette, plants that emerge in winter are likely to be shaded by the taller cereal crops.

Figure 4: Cumulative emergence of prickly lettuce seeds placed in the field at three sites in SA, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Seedbank persistence

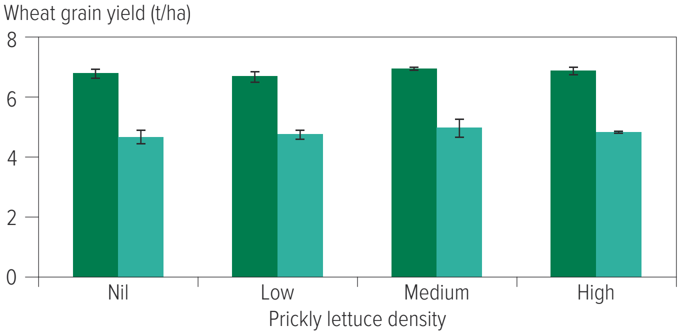
Persistence of prickly lettuce seeds was investigated by placing them in field soil at three sites in SA in April 2016 (Figure 4). In each May the crop seeding process was simulated, which would bury some seed and possibly return buried seed to the soil surface in subsequent years. At all the sites, most seedling emergence occurred in year one (2016) and then steadily declined in the second year, and no emergence was observed in years three and four. There were some differences in the level of seed persistence into the second year. At Karoonda, around eight per cent of the initial seedbank emerged in year two as compared with one per cent at Roseworthy and 0.7 per cent at Tarlee. In other words, the site with the lowest growing season rainfall had the highest level of seedbank persistence in year two. More importantly, prickly lettuce seedbank only persisted for two years at all three sites where these studies were undertaken.

These results are consistent with those of Wu et al. (2019), who showed that the NSW populations of prickly lettuce also persisted for two years. These results clearly highlight the short-term (two years) persistence of the seedbank of prickly lettuce. Seeds of prickly lettuce also persisted for two years in seedling emergence trays at Roseworthy, SA. In this study, 96 per cent of the cumulative emergence occurred in year one and four per cent in year two. There was no seedling emergence in the third year, which is consistent with the exclusion ring study in SA and results from Wagga Wagga, NSW.

Seed production and dispersal

Plants of prickly lettuce in wheat were smaller relative to lentils, and most had not flowered until crop harvest. Flowering buds of the plants were cut during crop harvest but they tend to regrow and produce seeds after harvest. The amount of seed produced depends on the level of soil moisture at harvest as well as post-harvest rainfall. In situations with high prickly lettuce infestations, it is important to apply post-harvest herbicide treatments to kill prickly lettuce regrowth in summer. If herbicide treatments are not applied at the correct timing, there can be considerable seed-set in the absence of crop competition and these seeds can be easily dispersed by winds. As seed-set in prickly lettuce usually occurs after the harvest of crops, harvest weed seed control tactics are likely to have no impact on the build-up of the seedbank.

Figure 5: Effect of prickly lettuce plant density (nil, low, medium and high) on wheat grain yield at Roseworthy, SA. Weed density was 3, 5 and 20 plants/m^2 in 2016, and 4, 6 and 17 plants/m^2 in 2017. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Competition

Field studies at Roseworthy, SA, in 2016 and 2017 showed no significant effect of prickly lettuce plant density on wheat yield (Figure 5). Even though the highest weed density established at the site was low (around 20 plants/m^2), this is fairly typical of prickly lettuce densities found in the field. Lack of yield losses incurred in both years appears to be related to delayed weed establishment and prostrate early growth habit of the weed, which allows wheat to shade it and reduce its growth. The major negative effects of prickly lettuce on crop production in SA appear to be associated with reduced grain quality and harvesting efficiency caused by clogging of harvest machinery due to its milky sap and green plant material. As stated by Amor (1986), flowering buds are cut together with grain during harvest, resulting in grain contamination and reductions in value. However, this weed species is highly tolerant to dry and hot conditions and can recover from defoliation at harvest and set seed.

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

Hanwen Wu
NSW Department of Primary Industries
hanwen.wu@dpi.nsw.gov.au

While this species is often a summer annual, roly poly can emerge at any time of the year, with different peak emergence times for different populations.
Photo: Dave Nicholson (DPIRD)

ROLY POLY

Salsola australis R.Br.

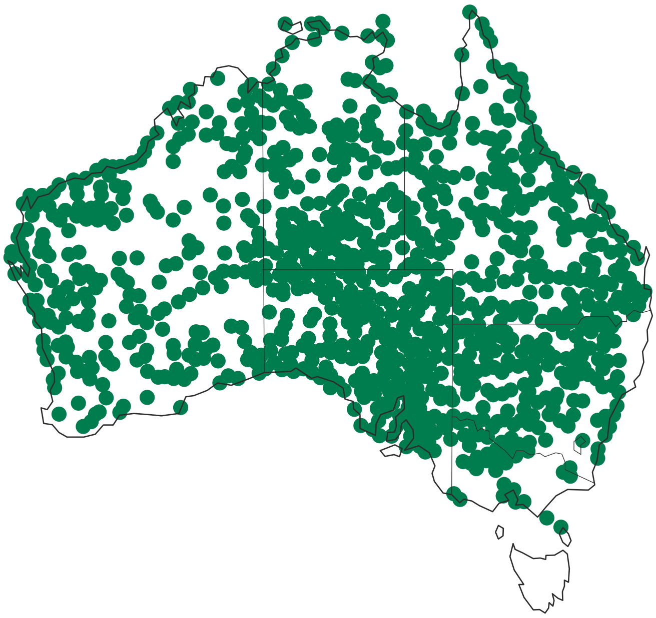
Other common names: prickly saltwort, tumbleweed, buckbush, prickly roly-poly, Russian thistle, saltwort and soft roly poly.

Synonyms: *Salsola tragus* L., *Salsola kali* L.

KEY POINTS

- This widespread native has a short-lived seedbank of one to two years
- Emergence can occur throughout the year as seeds have little dormancy and can germinate over a broad temperature range
- Roly poly is not usually highly competitive in crops but is more vigorous in areas with alkaline soil
- Can be a widespread weed of fallow and pasture
- Broad seed dispersal via the iconic 'tumbleweeds' means preventing plants from rolling into the field (from the fenceline or neighbouring fields) is as important as controlling plants within the field

Figure 1: *Salsola australis* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Roly poly belongs to the Chenopodiaceae family. It is a native species found throughout Australia, with the exception of Tasmania (Figure 1). It is similar to black roly poly (*Sclerolaena muricata*), kochia (*Kochia scoparia*) and tumbleweed (*Amaranthus albus*).

Description

- Mature plants are erect, approximately 60cm tall (maximum diameter of 2m), and usually mature in summer, although they can grow at other times of the year.
- Plants have tangled branches from the main stem and grow in a round or hemispherical shape, although plants may be prostrate particularly in a saline environment.
- Seedlings have two cotyledons, approximately 10mm long and round in section (for example like a cylinder, not flat like other plant leaves).
- Young plants have round, succulent leaves that are less than 5mm to more than 50mm long. Plants may stay in the juvenile growth stage for several weeks or months, or progress to the adult growth stage in two to three weeks.
- Mature leaves are short (less than 10mm), flat and taper to a spine (1 to 5mm long).
- Flowering/reproduction may start as soon as the plant enters the adult stage or up to six months later, generally in spring–autumn.
- Growth is indeterminate; juvenile growth (with round, succulent leaves) may sprout from axillary buds near the stem base when the plant is in the adult growth/reproductive stage.
- Single seeds form at the base of each leaf. Each seed is contained in a fruit with five papery wings, although wingless fruit are also found on each plant.
- Plants can grow as annuals or perennials, although life span is not related to size or seed production. Following senescence, the plant may break free at ground level, allowing the wind-driven plant to travel considerable distances.

Figure 2: Top left: Roly poly branches with seeds beginning to shed. Top right: A young plant in the juvenile growth stage. Bottom left: A mature plant bearing flowers. Bottom right: Dead plants along a fenceline. Photos: Catherine Borger and Dave Nicholson (DPIRD))

Figure 3: Viability of roly poly seed on the soil surface or buried at a depth of 2 or 10cm, over three to 36 months. Initial seed viability was 100 per cent when seeds were placed in the field (that is, zero months). Vertical bars indicate the standard error of the mean.

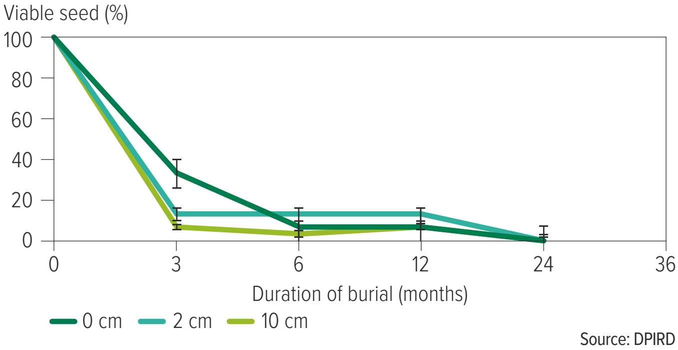
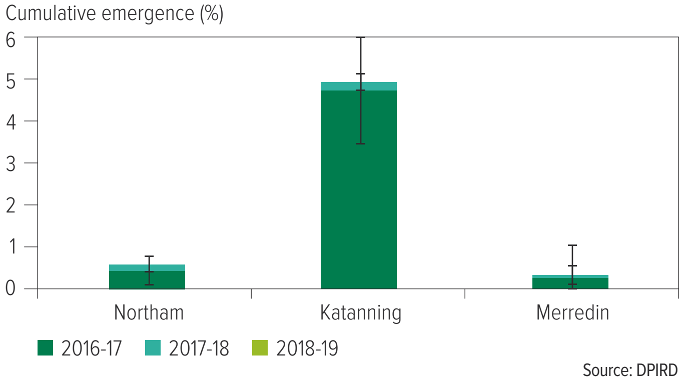


Figure 4: Cumulative annual emergence of roly poly (as a percentage of the total weed seeds planted) at three locations in WA from 2016 to 2019. Vertical bars indicate the standard error of the mean.



- There are many variants that are morphologically distinct (for example, populations of plants that look a bit different to roly poly) but are not classified as separate species/subspecies. For example, some plants have flowers crowded towards the end of the branches.
- Roly poly is commonly confused with black roly poly (*Sclerolaena muricata*), kochia (*Kochia scoparia*) and tumbleweed (*Amaranthus albus*). Black roly poly is hairier, and the seeds are a tube shape with spines rather than papery wings. Kochia is also hairy, has flat leaves that do not have a spine on the end, and star-shaped fruit. Tumbleweeds also have flat leaves that are not round like the juvenile roly poly leaves, or tipped with a spine like the adult roly poly leaves.

Why is it a weed?

Roly poly, along with a range of other species in the *Salsola* genus, is a prominent weed of agricultural systems globally. Like most summer weed species, roly poly utilises soil moisture and nutrients that would otherwise be available to the following crop. The time taken to clear uncontrolled plants may delay seeding. In some areas, plants may grow over winter/spring and directly compete with the crop.

Livestock will graze the young plants. However, stock will not eat the mature plants and are injured by the prickly leaves. This species has tentatively been linked to oxalate poisoning, but most tests indicate oxalate levels are too low to poison sheep. Levels of oxalates and nitrates in roly poly may increase in the presence of nitrogen fertiliser or legume species.

The dead, mobile plants are a fire hazard, particularly when too many plants pile up against fences or buildings. As a native species, roly poly is not a problem in areas of native vegetation and plays a valuable role in revegetation of disturbed sites.

Seed

Dormancy and germination

Roly poly seeds have variable dormancy. There are short-term after-ripening requirements as the seed finishes maturing, and then seedlings germinate following exposure to sufficient moisture. However, in the event of rainfall during seed production (direct water contact with the seeds), some seeds will sprout prior to shedding and while still attached to the plant. Seeds shed before, during and after the plant senesces (dies). A mature, senesced plant also contains younger seeds that will not initially shed. These retained seeds have similar viability to the shedding seeds, but have greater dormancy (due to lack of maturity). The retained seeds shed over time due to natural ageing and weathering, regardless of whether the senesced plant is mobile or stationary. The viability of the retained seed dropped to less than two per cent, two months after the plant reached senescence. Since these retained seeds have such low viability, they will have little impact on population growth. However, the retained seeds may be more broadly dispersed if the mature senesced plants continue to move.

Seeds will germinate over a wide temperature range, although 11 to 20°C is the optimal temperature. No germination occurs over 40°C and germination is reduced at 5°C. Burial is not necessary for germination, but increases the likelihood that a seedling will successfully establish.

As seeds have little dormancy and can germinate over a broad temperature range, emergence can occur throughout the year. Peak establishment is variable between populations. For example, roly poly seed collected from plants at Lake Grace, WA, had peak establishment in summer, while seed collected from Morawa, WA, had peak emergence in winter and seed from Merredin, WA, emerged in small cohorts throughout the year. All three populations had the same temperature range for optimal germination and yet all populations had different optimal germination times when grown in controlled conditions at Perth, WA. Clearly these populations have evolved differences in dormancy/after-ripening requirements in response to different environmental conditions or agronomic management regimes in the different regions.

Seedbank persistence

In field conditions at Northam, WA, viability of roly poly seed was investigated by placing seeds on the soil surface or at a depth of 2 or 10cm for three years (Figure 3). The results demonstrated that roly poly seeds either on the soil surface or buried at depth had high germination or degradation during the first three months after burial, with viability of seed dropping to less than four per cent after three months in the field. After 24 months the seedbank was completely exhausted.

Likewise, seed emergence of roly poly in irrigated conditions (averaged over 12 populations) was 89 per cent in the first year and less than three per cent in the second and third years. This indicates most seedlings result from mobile plants rolling into an area, rather than a dormant seedbank.

Roly poly seeds were placed in micro-plots in the field for three years (at three sites in WA), with the soil agitated each year (May) to simulate crop seeding (Figure 4). Under these conditions, emergence in the first year was related to rainfall, with greatest emergence at Katanning (higher rainfall) and reduced emergence at Merredin and Northam. However, emergence at all sites was low, indicating seed in field conditions either degraded or germinated after a small rainfall event and subsequently died without emerging. In the second year, emergence was lower than one per cent in all three sites and there was no emergence in the third year.

It is clear that, in field or controlled conditions, most emergence occurs in year one. A single year of complete control will remove most of the viable weed seedbank in a range of environments, regardless of whether the seeds are shallowly buried or on the soil surface. However, part of the control strategy needs to consider mobile plants from other areas. If dead senesced plants are not prevented from entering a field, new seed will be added to the seedbank.

Seed production and dispersal

Seed production of roly poly is highly variable, ranging from 95 to 19,596 seeds per plant, or up to 8303 seeds/m^2. Following senescence, mature plants may break free of their root system, although some plants remain stationary. The wind-driven plants travel considerable distances (from 1m to more than 1km), shedding seeds as they move. Eventually the plants become entangled in fencelines, vegetation or other dead roly poly plants. In a dense stand of roly poly, about half of the plants become entangled with other roly poly plants before they can travel far, but about 10 per cent of plants will move over fences to travel longer distances. Seed shedding commences before the plants become mobile and increases with movement, but is also related to the ageing and weathering experienced by plants. All plants retained a proportion of their seeds in spite of movement, weathering and ageing.

Competition

At Wongan Hills, WA, roly poly failed to establish in-crop or affect yield over three years. However, this species is most abundant in alkaline or saline soils. It has been recorded growing throughout the year in Lake Grace, WA, and staggered cohorts made it difficult to kill all plants in-crop. This species can be highly competitive in pasture as livestock avoid grazing the prickly mature plants, allowing them to outcompete more desirable pasture species. Roly poly can establish in high density in fallows, depleting moisture and nutrients.

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

Mature Sesbania pea plant.

Photo: Geoff Sainty

SESBANIA PEA

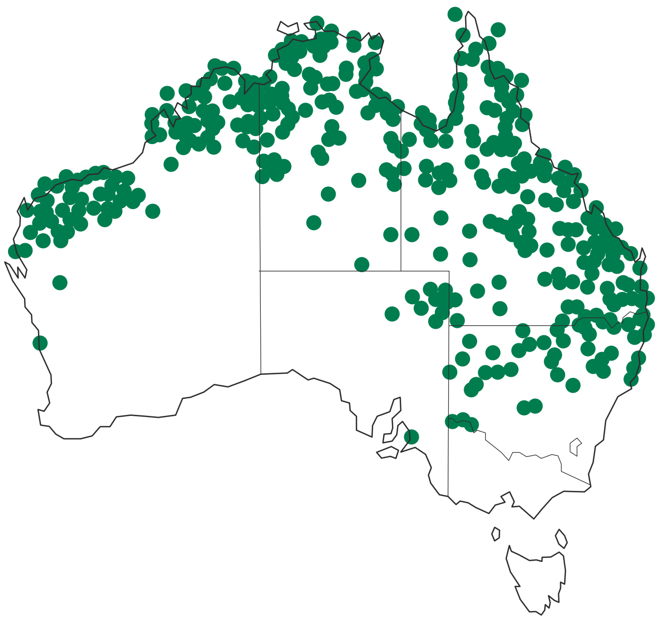
Sesbania cannabina (Retz.) Pers.

Other common names: Sesbania, yellow pea-bush.

KEY POINTS

- Sesbania pea seeds are highly dormant due to a hard seed coat, suggesting a protracted germination pattern for several years
- Seeds remain viable in the soil for more than 3.5 years and burial increases the seedbank life of sesbania pea
- It is highly competitive in mungbeans; 26 to 36 plants/m^2 reduced grain yield by 60 per cent
- Seed production in-crop was recorded to be up to 17,000 seeds/m^2 and all seeds were retained at harvest time, suggesting potential for harvest weed seed control

Figure 1: *Sesbania cannabina* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Sesbania pea is an annual broadleaf legume weed from the Fabaceae family. Its natural distribution includes Asia and Australia, so it is in fact a native. It has become increasingly prevalent across the northern regions of Australia, particularly in Queensland and NSW (Figure 1).

Description

- Dark green-brown seeds of 1 to 2mm have a hard seed coat (Figure 2).
- Cotyledons of 15 to 17mm are oblong and broad.
- At maturity, stems reach between 1 and 3m and produce green obovate stipules on alternating petioles of 5 to 20cm in length. One to five racemes with yellow corollas of 10mm appear at flowering.

Why is it a weed?

Sesbania pea is a dominant weed in summer grain systems and cotton due to its vigorous growth and competitiveness across a variety of growing conditions. Its prevalence in crops is exacerbated by tolerance to glyphosate and the difficulty of managing its presence in mungbeans and soybeans, which are from the same plant family.

Seed

Dormancy and germination

Sesbania pea possesses a high level of seed dormancy and is able to germinate across a broad range of conditions. Initial germination rates were 20 per cent in the lab under light/dark conditions at 30°/20°C day/night temperature. Germination increased to 87 per cent after hot water treatment for 3 minutes, suggesting that sesbania pea has physical dormancy due to a hard seed coat. In the field, seeds on or near the soil surface will experience greater fluctuations in temperature and moisture conditions and predation activities than buried seeds. These conditions will help seeds to germinate or decay faster on the soil surface than at soil depths.

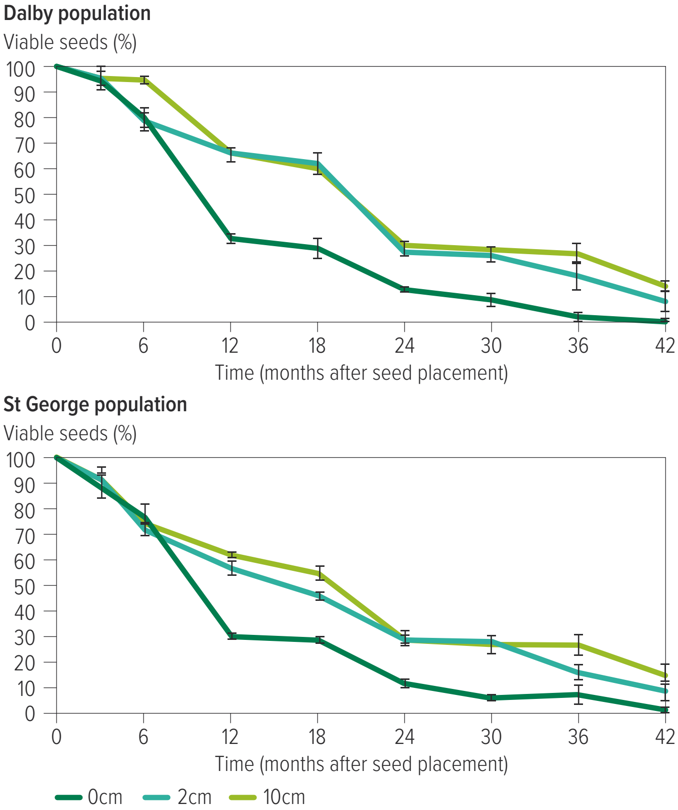
Sesbania pea seeds germinated at a wide range of constant temperatures ranging from 14°C (5 per cent) to 35°C and alternating day/night temperatures ranging from 20°/10°C (35 per cent germination) to 35°/25°C (83 per cent germination). The optimum constant and alternating temperature regimes were 32°C (86 per cent) and 30°/20°C (87 per cent germination), respectively. These results suggest that sesbania pea has high adaptability and can germinate throughout spring, summer, and autumn seasons in the northern grain region of Australia. Germination of sesbania pea was similar between light and dark conditions, suggesting that seeds can germinate under a closed crop canopy, crop residues, or mulches.

Seedling emergence in sesbania pea (scarified seeds) was greatest (82 per cent) at the depth of 1 cm and emergence decreased linearly from 48 to 13 per cent, with increases in burial depth from 2 to 8 cm. These results indicate the potential for minimising emergence of sesbania pea through implementation of inversion tillage to bury seeds deeper (>8 cm) in the soil profile.

Figure 2: Top left: Sesbania pea seed. Bottom left: Sesbania with cotyledons. Bottom right: Seedlings in a mungbean field.

Photos: Geoff Sainty and Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of sesbania pea seed on the soil surface or buried at a depth of 2 or 10cm, over three to 42 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland

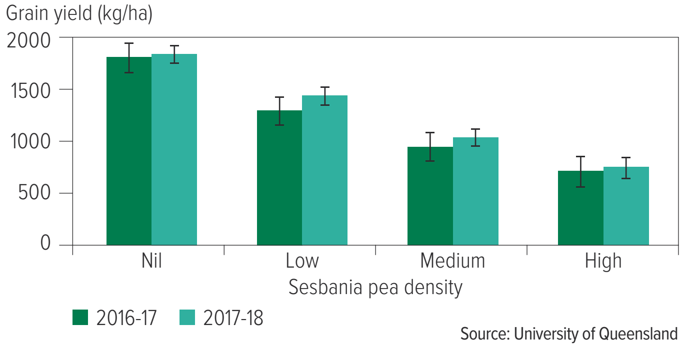
Seedbank persistence

A study was carried out on the seedbank persistence of two populations in Queensland (Dalby and St George). Seeds were collected in 2016 and placed in nylon bags, which were then placed at different depths in a field at Gatton, Queensland. For both populations, a high level of seedbank persistence was evident in this study (Figure 3). Persistence at the soil surface (0cm) after 12 months was 30 to 33 per cent, which reduced to 11 to 13 per cent after 24 months and two to seven per cent after 36 months. Even after 42 months, one per cent of seeds were still viable on the soil surface. Viability for buried seeds was much greater than the surface seeds. Even after 42 months, up to nine per cent of seeds were viable at a burial of 2cm and 15 per cent at 10cm depth. These results suggest burial will increase the seedbank life of sesbania pea.

Seed production and dispersal

Sesbania pea at a density of 26 to 36 plants/m^2 produced a maximum number of 12,500 and 17,200 seeds/m^2 in 2016 and 2017, respectively. All seed production was retained at the time of mungbean harvest. This high level of seed retention presents a favourable opportunity to utilise harvest weed seed control for management of a weed featuring such substantive seed production.

Figure 4: Effect of sesbania pea density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high sesbania pea density was 8, 15 and 26 plants/m^2 in 2016-17, and 10, 16 and 36 plants/m^2 in 2017-18.



Source: University of Queensland

Competition

Results in the field showed sesbania pea reduced mungbean yield significantly over both years studied. A lower density of eight to 10 plants/m^2 of sesbania pea led to mungbean yield reductions of 22 to 29 per cent (Figure 4). Where sesbania pea density increased to 26 to 36 plants/m^2, there was a 60 per cent yield reduction compared with the weed-free plots.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

An annual broadleaf herb that can establish any time of the year.

Photo: Bhagirath Chaunhan, University of Queensland

SOWTHISTLE

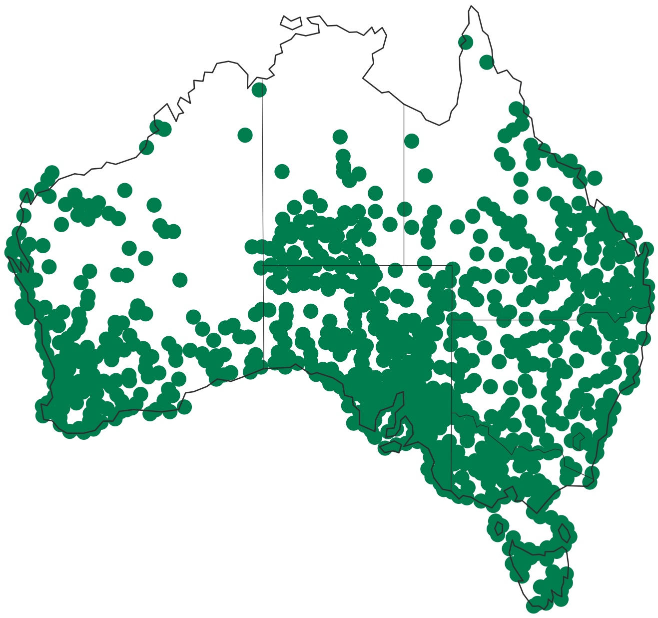
Sonchus oleraceus L.

Other common name: milk thistle.

KEY POINTS

- Sowthistle has low seed dormancy and can emerge following rainfall events at any time of year
- The seedbank is short-lived (one to three years), indicating two years of intensive control will reduce the population to very low levels. However, the broad seed dispersal, especially via wind, can allow sowthistle to quickly reinfest areas
- The competitive ability of sowthistle in-crop is moderate in the Mediterranean environment of WA and SA, and high in irrigated Queensland crops
- It can be a prevalent fallow weed

Figure 1: *Sonchus oleraceus* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Sowthistle is a broadleaf weed in the Asteraceae family, also commonly referred to as milk thistle. It has established prolific infestation across agricultural regions of Australia (Figure 1), with rapid emergence in the northern grain region.

Description

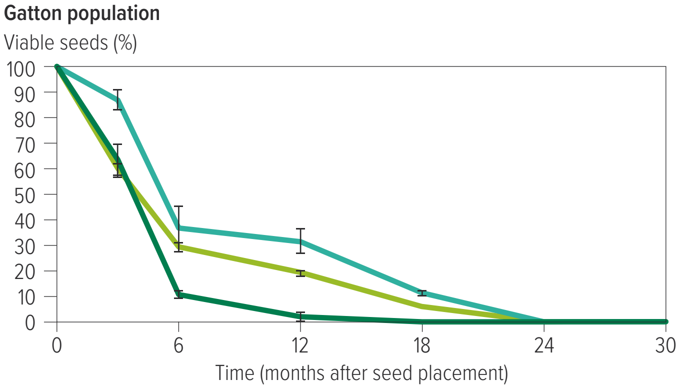
- Seedling cotyledons of 6 to 10mm are oval and hairless with flat to slightly indented tips (Figure 2).
- Young plants may form a rosette or have an upright growth form.
- Mature stems are 30 to 200cm tall with grooves and red coloration running their length. When damaged, the hollow stems secrete a white latex sap.
- Leaves are 6 to 30cm in length and are irregularly lobed or toothed with pointed tips, largely concentrated at the base of the plant.
- At maturity, clusters of conical flower heads with yellow petals develop, with very fine pappus and achene later forming.
- Individual seeds are enclosed in a brown, oblong achene of 2.5 to 3mm, with a tuft of fine hairs (pappus) on the end.
- Sowthistle features a robust and lengthy taproot with wide-spreading lateral roots.

Why is it a weed?

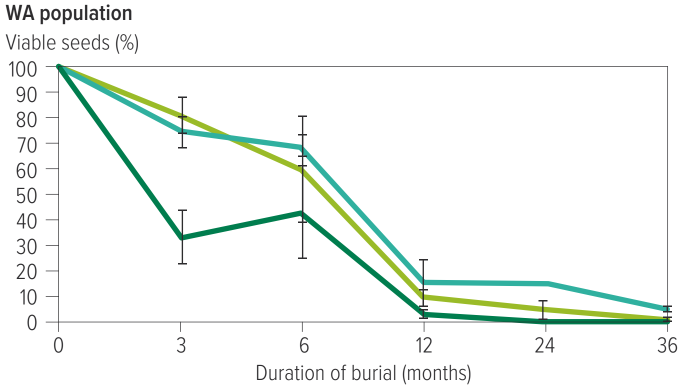
Sowthistle has rapidly emerged as a significant weed in Australian cropping systems, proliferating in fallows due to soil moisture, residual fertility and low competition. Its small seed size, vast seed production and rapid seed dispersal have also greatly contributed to this spread. Sowthistle germination under conservation agriculture is highly adaptable to varying environmental conditions. Resistance to Group B (ALS inhibitors), I (synthetic auxins) and M (glyphosate) herbicides have been documented in Australia. Sowthistle is a major problem across summer, winter and fallow cropping phases.

Figure 2: Top left: Sowthistle seeds. Top right: Seedlings. Bottom left: Young plants in a wheat crop. Bottom right: Mature plants. Photos: Catherine Borger (DPIRD)

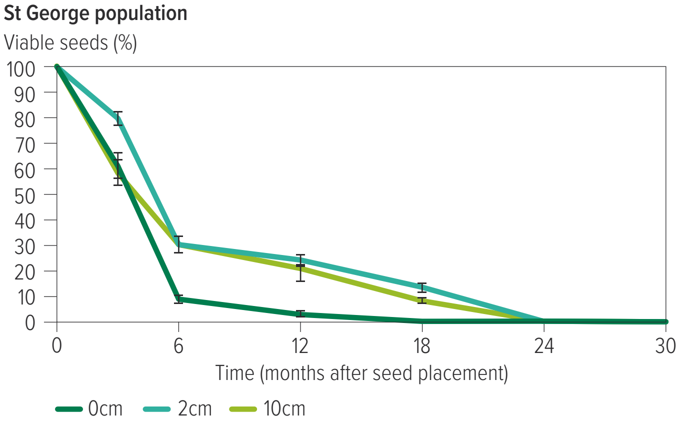
Figure 3: Viability of sowthistle seed on the soil surface or buried at a depth of 2 or 10cm, over three to 36 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland



Source: DPIRD



Source: University of Queensland

Seed

Dormancy and germination

Sowthistle is able to germinate under a wide array of environmental conditions and management strategies. Adaptability to varying pH, salinity, moisture and temperature conditions provides the weed with a highly competitive seeding potential. Sowthistle seeds are able to germinate shortly after reaching maturity. This low dormancy is compounded by the capacity to germinate under a broad range of moisture and temperature conditions.

Incubation studies on the effect of light and temperature on sowthistle germination found complete darkness to have the most significant effect. Across all temperatures, germination rates in darkness fell in the range of 47 to 53 per cent in two populations from Queensland. Initial germination tests immediately following seed collection found rates of 86 to 87 per cent in light/dark conditions for the two populations. Germination was above 84 per cent at temperature regimes of 20/10, 25/15 and 30/20°C day/night temperature, with decreased germination at 15/5°C. The capacity for sowthistle to germinate across broad temperature ranges, as well as complete darkness, demonstrates its adaptability to conditions occurring across all growing seasons.

Seedling emergence was highest at the soil surface, with 83 and 87 per cent germination recorded for Gatton and St George populations, respectively. Emergence decreased concurrent to increases in depth. No seedling emergence was observed from 6cm depth. These results indicate the use of occasional and deep inversion tillage, as well as the presence of thick crop residues, could reduce sowthistle populations.

Seedbank persistence

A study with three components was carried out for the seedbank persistence of two populations of sowthistle in Queensland and WA. In 2015, weed populations were sampled for mature seeds/fruits in the regions of Gatton (higher rainfall) and St George (lower rainfall) in Queensland, and York (higher rainfall) and Merredin (lower rainfall) in WA.

Seeds from all populations placed on the soil surface degraded rapidly, with less than five per cent viable seed remaining after 12 months (Figure 3). No seeds remained viable at the soil surface at 18 months. In Queensland, complete seed depletion was recorded at 24 months for all depths. In WA, seed buried at 2 or 10cm retained a low level of viability at 24 and 36 months.

When the seeds of each population were sown in plots and left in field conditions for three years (with the soil agitated once a year to simulate crop seeding), similar results were found for all populations. In both Queensland and WA, total seedbank depletion occurred within 2.5 years. Again, the use of deep inversion tillage may have strong potential for reducing seedbank persistence.

Similar results were obtained at two field sites (Karoonda and Tarlee) in SA, where seedling emergence of sowthistle was only observed over the first two years after the establishment of the seedbank (Figure 4). However, at a third SA site, Roseworthy, some seedling emergence was also observed in the third year (2018) after the introduction of the seedbank. There was no seedling emergence of sowthistle in 2019 (fourth year). Therefore, seedbank persistence in sowthistle appears to last for two to three years across the northern, southern and western regions.

Seed production and dispersal

Sowthistle is a prolific seed producer and its seeds can be readily dispersed by wind. Maximum seed counts of 183,000 and 193,000 seeds/m^2 were recorded in irrigated wheat in Queensland, and 886 to 3344 seeds/m^2 in dryland wheat in WA. In a field trial at SA in 2019, seed production in sowthistle growing in a wheat crop ranged from zero to 450 seeds/plant. In contrast, seed production by this weed species in lentils ranged from 400 to 8300 seeds/plant. In Queensland, 95-95 per cent of these seeds had dispersed by the time of crop harvest. In WA, shedding commenced in October and seed loss at harvest ranged from 55 to 95 per cent. The trends observed in the timing of seed dispersal in SA were very similar to WA. Due to this high pre-harvest dispersal in sowthistle, opportunities for capturing seed for harvest weed seed control are very limited.

Figure 4: Cumulative yearly emergence of sowthistle (as a percentage of the total weed seeds planted) at three locations in SA from 2016 to 2019. Vertical bars indicate the standard error of the mean.

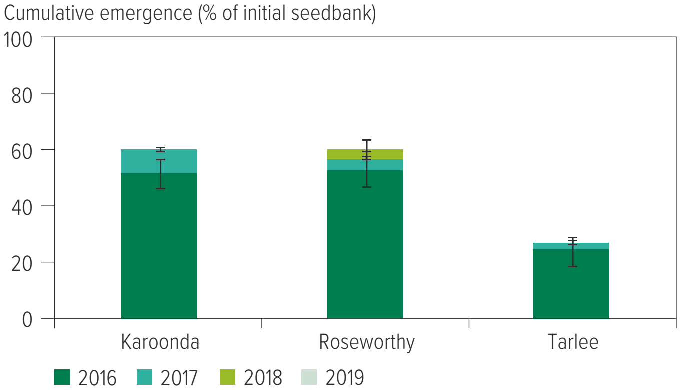
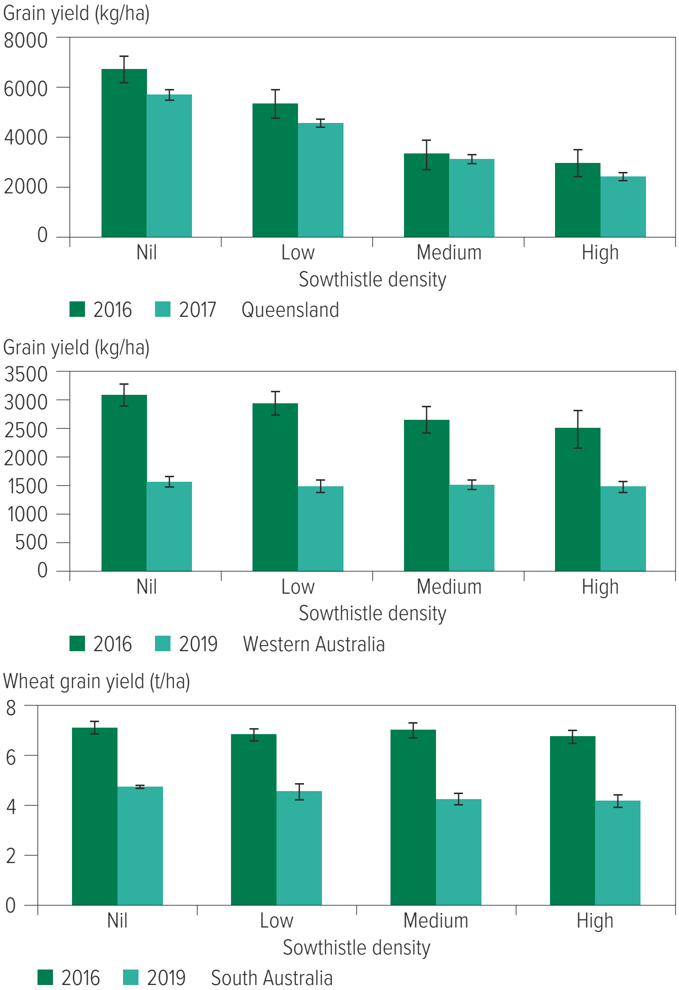


Figure 5: The response of wheat grain yield to increasing densities of sowthistle at Gatton, Queensland (top), Wongan Hills, WA (middle), and Roseworthy, SA (bottom). In Queensland, sowthistle density in the low, medium and high density plots was 13, 36 and 70 plants/m² in 2016, and 19, 44 and 70 plants/m² in 2017. In WA, sowthistle density was 99, 166 and 287 plants/m² in 2016, and 19, 55 and 98 plants/m² in 2019. Weed densities in SA were 12, 38 and 160 plants/m² in 2016, and 27, 50 and 169 plants/m² in 2019.



Source: DPIRD, University of Adelaide and University of Queensland

Competition

At Gatton (Queensland), compared with the weed-free (nil) plots, the high density (70 plants/m²) of sowthistle reduced wheat yield by 56 to 57 per cent (Figure 5). Under lower sowthistle density (13 to 19 plants/m²) yield reduction was 20 per cent. In field trials in WA (Wongan Hills), wheat yield was more closely related to sowthistle emergence time than density. Wheat emerged in May or June but, depending on season, initial sowthistle cohorts emerged in June, July or even August. Where the crop was weed free for the first weeks of development, even 349 sowthistle plants/m² could not affect yield. The competitive effect of sowthistle on wheat yield in SA (Roseworthy) was modest and quite similar to that observed in WA. This weed species appears to exert much larger competitive effects on wheat under warmer growing conditions in the northern region, as compared with the cooler Mediterranean environment of WA and SA.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

A winter annual that emerges in autumn and winter and matures in late summer.

Photo: Sam Kleemann (University of Adelaide)

STATICE

Limonium lobatum (L.f.) Chaz.

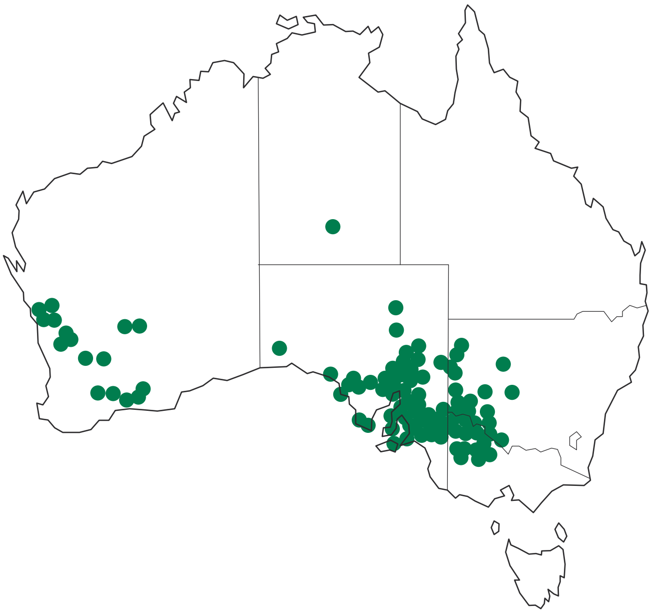
Other common names: statice, winged sea lavender, winged sea-lavender.

Synonyms: *Limonium thouinii* (Viv.) *Kuntze, Statice lobata* L.f., *Statice thouinii* Viv.

KEY POINTS

- Statice is a localised weed of significance on sandy textured soils, often associated with sodicity or salinity. Such conditions occur in agricultural areas in the Mallee of SA and Victoria
- The seedbank of statice was found to decay at a rapid rate with no new seedling establishment in the second year on soils with medium to high soil organic carbon. However, on a sandier, low organic carbon soil, seeds of statice were able to produce some seedlings in the second year. Rapid seed decay observed in some soils appears to be associated with higher soil organic carbon and microbial biomass
- Seed germination in statice is strongly stimulated by exposure to light, which is consistent with high seedling establishment observed on the soil surface and its preference for pastures and no-till systems
- Low seedling establishment in crops and its flat growth habit early in the season may be responsible for its inability to cause a significant yield loss in wheat in the field trials undertaken
- Seed production in statice often occurs after crop harvest. Therefore, post-harvest control tactics are likely to be very important to prevent weed population build-up

Figure 1: ***Limonium lobatum*** **incidence in Australia.**



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Statice is a weed in the Plumbaginaceae family, which is native to northern Africa (Algeria, northern Egypt, Libya, Morocco and Tunisia), the Canary Islands, south-eastern Spain, southern Greece and western Asia. In Australia, this species is more prevalent in SA, Victoria, NSW and WA (Figure 1).

Description

- An autumn or winter-germinating annual, more or less glabrous (hairless) to 1m high.
- Basal leaves 3 to 10cm long, 10 to 40mm wide, five to seven-lobed.
- Flowering stems three-winged (Figure 2 top right); wing 3 to 8mm wide, terminal lobe stiff to 30mm long.
- Terminal units of flowers with a three-toothed wing, 20cm long, 5mm wide; flowers are pale blue or whitish.

Figure 2: Top left: Statice seeds and seedlings. Top right: Mature plant flowering. Bottom left: Flowering plants in lupins. Bottom right: Flowering plants in barley.

Photos: Sam Kleemann (University of Adelaide)

Table 1: Effect of burial depth on seedling emergence (%) of a statice population in a glasshouse 30 days after burial. Each data value represents the mean of two experiments pooled with four replicates. Values within the column followed by different letters are significantly different (Fisher's protected LSD test P ≤ 0.01).

Burial depth (cm)	Seedling emergence (%)
0	56.5 b
1	1 a
2	1 a
5	0 a

Source: University of Adelaide

Table 2: Seedling recruitment from the seedbank of two statice populations (S8 and S12) in 2016 and 2017 at Karoonda, Roseworthy and Tarlee, SA. Each data value represents the mean of three replicates. Values within the column followed by different letters are significantly different (Fisher's protected LSD test P ≤ 0.01).

	Seedling recruitment (% of initial seedbank)			
	2016		2017	
Location	S8	S12	S8	S12
Karoonda	34.6 c	31.0 b	2.3 b	4.3 b
Roseworthy	11.6 b	7.0 a	0.0 a	0.0 a
Tarlee	1.5 a	3.5 a	0.0 a	0.0 a

Source: University of Adelaide

- Plants flower in summer, often after crop harvest. In Figure 2 (bottom left and right), statice plants are actively flowering in lupins and barley crops ready for harvest.
- Often found in areas of low to moderate rainfall on sandy to loamy, often calcareous sodic soils of neutral to high pH.

Why is it a weed?

Infestations are more common in pastures, roadsides and undisturbed habitats; however, more recently this species has become a more common weed in areas where crops are often grown after pasture phases. Over-reliance on glyphosate in reduced tillage systems has favoured statice, which tends to have a higher tolerance to this herbicide than other weeds present (Taylor and Brown 2014). It can also cause problems at harvest, with high levels of green leaf material often discolouring and contaminating grain.

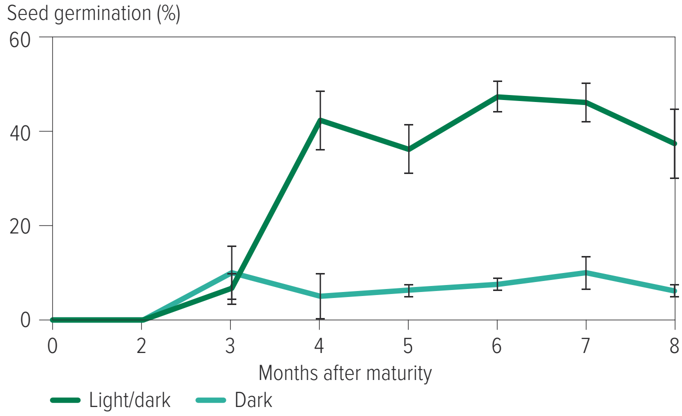
Research has also shown a much higher tolerance of statice seeds to salinity than other common weed and crop species (Kleemann and Gill, 2018). Salinity tolerance of statice correlates well with its observed distribution in the Mallee region of SA and Victoria.

Seed

Dormancy and germination

Freshly produced statice seeds did not germinate until they had after-ripened for about two months (that is, short-term dormancy). Exposure of statice seeds to light substantially increased their germination as compared with seeds in continuous darkness. Seeds retained a high level of seed dormancy until about 3 months after maturity. Thereafter, seed germination increased sharply for seeds exposed to light. However, the inhibitory effect of darkness was evident even for older seeds (Figure 3). Presence of light requirement is quite common in small seeded species and is a cue for them to germinate on or near the soil surface. Absence of light requirement for germination in small seeded species could lead to failure of seedlings to emerge from soil and establish a weed population. Even though seeds of statice readily imbibed water (that is, did not have physical dormancy), their germination increased to 100 per cent when seeds were scarified (cut) as compared with 54 per cent germination of intact seeds. It appears presence of an intact seed coat prevents release of germination inhibitors within the seed. Therefore, physical damage to the seed coat allows a release of germination inhibitors in statice seeds and increases their germination.

Figure 3: Stimulation of statice seed germination by exposure to light. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

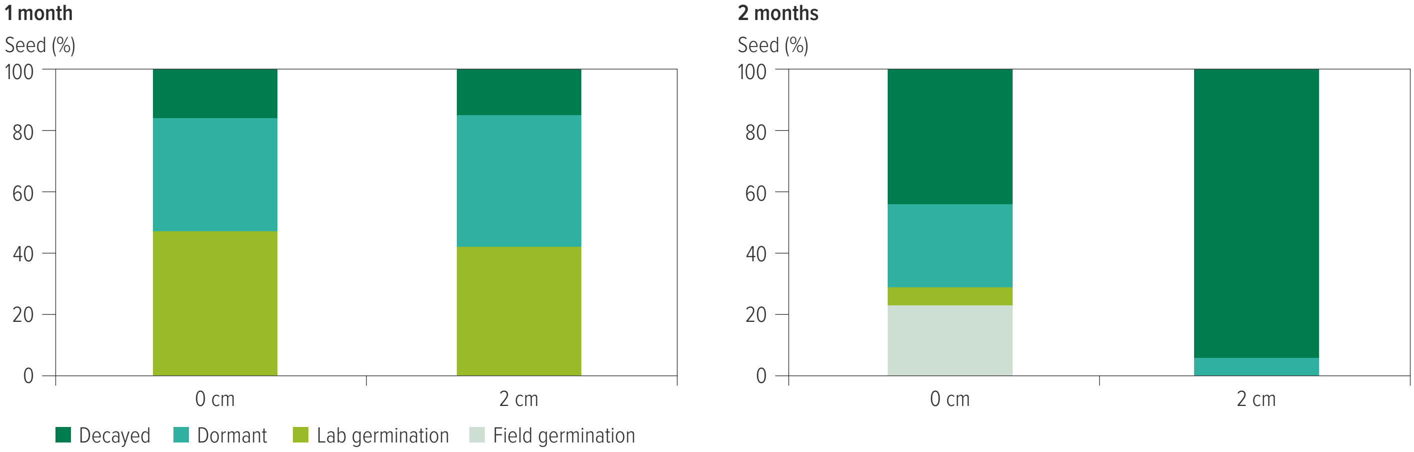
Seedling emergence of statice was highly sensitive to the depth of seed burial in soil (Table 1). Seedling emergence declined sharply even at a shallow burial depth of 1cm, which is highly likely to be related to its requirement for light for germination. Therefore, pastures and no-till systems, or non-crop habitats, are likely to favour statice plant establishment due to concentration of weed seeds on or close to soil surface.

Seedbank persistence

The rate of seed decay in statice was investigated at Roseworthy, SA. Seeds present on the soil surface decayed at a slower rate than those buried at 2cm depth. After two months of burial in the field, seeds placed on the soil surface either germinated in the field (23 per cent) or germinated in the laboratory after retrieval (six per cent) or were still dormant (27 per cent). In contrast, more than 94 per cent of seeds buried at 2cm had decayed within two months of placement in the field as compared with 44 per cent decay in seeds present on the soil surface (Figure 3). This result helps to explain much greater infestation of this weed in pastures, no-till systems or in non-crop situations.

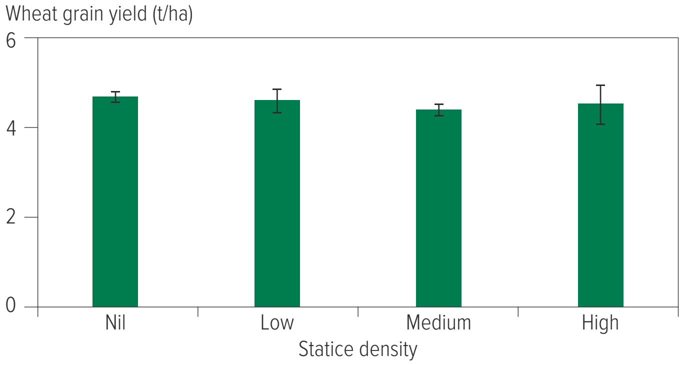
In another investigation of seed persistence in statice, seedling establishment was recorded at three different field locations in SA (Tarlee, Roseworthy and Karoonda). Seeds were placed in the field in February 2016 and seedling emergence counted during subsequent growing seasons (Table 2). Soils at these sites ranged from low organic carbon at Karoonda (1.01 per cent), medium at Roseworthy (1.75 per cent) and high at Tarlee (2.82 per cent). At Karoonda, the site with the lowest soil OC and soil microbial biomass, two to four per cent of the statice seedbank

Figure 4: Effect of burial depth on seed fate of statice after one and two months in the field.



Source: University of Adelaide

Figure 5: The effect of statice on the grain yield of wheat at Roseworthy in 2019. The error bars represent the standard error of the mean. Density of statice in this trial was 0, 4, 10 and 15 plants/m^2.



Source: University of Adelaide

persisted until the second year. In contrast, at sites with medium to high soil OC and microbial biomass (Roseworthy and Tarlee), the statice seedbank did not persist into the second year. The results of this study highlight the sensitivity of statice seeds to microbial decay in the field.

Seed production and dispersal

In the absence of competition, a single plant can produce more than 60 dense flower heads and more than 2000 seeds. Flowering tends to occur in spring to early summer (October–December), with a majority of seeds retained on the plant at maturity. In studies undertaken in wheat at Roseworthy, seed production in statice occurred after crop harvest. Statice plants tend to recover and regrow after crop harvest. In such situations post-harvest weed control is needed to prevent seed-set.

Competition

On fertile agricultural soils at Roseworthy, statice did not have a significant negative effect on wheat grain yield in any growing season from 2016 to 2019. High sensitivity of statice seeds to rapid decay and seed burial did not allow establishment of high weed infestations in these trials. Low competitive effects of statice on wheat could be partly related to its small seed size (approximately 4mg) and seedlings of low early vigour and prostrate growth habit, which are unable to shade the crop. Results for 2019 are shown to illustrate the weak competitive effects of statice on wheat at Roseworthy (Figure 5). These results, however, do not rule out the possibility of crop yield loss from statice on sodic or saline soils due to superior tolerance of statice to these stresses than crops.

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

A summer annual.

Photo: Bhagirath Chauhan (University of Queensland)

SUMMER GRASS

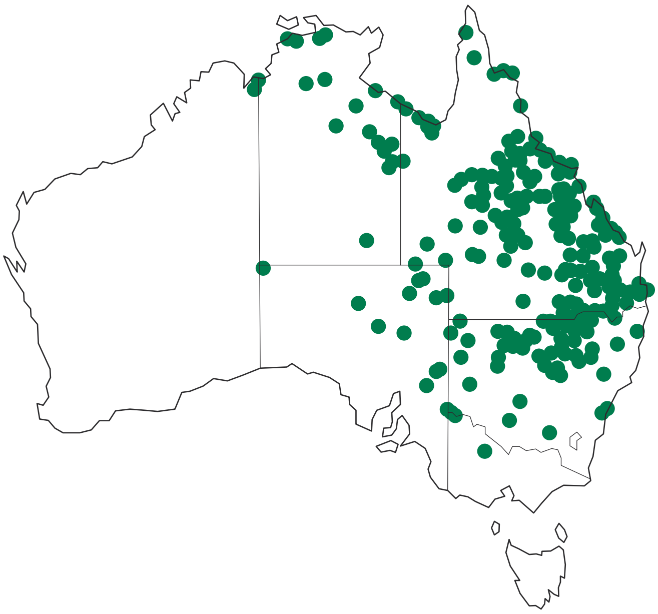
Eriochloa crebra S.T.Blake

Other common name: cup grass.

KEY POINTS

- Summer grass is an emerging weed species in the northern grains region of Australia
- Summer grass seeds have moderate dormancy
- The surface seedbank depletes within three years, but buried seeds can persist longer than this
- Summer grass is highly competitive in mungbean crops, but more than 85 per cent seed retention at mungbean harvest presents a favourable opportunity to utilise harvest weed seed control practices for management

Figure 1: *Eriochloa crebra* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Summer grass, also known as cup grass, is a perennial weed of the Poaceae family. It is native to Australia and is generally found in Queensland, NT and NSW (Figure 1). It can be confused with similar annual sweet signal grass (*Moorochloa eruciformis* (Sm.) Veldk.) and perennial early spring grass (*Eriochloa pseudoacrotricha* (Stapf ex Thell.)). Many grasses are called summer grass, depending on location. It is an emerging threat to summer cropping systems of the northern grains region.

Description

- Erect culms are 35 to 100cm in length with some lateral branching.
- Smooth leaves are 4 to 25cm in length and 2 to 7mm wide.
- Inflorescences are 10 to 25cm in length, with clustered or paired ovate spikelets of green and dark purple along the lower glume.

Why is it a weed?

Summer grass is a highly competitive weed that features prolific seed production. It is an emerging threat and has not been well studied. The following information is some of the most comprehensive work on the ecology of this species.

Seed

Dormancy and germination

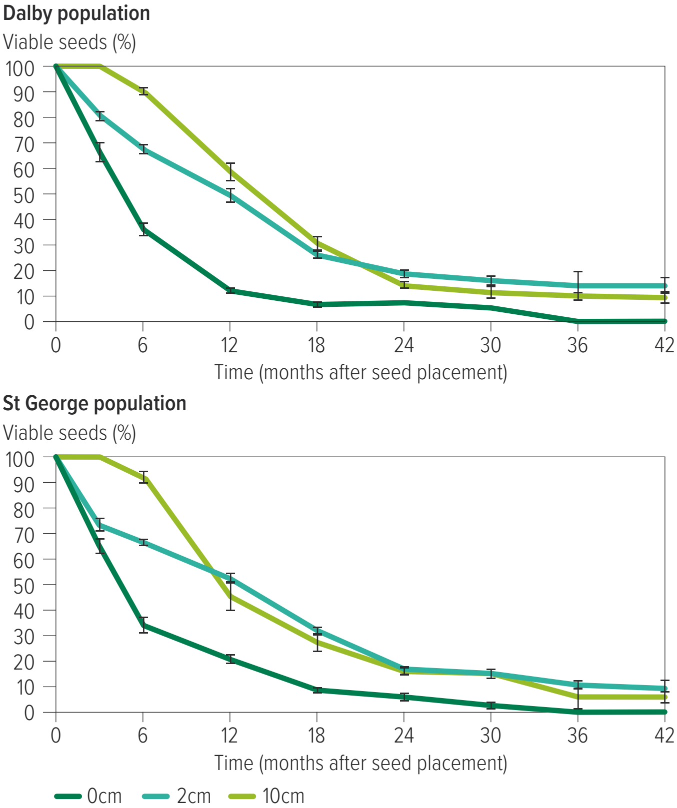
Initial germination rates were 30 to 48 per cent for the populations collected in 2016 and 29 to 32 per cent for the populations collected in 2017. After four months of storage, germination reached more than 80 per cent. These results suggest summer grass has a moderate level of seed dormancy.

Seedbank persistence

A study of the seedbank persistence of summer grass was conducted using two Queensland populations collected from Dalby (higher rainfall) and St George (lower rainfall). Seeds were collected in 2015 and placed in nylon bags, which were

Figure 2: Top left: Summer grass seeds. Top right: Infestation in a mungbean crop. Bottom left: Close up of a plant. Bottom right: Summer grass.
Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of two populations of summer grass seed on the soil surface or buried at a depth of 2 or 10cm, over three to 42 months. Vertical bars indicate the standard error of the mean.



Source: University of Queensland

then placed at different depths in a field at Gatton. For both populations, a high level of seedbank persistence was evident in this study (Figure 3).

For both populations, the depletion of the seedbank was greatest at the soil surface, with only 12 to 21 per cent of seeds viable at 12 months and no viable seeds after 36 months. Viability for buried seeds was much greater than the surface seeds. Even after 42 months, three to nine per cent of buried seeds were viable. These results suggest burial will increase the seedbank life of summer grass.

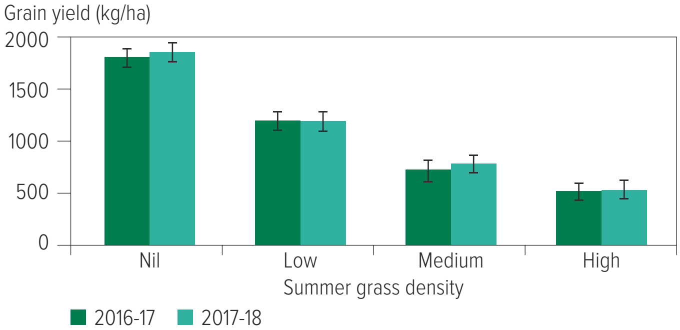
Seed production and dispersal

Maximum summer grass seed production was 60,800 and 77,000 seeds/m^2 in 2016-17 and 2017-18, respectively. Even at a high density, each summer grass plant produced 1350 to 1450 seeds. However, high levels of seed retention (87 to 92 per cent) were observed in this weed species at mungbean harvest. These observations suggest a favourable opportunity to utilise harvest weed seed control for management of this weed.

Competition

Despite emerging a few days later than mungbean, summer grass had a very significant effect on grain yield. Compared with the weed-free plots, a low summer grass density (13 to 15 plants/m^2) resulted in a mungbean grain yield loss of 35 per cent (Figure 4). These losses increased to 71 per cent at high summer weed density (45 to 53 plants/m^2).

Figure 4: Effect of summer grass density on mungbean grain yield at Gatton in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high summer grass density was 13, 30 and 45 plants/m^2 in 2016-17, and 15, 33 and 53 plants/m^2 in 2017-18.



Source: University of Queensland

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

An annual or biennial herb.

Photo: Bhagirath Chauhan (University of Queensland)

TURNIP WEED

Rapistrum rugosum (L.) All.

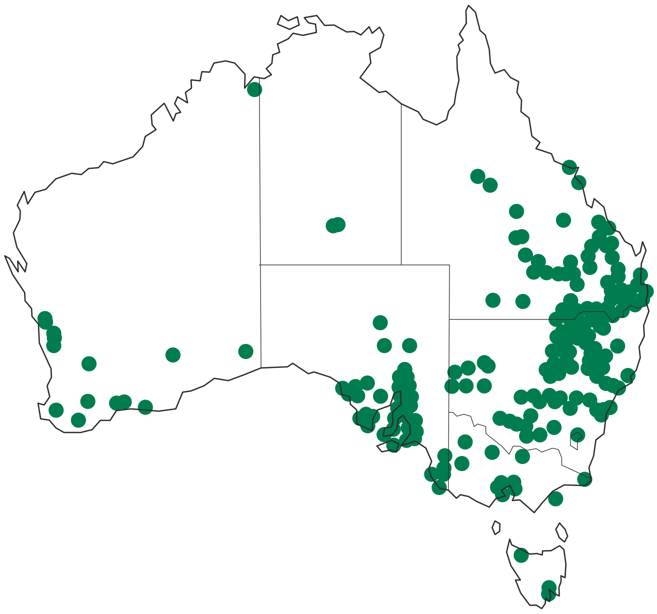
Other common names: annual bastardcabbage, giant mustard, jointed charlock, wild turnip.

Synonym: *Myagrum rugosum*.

KEY POINTS

- Turnip weed seeds have a high level of dormancy, making them conducive to germination at different times of year
- Buried seeds persist longer than surface seeds; in Queensland, all surface seeds decayed within 2.5 years but five to 13 per cent of seeds buried at 2 to 10cm depth were still viable after 3.5 years. In SA, seeds persisted for more than four years
- The competitive ability of turnip weed was greater in Queensland than in SA, suggesting this weed thrives in warmer conditions. In Queensland, a high density of turnip weed reduced wheat yield by 72 to 78 per cent
- In both regions, plants retained all seeds at wheat harvest, suggesting this species is highly suitable for harvest weed seed control

Figure 1: *Rapistrum rugosum* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Turnip weed is a broadleaf weed in the Brassicaceae family. It is native to the Mediterranean region and eastern Europe. It has established widespread infestation across agricultural regions of Australia, with increasing prevalence in Queensland, NSW and SA (Figure 1).

Description

- Cotyledons are hairless and convex with indented tips.
- First leaves are oval with a rounded apex, toothed margin and hairs on all surfaces. Leaves at base form a rosette.
- At maturity, erect stems of 150 to 1200mm with bristly hairs feature deeply lobed leaves of 80 to 250mm with coarsely toothed edges.
- Mature plants produce yellow flowers with four petals and subsequent fruit that alternate up the stem.
- A distinct seed capsule of 5 to 10mm with a blunt beak contains between one and three yellow-brown, egg-shaped seeds of 1 to 2mm (Figure 2).
- Can be confused with wild turnip and wild radish.

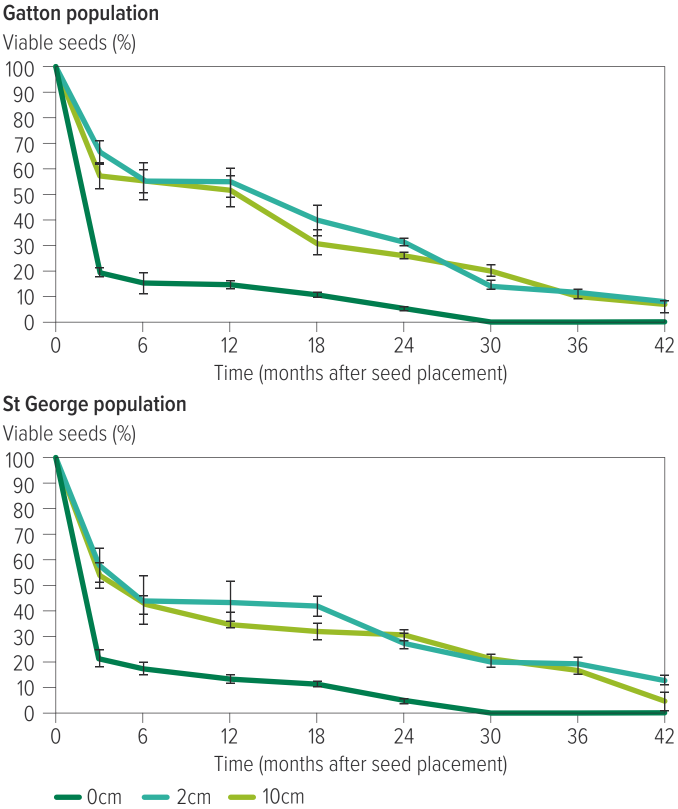
Why is it a weed?

Adaptability to environmental conditions and crop management practices have made turnip weed a major agricultural weed of increasing concern. It is a highly competitive species, resulting in significant reductions in crop yield. Rapid emergence has occurred under conservation agriculture practices, particularly in chickpeas and wheat. It is able to emerge and establish at different phases of the crop growing season. Turnip weed is not limited to winter crops, as it has also been observed in some summer crops. Cases of herbicide resistance to ALS inhibitors have been recorded in Australia.

Figure 2: Top left: Turnip weed seeds. Top right: Seedlings. Bottom left: Flowering plants in wheat. Bottom right: Matured plants in wheat.

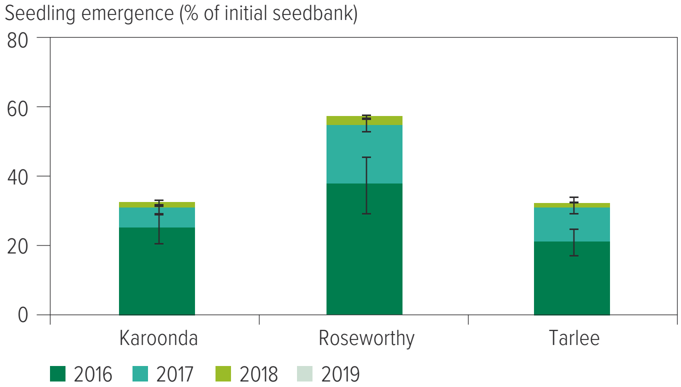
Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Viability of two populations of turnip weed seed on the soil surface or buried at a depth of 2 or 10cm, over three to 42 months. Vertical bars indicate the standard error of the mean.



Source: Source: University of Queensland

Figure 4: Turnip weed seedling emergence over four years from the seedbank established at three field sites in SA. Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

Seed

Dormancy and germination

Turnip weed possesses a high level of seed dormancy. Seeds were almost completely dormant (98 to 100 per cent) immediately after harvest.

Turnip weed germination occurs predominantly in the winter season, although the plant is well adapted to warmer conditions. Germination was more than 85 per cent at temperatures ranging from 15/5°C to 25/15°C day/night temperature, indicating its ability to germinate at a broad range of winter and spring temperatures. Seeds also germinated at 30/20°C.

Seedling emergence was higher at a burial depth of 1cm compared with those at the soil surface or at 0.5cm. No seedling emergence was observed from 6cm depth. These results indicate the use of shallow tillage promotes, rather than inhibits, the emergence of turnip weed and suggest the potential for minimising emergence through implementation of inversion tillage to bury seeds deeper in the soil profile.

Seedbank persistence

In Queensland, seeds of two turnip weed populations (Gatton – higher rainfall, St George – lower rainfall) were collected and studies carried out to determine the turnip weed seedbank persistence.

For both populations, the depletion of the seedbank in the mesh bag study was rapid at the soil surface; less than five per cent of seeds remained at 24 months after placement and no seeds persisted at 30 months (Figure 3). Persistence at depths of 2 and 10cm was about 30 per cent at 24 months and 15 to 20 per cent of seeds remained at 30 months (Figure 3). Persistence of buried seeds at 42 months (last exhume) was five to 13 per cent, suggesting buried seeds may survive more than 3.5 years. These results suggest seeds in no-till farming systems will decay faster than in conventional tillage systems. The build-up of a seedbank on the soil surface could be reduced using a soil inversion tillage operation. However, a subsequent shallow tillage operation may bring back the buried seeds on or near the soil surface and, therefore, should be avoided for several years.

In SA, persistence of turnip weed was investigated at three different sites, representing the low, medium and high rainfall zones. The highest overall seedling establishment was found at Roseworthy (medium rainfall) where around 60 per cent of the initial seedbank produced turnip weed plants over the four years (Figure 4). At Tarlee (higher rainfall) and Karoonda (lower rainfall), there was around 33 per cent recruitment over the four years. At all the sites, most of the seedlings of turnip weed emerged in year one and emergence declined markedly after the second year. However, a small fraction of the initial seedbank was able to produce seedlings even after four years of the start of the study (0.33 to 0.5 per cent). The results of this study clearly show the turnip weed seedbank can persist in the soil for four years. Once the seedbank of this persistent weed has declined to low levels, all efforts need to be maintained to prevent replenishment.

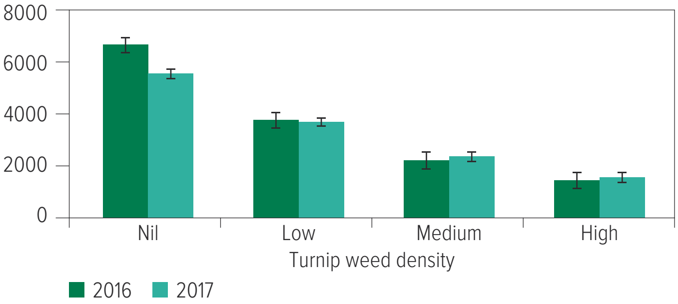
Seed production and dispersal

In Queensland, a high density (47 to 48 plants/m^2) of turnip weed produced 32,000 and 29,800 seeds/m^2 in 2016 and 2017, respectively. Even at a density of 10 plants/m^2 turnip weed can produce up to 13,000 seeds/m^2. At Roseworthy in the southern region, seed production by turnip weed in a wheat crop in 2017 was 250 seeds per plant, as compared with 1000 seeds per plant in a lentil crop. These results highlight lower seed-set by turnip weed in the southern region, but they also suggest the large impact of crop competition on its fecundity. Consistent with the findings in Queensland, turnip weed seed capsules were retained on the plants right up to crop harvest at Roseworthy in SA. This species appears to be highly suitable for harvest weed seed control.

Competition

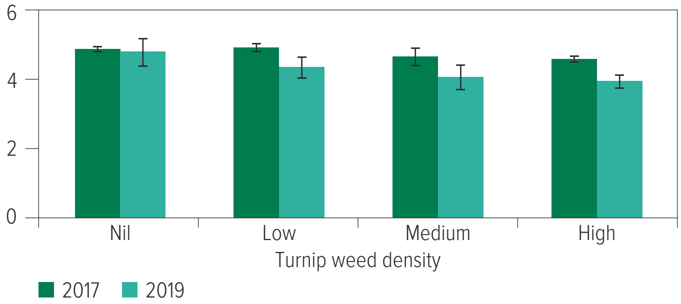
In Queensland, turnip weed had a very significant effect on wheat grain yield. Compared with the weed-free plots, the low density (10 to 12 plants/m^2) of turnip weed reduced wheat yield by 33 to 44 per cent (Figure 5), demonstrating its high competitiveness in a wheat crop. The high density of turnip weed (47 to 48 plants/m^2) resulted in yield reductions of 72 to 78 per cent.

Figure 5: Effect of turnip weed density on wheat grain yield at Gatton in 2016 and 2017. Error bars are least significant difference at the five per cent level of significance. Low, medium and high turnip weed density was 10, 26 and 48 plants/m^2 in 2016, and 12, 29 and 47 plants/m^2 in 2017.



Source: University of Queensland

Figure 6: Effect of turnip weed density on wheat grain yield at Roseworthy in 2017 and 2019. Vertical bars indicate the standard error of the mean. Low, medium and high turnip weed density was 4, 11 and 29 plants/m^2 in 2017, and 13, 16 and 25 plants/m^2 in 2019.



Source: University of Adelaide

Turnip weed caused much smaller reductions in wheat grain yield at similar weed densities at Roseworthy as compared with Gatton (Figures 5 and 6). It appears turnip weed grows better under the warmer growing conditions in Queensland as compared with much cooler conditions in SA. These differences in turnip weed competitiveness across these two regions are also consistent with its higher impact as a weed species in Queensland and NSW than in SA and Victoria.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

Wild oat in fallow. Photo: Bhagirath Chauhan

WILD OAT

Avena fatua and *Avena ludoviciana*

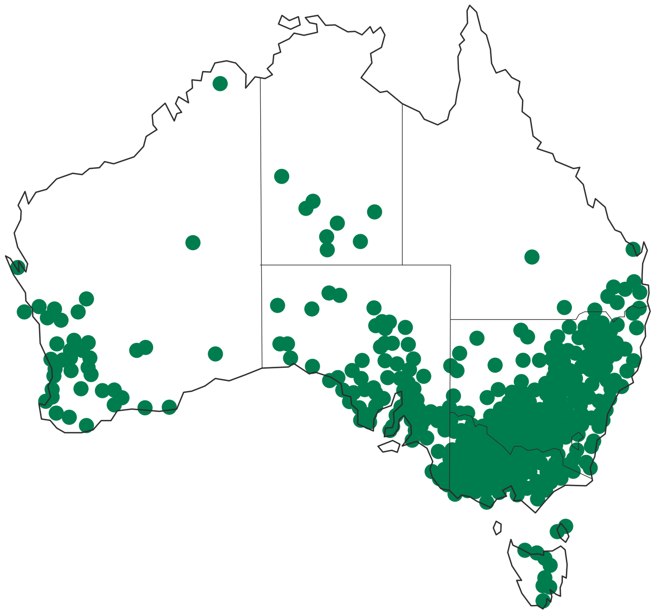
Other common names: black oat, sterile oat, winter wild-oat, ludo wild oat.

KEY POINTS

- Wild oat poses a significant challenge as a weed in Australian grain-producing regions
- These plants are prolific seed producers, displaying staggered germination patterns spanning from March to October, with peak emergence typically observed in May and June
- Wild oat seeds exhibit slower decay when buried at a shallow depth (two centimetres) compared with 10cm. Regardless of the burial depth, the seedbank remains short-lived, lasting less than two years. This underscores the importance of preventing seed dispersal in the paddock to minimise infestation levels
- To ensure long-term weed control, it is crucial to prevent seed-set by monitoring and managing survivors in the field regularly
- Adopting sustainable weed control strategies for wild oat involves leveraging crop competition through effective crop management practices such as closer row spacing, adjusting sowing time and seeding rate, reducing the spread of weed seeds and monitoring herbicide-resistant weed populations
- Infestation by wild oat in winter crops such as wheat and chickpea results in substantial yield losses. Implementing integrated weed management practices is advisable, emphasising the use of crop competition and focusing on reducing the soil seedbank
- Wild oat thrives not only in cultivated fields but also in non-cropping areas such as fencelines. Maintaining high on-farm hygiene is crucial to prevent new infestations, particularly in spring when these plants tend to produce a significant number of seeds rapidly

Wild oat seeds (two on left are ***A. ludoviciana*** and two on right are ***A. fatua***).
Photo: Bhagirath Chauhan

Figure 1: Wild oat incidence in Australia.



Source: The Australasian Virtual Herbarium

Background

Wild oat was introduced to mainland Australia through contaminants of wheat and barley seeds in Tasmania. It is believed that wild oat entered Western Australia in the 1830s through contaminants of wheat seeds from Launceston. Thereafter, it was spread throughout Australia (Western Australia, New South Wales, Queensland, South Australia, Tasmania). Among Australian growers, wild oat plants are also called black oats and bearded oats. Two species, *Avena fatua* and *A. ludoviciana*, are the dominant species (80 per cent of area) in Australian paddocks. However, an infestation of *A. barbata* can also be seen on roadsides and in non-agricultural areas. Infestations of *A. fatua* are most common in southern Australia, while *A. ludoviciana* is the dominant species in northern New South Wales and southern Queensland.

Description

- Wild oat plants are self-pollinated and have a fibrous root system.
- The cotyledon of wild oat plants remains underground.
- The ligule is large and auricles are absent.
- Leaves have few hairs and the emerging leaf is rolled.
- Wild oat plants can be differentiated from wheat and barley at an early stage as their seedling leaves are twisted anticlockwise, while seedlings of wheat and barley are twisted clockwise.
- Wild oat plants are similar to *Bromus* spp. at an early stage and can be differentiated as wild oat plants have few hairs on the leaves and a rolled emerging leaf, while *Bromus* spp. have more hairs on the leaves and tubular leaf sheath.
- Seeds are usually dark and vary in hairiness.

A. fatua and *A. ludoviciana* can only be differentiated at maturity by assessing their shattering pattern. *A. fatua* seeds shatter in pairs, while *A. ludoviciana* seeds shatter single.

Why is it a weed?

Wild oat plants (*A. fatua* and *A. ludoviciana*) are highly competitive and could cause 70 to 80 per cent yield loss if left uncontrolled in winter crops such as wheat and barley. In recent trials at Gatton, wild oat (*A. ludoviciana*) at 15 plants m^{-2} reduced chickpea yield by >80 per cent. Yield reductions could be high if the emergence time of wild oat matches with the emergence time of crops. Wild oat has been estimated to cost grain growers $28 million in lost revenue annually. This weed has evolved resistance to multiple herbicide groups.

Wild oat plants are prolific seed producers. Their favourable biological attributes (staggered germination pattern, awns on seeds and dormancy behaviour) enhance seed persistence and dispersal. Wild oat plants may act as an alternate host for many diseases in cereals, such as cereal cyst nematode (*Heterodera avenae*), crown rot (*Fusarium graminearum*), Rhizoctonia (*Rhizoctonia solani*), stem nematode (*Ditylenchus dipsaci*) and root lesion nematode (*Pratylenchus neglectus*).

Seed

Dormancy and germination

A seed germination ecology study revealed that germination of *A. ludoviciana* was higher at alternating day/night temperatures of 20/10°C and 25/15°C compared with temperature regimes of 15/5°C, 30/20°C and 35/25°C (Table 1). However, for *A. fatua*, germination was highest at 20/10°C compared with other temperature regimes (Table 1). These observations suggested that *A. ludoviciana* could emerge in the autumn season, and earlier than *A. fatua*.

Table 1: Effect of alternating day/night temperatures (15/5°C to 35/25°C) on the germination of wild oat (lab study).

Day/night temperature regimes (°C)	Germination (%) ± SE	
	A. fatua	*A. ludoviciana*
15/5	43 ± 7	83 ± 3
20/10	73 ± 12	100 ± 0
25/15	53 ± 7	97 ± 3
30/20	17 ± 7	83 ± 7
35/25	0 ± 0	3 ± 3

Wild oat-infested chickpea. Photo: Bhagirath Chauhan

These speculations were confirmed in field studies, in which *A. ludoviciana* emerged earlier than *A. fatua*. In the emergence pattern trial at Gatton, it was observed that *A. ludoviciana* emerged from a five-centimetre soil depth in March, while *A. fatua* did not emerge in March. The emergence of *A. fatua* and *A. ludoviciana* was found to be greater from 2cm and 5cm soil depths compared with 0 (on the surface) and 10cm soil depths.

The emergence of *A. fatua* and *A. ludoviciana* was noticed even in October; however, the peak emergence of *A. fatua* and *A. ludoviciana* occurred between May and June following rainfall. This suggests that peak emergence occurs when there is adequate moisture and temperature is low (May and June). The continuous emergence of wild oat during the entire winter season emphasised the need for an extended period of weed control in crops to restrict its seed production.

Wild oat seed production, if not controlled, could result in an increased seedbank due to its high shattering ability. Persistence of wild oat is mainly due to fresh seed production each year rather than dormancy in carrying seeds from one season to the next.

An emergence pattern study on 10 populations of *A. ludoviciana* revealed that its germination was lower on the soil surface (<10 per cent) and greater from the 5cm depth (>30 per cent). Populations of *A. ludoviciana* differed in their emergence behaviour from 5cm, varying from 30 to 80 per cent depending on the population.

Another study revealed that *A. fatua* and *A. ludoviciana* emergence was slightly greater in the plots where barley and wheat residues were retained compared with no residue, suggesting that emergence may increase in the no-till system. These observations suggest that, where applicable, shallow cultivation would allow wild oat to emerge, which can be knocked down by effective herbicides or pre-sowing tillage operations.

Seed persistence

Seeds of *A. fatua* and *A. ludoviciana* decayed fast on the soil surface and at 10cm soil depth. However, seeds persisted for a longer time (18 months) at a shallow depth (2cm). The half-life of *A. fatua* and *A. ludoviciana* was found to be six months on the soil surface and at 10cm, suggesting that the seedbank at these depths is lost due to germination or death through metabolic failure or predation.

Table 2: Seed persistence (%) of wild oat at Gatton and St George in response to seed burial duration and depth starting from November 2017.

Weed	Location	Depth (cm)	Viable seeds % ± SE (after months)			
			6 mths	12 mths	18 mths	24 mths
A. fatua	Gatton	0	13 ± 8	1 ± 1	1 ± 1	0 ± 0
		2	61 ± 1	16 ± 6	7 ± 2	0 ± 0
		10	34 ± 8	4 ± 2	1 ± 1	0 ± 0
	St George	0	41 ± 5	7 ± 2	1 ± 1	0 ± 0
		2	60 ± 0	51 ± 4	17 ± 5	16 ± 5
		10	60 ± 0	16 ± 8	1 ± 1	0 ± 0
A. ludoviciana	Gatton	0	13 ± 3	0 ± 0	0 ± 0	0 ± 0
		2	34 ± 2	18 ± 5	14 ± 4	0 ± 0
		10	37 ± 13	1 ± 1	0 ± 0	0 ± 0
	St George	0	27 ± 9	8 ± 3	2 ± 1	0 ± 0
		2	30 ± 1	29 ± 1	12 ± 2	12 ± 3
		10	33 ± 3	10 ± 10	2 ± 2	0 ± 0

Table 3: Seed number (%) of *A. fatua* and *A. ludoviciana* in wheat competition.

Competition	Seed number %	
	A. fatua	*A. ludoviciana*
No competition	100	100
25cm row spacing in wheat	6	5
50cm row rows spacing in wheat	15	11

After six months of seed placement in the soil at 10cm burial depth, the majority of *A. fatua* and *A. ludoviciana* seeds were found to be rotten. Long persistence of *A. fatua* and *A. ludoviciana* at a shallow depth (2cm) suggests that shallow seed burial may increase dormancy in seeds. Seeds of both *A. fatua* and *A. ludoviciana* persisted for a long time in St George paddocks compared with Gatton paddocks, which could be due to a relatively high clay content and the low rainfall at St George. These results suggest that soils with better aeration ability could facilitate rapid seed germination of *A. fatua* and *A. ludoviciana* and may result in fast seed decay.

Seed production and dispersal

A phenology study revealed that under fallow conditions, early (May) and late (August) cohorts of wild oat took 145 and 104 days for maturity, respectively. The seed production potential for early cohorts was found to be higher than late cohorts. Early (May) cohorts of *A. fatua* and *A. ludoviciana* produced 3300 and 4000 seeds plant^{-1}, respectively. Late (August) cohorts of *A. fatua* and *A. ludoviciana* cohorts produced 590 and 440 seeds plant^{-1}, respectively.

Under fallow conditions, the seed retention ability of *A. fatua* and *A. ludoviciana* for early cohorts was 40 per cent and 80 per cent, respectively, while for late cohorts it was 60 and 90 per cent, respectively. However, the seed retention ability of wild oat varied with crop competition. In chickpea, *A. ludoviciana* seed retention varied from 45 to 59 per cent. In wheat, *A. fatua* and *A. ludoviciana's* seed retention ability varied from 18 to 38 per cent and 64 to 80 per cent, respectively. A population behaviour study in fallow revealed that *A. ludoviciana* populations collected from the northern cropping region did not differ in seed production potential. Averaged over six populations of *A. ludoviciana*, the seed production potential of mid (June) and late cohorts (July) was reduced by 20 and 80 per cent, respectively, compared with early cohorts of May (2600 seeds plant^{-1}).

A water stress study on *A. fatua* and *A. ludoviciana* revealed that at 60 per cent water-holding capacity (WHC), *A. fatua* and *A. ludoviciana* produced 49 and 70 per cent seeds, respectively, compared with their seed production potential at 100 per cent WHC. At 40 per cent WHC, *A. fatua* plants did not survive; however, *A. ludoviciana* plants produced 54 seeds plant^{-1}.

Table 4: Seed production potential of *A. fatua* and *A. ludoviciana* cohorts (without crop competition under field conditions).

Cohorts	Seed production (number plant^{-1})	
	A. fatua	*A. ludoviciana*
Early (May)	3363	4058
Mid (June)	2512	3248
Late (July)	997	654
Very late (August)	589	438
LSD (0.05)	1243	1259

Table 5: Wheat yield reduction in response to *A. fatua* and *A. ludoviciana* interference.

Weed density (plants m^{-2})	Wheat yield reduction (%)	
	A. fatua	*A. ludoviciana*
0	0	0
3	9	14
6	38	37
12	48	46
24	64	61
48	76	71

Wild oat-infested wheat. Photo: Bhagirath Chauhan

In a wheat/wild oat interference study, *A. fatua* and *A. ludoviciana* at an infestation of 48 plants m^{-2} produced a maximum of 4800 and 3970 seeds m^{-2}, respectively. In the same study, it was found that *A. fatua* exhibited lower seed retention (20 to 40 per cent) than *A. ludoviciana* (60 to 80 per cent) at wheat harvest. In another study, a closer row spacing of wheat (25cm) reduced the seed production potential of *A. fatua* and *A. ludoviciana* by 63 and 56 per cent, respectively, compared with a wider row spacing (50cm) (Table 3).

The above observations suggest that *A. fatua* and *A. ludoviciana* plants are prolific seed producers. Early cohorts of *A. fatua* and *A. ludoviciana* have a greater seed production potential than late cohorts (Table 4). *A. ludoviciana* plants have a relatively higher level of tolerance to water stress than *A. fatua* plants. The seed production potential of *A. fatua* and *A. ludoviciana* is very high when plants are grown under fallow conditions.

However, crop competition (such as closer row spacing in wheat) could reduce the seed production potential of these species. High shattering ability of *A. fatua* in crops does not provide an opportunity for harvest weed seed control (HWSC), while there is an opportunity to control *A. ludoviciana* through HWSC depending on the duration of crops/varieties chosen.

Competition

A two-year study on *A. fatua* and *A. ludoviciana* interference in wheat revealed that wheat yield was reduced by 50 per cent at *A. fatua* and *A. ludoviciana* infestations of 15 plants m^{-2}. *A. fatua* and *A. ludoviciana* at 48 plants m^{-2} caused more than 75 and 70 per cent reductions in wheat yield, respectively, compared with weed-free situations (Table 5). Another study in chickpeas revealed that seven and 15 plants m^{-2} of *A. ludoviciana* caused a 50 and 80 per cent reduction in yield, respectively. In winter-planted sorghum, 14 plants m^{-2} of *A. ludoviciana* caused about a 60 per cent reduction in sorghum yield compared with weed-free situations.

A high seeding rate (200 seeds m^{-2}) in early planted wheat (May) could suppress the growth of *A. ludoviciana*, reduce weed seed production and increase grain yield. In paddocks with a history of high infestations of *A. ludoviciana*, late planting of wheat could result in improved yield by having control of early cohorts of *A. ludoviciana* through pre-sowing tillage.

In conclusion, for effective wild oat control, all techniques that prevent the seed rain in the soil, whether management-based (crop competition) or mechanical or chemical, could aid in reducing the wild oat pressure in the following years and help in maintaining the sustainability of northern region cropping systems in the future.

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A winter annual that emerges in autumn and winter and matures in late spring or summer.

Photo: Peter Boutsalis (University of Adelaide)

WILD TURNIP

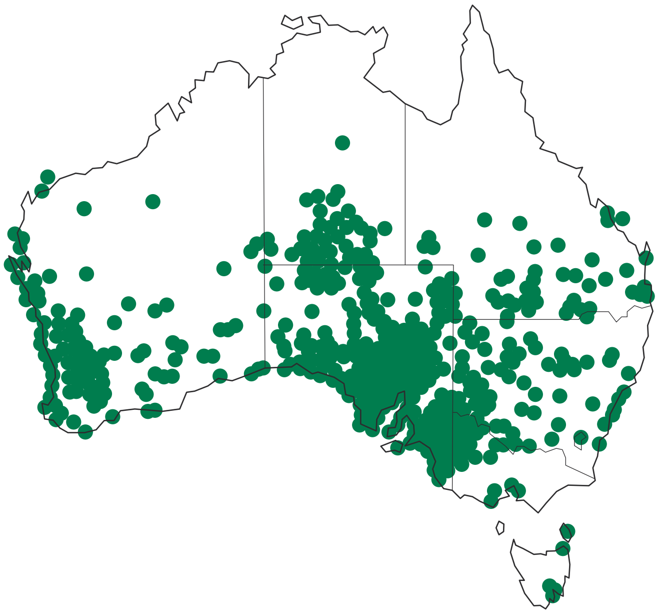
Brassica tournefortii Gouan

Other common names: African mustard, long fruited turnip.

KEY POINTS

- Seed dormancy in wild turnip was alleviated by an exposure to cold temperature (5°C) for 14 days. Therefore, seedling emergence in this species is likely to occur in late autumn to winter when night temperatures decrease
- Wild turnip can be a prolific seed producer in pulse crops with seed-set of 13,700 seeds m^2 recorded in lentils. The wild turnip seedbank persisted in soil for three years. The combination of high seed-set potential and long persistence means growers need to consider multi-year management strategies
- Most of the wild turnip seeds produced (more than 75 per cent) were retained on the plant until crop harvest. Therefore, wild turnip is a suitable target for harvest weed seed control tactics
- In field studies at Roseworthy, SA, wild turnip reduced wheat yields by five to 10 per cent. However, the yield loss caused by wild turnip was lower than more aggressive competitors, such as brome grass

Figure 1: *Brassica tournefortii* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Wild turnip is native to the arid regions of North Africa and the Middle East. It belongs to the family Brassicaceae and is also often referred to as long fruited turnip. The plant is generally similar to other mustards, but the yellow flowers are not as bright and flashy as closely related species. It is a spreading annual herb with long stems up to 1m in height.

Description

- Wild turnip is an erect annual plant that has stems that can be from 10 to 100cm tall, and a well-developed taproot system.
- The lower stems are densely covered with stiff bristles, the leaves are green and there is usually a moderately well-developed basal rosette. The lower leaves are large and reduce in size upwards along the stem. The leaves vary from 7 to 30cm in length and are pinnately lobed, eight to 14 lobes per leaf.
- During inflorescence a typical stem will consist of racemes (cluster) of six to 20 flowers. The racemes become greatly elongated when in fruit.

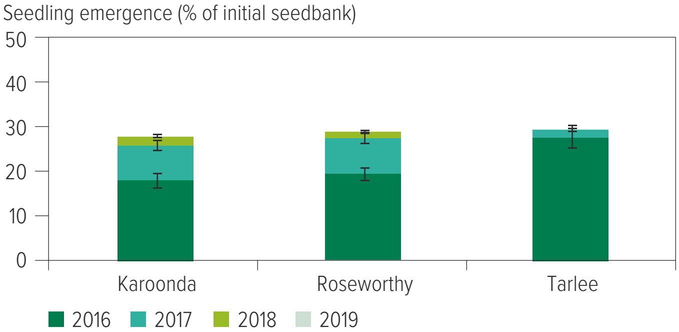
Figure 2: Top left: Seeds of wild turnip are red-brown in colour and 1mm in diameter. Top right: Seedlings at four-leaf stage. Bottom left: Flowers are dull yellow in colour. Bottom right: Plants can produce many seed capsules and set a large amount of seed. Photos: University of Adelaide

Table 1: Effect of duration of chilling at 5°C on seed germination of a South Australian wild turnip population in 2017. Each data value represents the mean of four replicates. Values within the column followed by different letters are significantly different.

Chilling period at 5°C (days)	Germination (%)
0	18 b
7	13 ab
14	97 c
28	96 c

Source: University of Adelaide

Figure 3: Cumulative emergence of wild turnip seed placed in the field at three sites in SA, in soil that was agitated each May (to simulate the crop seeding operation and bury the weed seed). Vertical bars indicate the standard error of the mean.



Source: University of Adelaide

- The flowers are a dull yellow in colour (Figure 2 bottom left) and individual flowers are approximately 1.5cm in width, with the petals measuring 5 to 7mm in length.
- The fruit of wild turnip is dehiscent silique, typical of fruit of the mustard family, and is about 3.5 to 6.5cm long with a diameter of 2 to 3mm. The fruit consists of two locules (compartments). Each locule contains a single row of seven to 15 seeds. The fruit ends with an obvious beak capsule, 1 to 2cm long. The seeds are red, with a diameter of 1mm (Figure 2 top left).

Why is it a weed?

Wild turnip is widely distributed across the agricultural regions of Australia, showing wide adaptation. It often forms very dense infestations on roadsides and unmanaged areas, which act as a reservoir for new incursions in adjacent areas. Herbicide resistance in wild turnip to group 2 (B) herbicides was first reported in WA in 1992 and in SA in 1996. Presence of resistance to this important herbicide group has made it more difficult to control this weed species.

Seed

Dormancy and germination

Previous studies of seed dormancy in wild turnip have shown most seeds (more than 70 per cent) could germinate at one month after maturity when provided with optimum temperatures and light conditions (Chauhan et al. 2006). However, recent studies showed seed germination in several populations from SA and Victoria, at six months after maturity, was much lower than previously reported. Seeds were subsequently tested for viability and were found to be highly viable (more than 90 per cent) but dormant. Dormant seeds of wild turnip were able to rapidly absorb water, which indicated seed dormancy was not due to a physical dormancy.

In the absence of chilling (cold stratification), germination in wild turnip seeds was quite low (18 per cent) (Table 1). However, exposure of wild turnip seeds to chilling at 5°C increased germination to more than 90 per cent. Previous research has shown chilling can increase endogenous gibberellic acid within the seed, which is known to stimulate germination of otherwise dormant seed. In cropping fields, seed dormancy mechanisms regulated by cold stratification are likely to delay seedling emergence to enable part of the seedbank to escape pre-sowing weed control tactics. Higher seed dormancy in current wild turnip populations than previously reported helps explain the increasing abundance of wild turnip in the low to medium rainfall cropping areas in southern Australia.

Seedbank persistence

Field studies were undertaken at three sites in SA to investigate the persistence of the wild turnip seedbank. At two of the field sites (Karoonda and Roseworthy), wild turnip seedlings established for three years after the start of the trial but no emergence was detected in year four (Figure 3). At Tarlee, wild turnip seedlings only established for the first two years of the study. The total seedling establishment from the initial seedbank was close to 30 per cent, which indicated around 70 per cent of the seedbank decayed over time, or some of the seedlings may have established but died before they could be counted. More importantly, the results of this study showed that the wild turnip seedbank can persist or remain viable in the soil for up to three years.

Seed production and dispersal

Depending on wild turnip plant density, its seed production in wheat in 2019 ranged from 150 to 6200 seeds/m^2. In contrast, in a lentil crop in the same season, wild turnip produced 243 to 13,700 seeds/m^2. However, it should also be noted that wild turnip is a prolific seed producer and its seeds can survive in the soil for up to three years. In this field trial, the pattern of weed seed retention leading up to crop harvest was also investigated. The results showed there was complete retention of wild turnip seeds in plants growing in a lentil crop. The level of seed retention was somewhat lower (75 per cent) in a wheat crop (Figure 4). However, the high level of seed retention in both crops makes wild turnip an excellent target for harvest weed seed control tactics.

Figure 4: The pattern of seed retention by wild turnip plants growing in wheat or lentils at Roseworthy, SA, in 2019. Note the complete retention of seeds in lentils and the high level of retention in wheat. Vertical bars indicate the standard error of the mean for four replicates. Values within the column followed by different letters are significantly different.

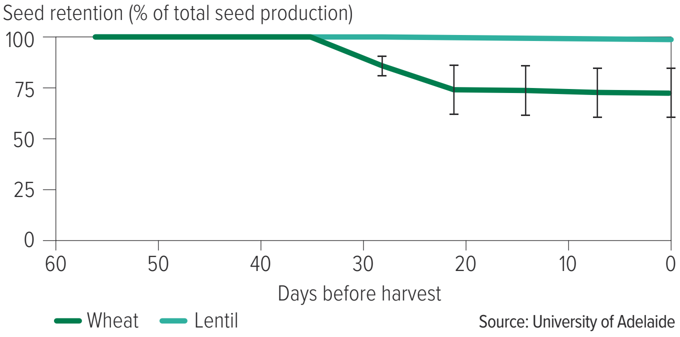
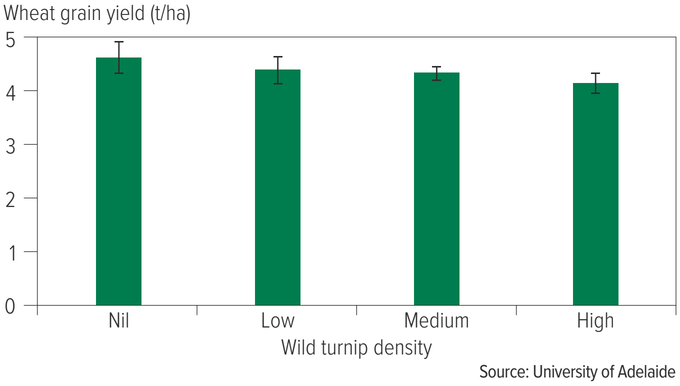


Figure 5: The effect of wild turnip on the grain yield of wheat at Roseworthy, SA, in 2019. Vertical bars represent the standard error of the mean. Density of wild turnip in this trial was 0, 5, 19 and 80 plants/m^2.



Competition

In field studies at Roseworthy, SA, wild turnip reduced wheat yields by five to 10 per cent (Figure 5). Wild turnip remains in the rosette (flat) stage in the early part of its life cycle, which may enable wheat and other cereals to suppress its growth and reduce its impact on grain yield. Furthermore, delayed seedling emergence in wild turnip due to the high level of seed dormancy may allow the crop an early period of low competition and reduce the competitive effect of wild turnip.

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KEY CONTACTS

Gurjeet Gill
The University of Adelaide
0428 592 825
gurjeet.gill@adelaide.edu.au

A summer annual.

Photo: Bhagirath Chauhan (University of Queensland)

WINDMILL GRASS

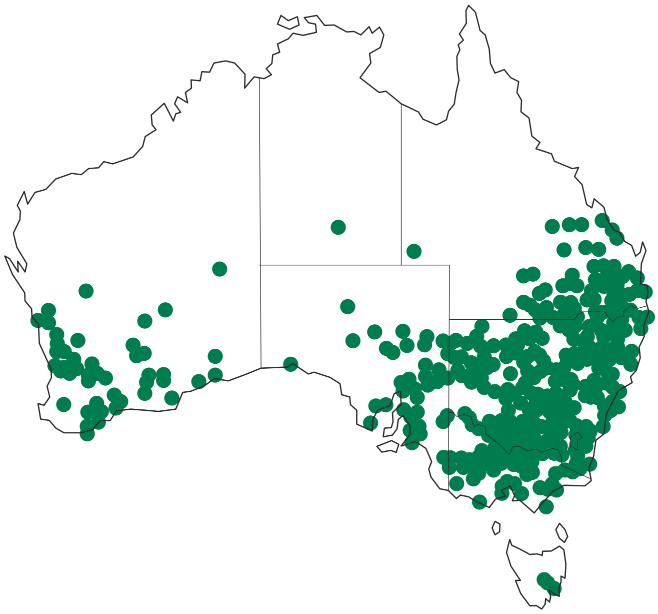
Chloris truncata (R.Br.).

Other common name: umbrella grass.

KEY POINTS

- Windmill grass seeds have a moderate level of dormancy, suggesting some seeds may germinate immediately after maturity
- Seed persistence in Queensland and WA cropping environments was variable, but generally seed depletion occurs by 12 to 24 months
- It is a highly competitive weed in mungbeans, but up to 85 per cent seed retention provides opportunities for management using harvest weed seed control practices

Figure 1: *Chloris truncata* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Windmill grass is an Australian native summer grass weed species of the Poaceae family. It has established widespread infestation across eastern, south-eastern and western agricultural regions of Australia, with increasing prevalence in Queensland and NSW (Figure 1).

Studies in the low-rainfall wheatbelt of WA showed the dry biomass of windmill grass reached 1460kg/ha. Windmill grass has 61 to 63 per cent digestible dry matter, 10.4 to 14.2 per cent crude protein and nine megajoules of metabolisable energy per kilogram of dry matter, and so can provide acceptable forage for livestock maintenance. Mixed farms may choose to retain this species as pasture rather than controlling it over the summer–autumn fallow.

Description

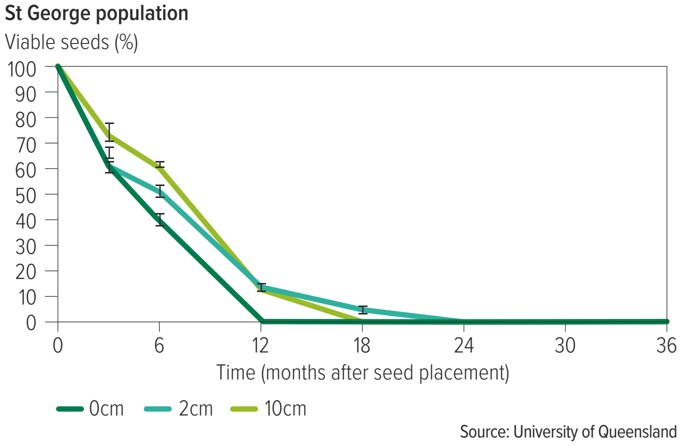
- Small, black seeds of 1.5mm in length have a pointed tip at one end and two long hairs at the opposite end (Figure 2).
- Plants grow as an annual or perennial tuft with a fibrous root system.
- The stems are erect or kneed and 16 to 50cm tall. Stems are topped with a 'windmill' shaped seed head with six to nine spikes, each containing spikelets of two to three florets crowded with seeds on their underside.
- Windmill grass has narrow, rough, bluish-green leaves of 5 to 14cm long, with a distinctive blunt tip and flat leaf sheath at the base.

Why is it a weed?

Windmill grass has become a significant weed in summer grain and cotton cropping systems under the practice of conservation agriculture and in fallows. It competes with crops for soil moisture, grows in fallows and exhibits prolific seed production and dispersal. This highly versatile weed can germinate at a wide range of temperature, pH, salinity and moisture levels, so is suited to most soil types and environments. Windmill grass has developed resistance to glyphosate.

Figure 2: Top left: Windmill grass seeds. Top right: Seedlings. Bottom left: A seed head. Bottom right: Infestation in mungbeans.
Photos: Bhagirath Chauhan (University of Queensland)

Figure 3: Effect of burial depth and duration on seedbank persistence of two populations of windmill grass from Queensland (left) and seedbank persistence averaged over two populations from WA (right). Vertical bars indicate the standard error of the mean.



These results indicate the use of tillage inhibits the emergence of windmill grass and suggest the potential for minimising emergence with tillage to bury seeds deeper (more than 3cm) in the soil profile. However, the results also highlight that if windmill grass seed is introduced after the crop is seeded, from seed heads blowing in from the fenceline, seedlings can infest the winter crop.

Seedbank persistence

In 2016, four windmill grass populations (Dalby – higher rainfall, St George – lower rainfall, Queensland, and Northam – higher rainfall, Merredin – lower rainfall, WA) were collected and studies carried out to determine their seedbank persistence.

For both Queensland populations, the depletion of the seedbank was rapid for seeds on the soil surface, with total depletion at 12 months (Figure 3). For seeds buried at 2 to 10cm, there was about 20 per cent viable seed after 12 months. No viable seeds remained at 18 months. For both WA populations, seeds on the soil surface or at depth remained viable for longer, with low-level viability at 24 months. Seeds buried at 2cm retained 5 per cent viability at 36 months.

In irrigated conditions at Northam, WA, 12 windmill grass populations had an average of 97 per cent emergence in year one, followed by one per cent and 0.1 per cent emergence in year two and three. In WA field conditions at Katanning (higher rainfall), Northam (medium rainfall) and Merredin (lower rainfall), seeds were planted and the soil was agitated to simulate crop seeding. Emergence in year one ranged from one to 41 per cent, with emergence likely reduced due to seed burial (Figure 4). Emergence in years two and three was zero to 0.2 per cent. Clearly, even though seeds may remain viable in the soil, most emergence will occur within 12 months of seed production.

Seed production and dispersal

At a density of 10 plants/m^2, windmill grass seed production was estimated at 29,100 and 40,500 seeds/m^2 in 2016-17 and 2017-18 in irrigated conditions in Queensland. At the highest weed density, windmill grass seed production was 62,700 and 88,200 seeds/m^2 in 2016-17 and 2017-18, respectively, with a dispersal rate ranging from 15 to 21 per cent at mungbean harvest. Harvest weed seed control may be a viable control option.

By comparison, in Wongan Hills, WA, windmill grass failed to set seed over three years. Two populations in Merredin, WA, produced zero to 20,369 seeds/plant from a maximum of 52 seed heads/plant. Total seed production was 2712 to 61,383 seeds/m^2. It is clear that growth over the summer fallow of southern Australia is highly variable and dependent on rainfall.

Seed

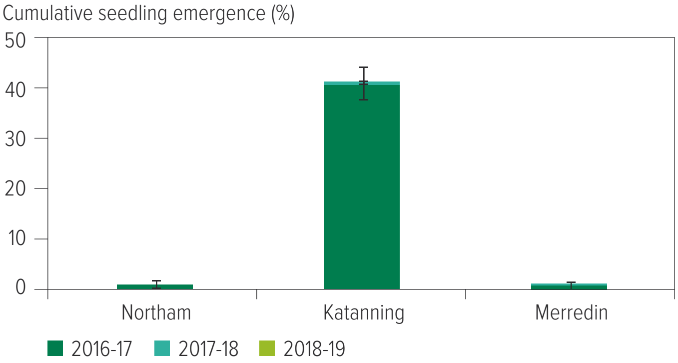
Dormancy and germination

Fresh seeds of windmill grass had up to 48 per cent germination across eight populations in Queensland, which increased to 87 per cent after four months. These results suggest windmill grass seeds have a moderate level of dormancy. Windmill grass is able to germinate under a wide array of environmental conditions and management strategies.

Germination in a light/dark regime ranged from 67 to 87 per cent at temperatures ranging from 15°/5°C to 30°/20°C day/night, indicating windmill grass's ability to germinate and emerge under field conditions throughout spring, summer and autumn in Queensland. Likewise, windmill grass emerges throughout the year in southern WA, although emergence is higher in spring and summer. These results also suggest it could become a potential problem in winter crops. Germination was stimulated by light, but up to 71 per cent of seeds germinated in the dark as well, suggesting buried seeds are still capable of germination.

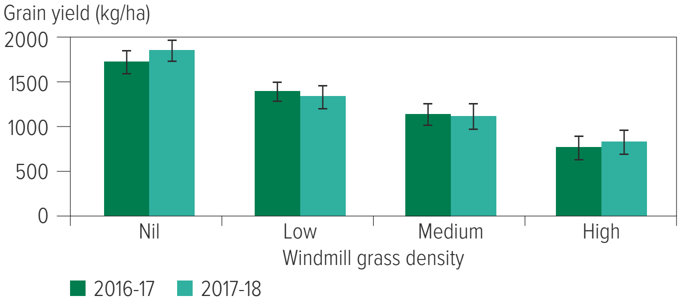
Seed germination of windmill grass was highest (67 per cent) at the soil surface and a burial depth of 0.7cm reduced seedling emergence by half in Queensland. Burial of seeds at 1 and 2cm resulted in 25 and nine per cent emergence, respectively. No seedlings emerged from the 3cm burial depth. At Wongan Hills, WA, windmill grass seeds sown prior to seeding the winter annual crop with knife points and press wheels to a depth of 3 to 4cm (at 22cm row spacing) resulted in zero per cent emergence of windmill grass. However, if seeds were sown directly after seeding the crop, windmill grass emergence was 19 per cent.

Figure 4: Cumulative yearly emergence of windmill grass (as a percentage of the total weed seeds planted) at three locations in WA from 2016 to 2019. Vertical bars indicate the standard error of the mean.



Source: DPIRD

Figure 5: Effect of windmill grass density on mungbean grain yield at Gatton, Queensland, in 2016-17 and 2017-18. Error bars are least significant difference at the five per cent level of significance. Low, medium and high windmill grass density was 11, 25 and 39 plants/m^2 in 2016-17, and 16, 32 and 47 plants/m^2 in 2017-18.



Source: University of Queensland

Competition

In Queensland, a low density of windmill grass resulted in a mungbean grain yield loss of up to 28 per cent (Figure 5). These losses increased to 40 per cent at medium weed density and 56 per cent at high weed density.

Windmill grass at Wongan Hills, WA, growing in the summer fallow failed to reduce yield of winter annual crops from 2016 to 2019. By comparison, windmill grass at Merredin, WA, reduced wheat yield by 25 per cent. The loamy Merredin site was more likely to see improved water use efficiency of the winter annual crop following summer rainfall.

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KEY CONTACTS

Bhagirath Chauhan
The University of Queensland
0427 923 272
b.chauhan@uq.edu.au

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

A versatile weed that will emerge throughout the year, set seed from spring to autumn, and can grow as a perennial if left uncontrolled.
Photo: Catherine Borger (DPIRD)

WIREWEED

Polygonum aviculare L.

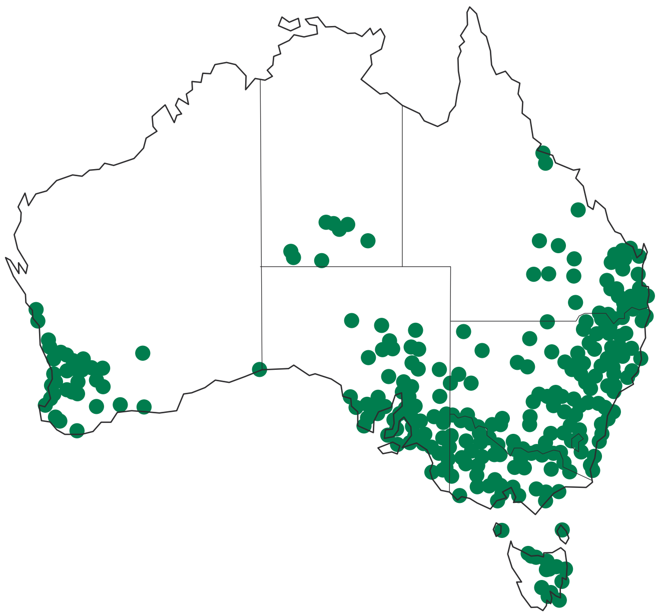
Other common names: hogweed, knot weed, prostrate knotweed, yard knotweed, birdweed, pigweed, lowgrass.

Synonyms: *Polygonum aviculare* L. var. *diffusum* Meisn., *Polygonum monspeliense* Pers.

KEY POINTS

- If mature wireweed plants are not fully controlled at seeding in autumn, plants will continue to grow in crop
- The seedbank lasts over three years and, in some areas, seeding emergence can be higher in the second year after seed production than in the first year
- Wireweed is not highly competitive due to a prostrate growth, delayed emergence compared with the winter annual crop and slow initial growth. However, when present at high densities, wireweed can reduce crop yield

Figure 1: *Polygonum aviculare* incidence in Australia.



Source: The Australasian Virtual Herbarium (AVH 2020)

Background

Wireweed is a weed in the Polygonaceae family, which likely originated from Europe. It is common to southern WA, SA, Victoria, NSW, Queensland and Tasmania, and is occasionally found in the NT (Figure 1). A close relative is the less common *P. arenastrum* Boreau.

Description

- Wireweed has spear-shaped cotyledons with a pointed tip, 7 to 15mm long and blue-green.
- Mature plants develop alternate leaves along the stems and small, pinkish-white flowers. Growth is prostrate, and the tough branches form a dense mat up to 1.2m wide.
- Wireweed has hard, rusty-brown seeds, about 2mm long, and the dead plants are also a rusty-brown colour.
- This species (*Polygonum aviculare*) is highly similar to the closely related *P. arenastrum*. A key difference is that *P. aviculare* has branch leaves half the size of the stem leaves, and *P. arenastrum* has all leaves of similar size. While this document refers to *P. aviculare*, both species have similar characteristics of seed biology and ecology.

Why is it a weed?

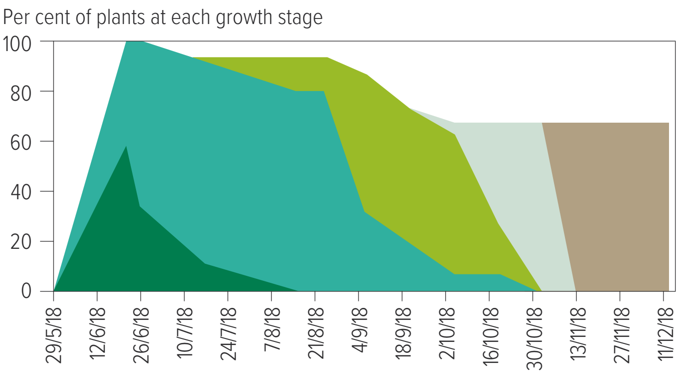
Wireweed is a major problem in Australia because the delayed and scattered emergence makes it difficult to target with herbicides. It germinates after the crop or pasture, due to a physiological requirement for low soil temperatures to break dormancy. The late emergence ensures it has minimal impact on yield of winter crops, but the long, tough branches interfere with harvest and seeding machinery and cause blockages if plants are not controlled. Wireweed growth over the summer fallow removes soil moisture and nutrients that would otherwise be available to the following crop.

Wireweed has some allopathic effects, most commonly affecting medic or lucerne. It cannot easily be controlled by grazing. Stock will eat young plants, but forage quality is low and the mature plants are unpalatable. Wireweed does regrow well from severe defoliation.

Figure 2: Top left: Wireweed seeds. Top right: Seedlings. Bottom left: Mature branches with flowers. Bottom right: Mature plants forming a mat after harvest.

Photos: Catherine Borger (DPIRD)

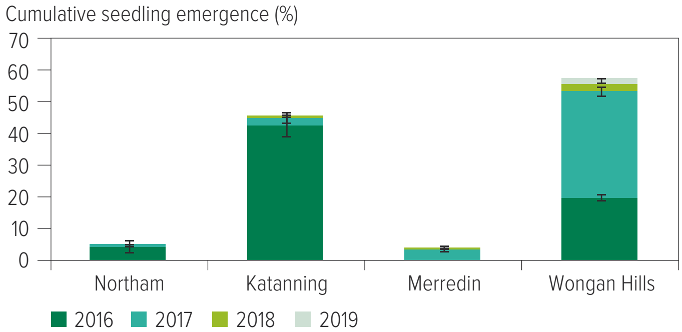
Figure 3: The growth of wireweed plants in a field trial at Wongan Hills, WA.



Individual plants were monitored after seeding wheat on 29 May 2018 to identify the percentage of wireweed plants at each growth stage (seedling, vegetative, branching, flowering, seed production) throughout the cropping season. Note that some plants died prior to reaching the branching or seed production stage. Plants continued to grow throughout summer, but the graph only shows plant growth up to crop harvest in December.

Source: DPIRD

Figure 4: Emergence of wireweed seed (as a percentage of the initial seedbank) collected over the summer of December 2015 to February 2016 and sown in field conditions in four locations in WA in April 2016. Vertical bars indicate the standard error of the mean.



Source: DPIRD

Seed

Dormancy and germination

A large proportion of wireweed seed is dormant, and seed requires cold temperatures of 2° to 4°C and exposure to light to remove dormancy. Once dormancy is removed, germination will occur at temperatures between 5°C and 55°C, although optimal germination occurs at 15°C. This highlights that wireweed will germinate more easily in winter, but non-dormant seeds can also respond to spring and summer rainfall. Seeds can imbibe (absorb water) in as little as two hours, allowing rapid germination of non-dormant seed following exposure to moisture. This would help seeds take advantage of transient moisture from spring or summer rainfall. Seed germination increases from 5.3 per cent in dark conditions to 44 per cent in light. Clearly germination is favoured by a zero/no-tillage system that leaves more seeds on the soil surface, rather than a full inversion system where seeds are buried. Burial will increase the size of the dormant seedbank.

Germination was reduced by scarification (that is, physical damage to the seed), indicating seeds on the soil surface will lose viability if damaged by stock or granivorous (seed eating) species over the summer fallow.

In 2018 at Wongan Hills, WA, wireweed seed was sown directly before seeding a wheat crop in late May (Figure 3). Wireweed cohorts emerged for 60 to 80 days after crop sowing, with emergence in June, July and early August. However, once seedlings emerged, they remained small (that is, four to six leaves, in the vegetative growth stage) for several weeks, and plants did not set seed until November and December. Therefore, there is a long period in which plants can be controlled prior to seed production. Staggered emergence will make this species more difficult to target with herbicides.

Seedbank persistence

In ideal (controlled, irrigated) conditions at Northam, WA, seed of 12 wireweed populations had an average of 75 per cent emergence in the first year after they were planted, with 13 per cent and six per cent emergence in years two and three. Seeds were also sown in plots in different field locations and monitored for three years, and the soil was agitated each year to simulate crop seeding. These seeds had highly variable emergence (Figure 4). Emergence at Northam and Merredin was low overall, but at Merredin seed had greatest emergence in the second year rather than the first year. Total emergence at Katanning and Wongan Hills was much higher, but wireweed at Wongan Hills had greatest emergence in the second year. Wongan Hills was the only site where the seedbank lasted four years. It is clear dormancy is highly dependent on environmental conditions. Seed may germinate in the first year after it is produced, or the bulk of the seed may remain dormant until the second year.

Seed left on the soil surface had a high rate of seed degradation (likely due to seed germination) over the first 3 months. The remaining seed on the soil surface retained viability for the following two years, with 0 per cent viability when seed was retrieved after three years. By comparison, seed buried at 2 or 10cm had a 4 to 5 per cent viability after three years. It is clear that the seedbank can persist for at least three to four years, and seedbank persistence will be longer where the seeds are buried.

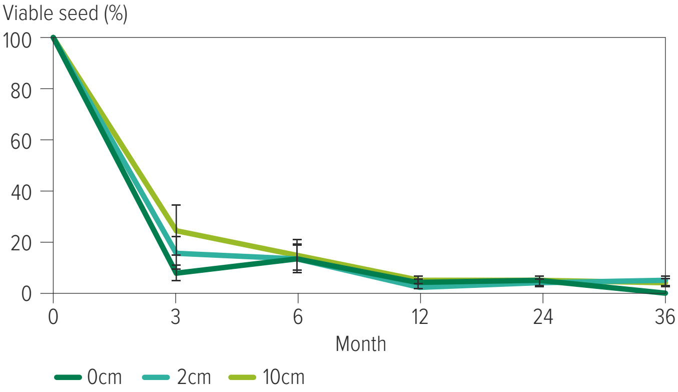
Seed production and dispersal

Individual wireweed plants can grow over one year or two (that is, as annuals or perennials), and individual plants can produce 52,400 seeds, or 123,000 seeds/m^2. Seed is initially produced at the base of the branches, near the centre of the plant. As the mature plant spreads and grows, new seed is produced on the ends of the branches, after the initial seed has matured and shed. As a result total seed production is directly related to plant size (Figure 6). Prior to shedding, the seeds can be dragged considerable distances if the branches are caught in machinery at seeding. The hard seed coat allows some seeds to survive if ingested by stock and this can be a mechanism of seed dispersal.

Competition

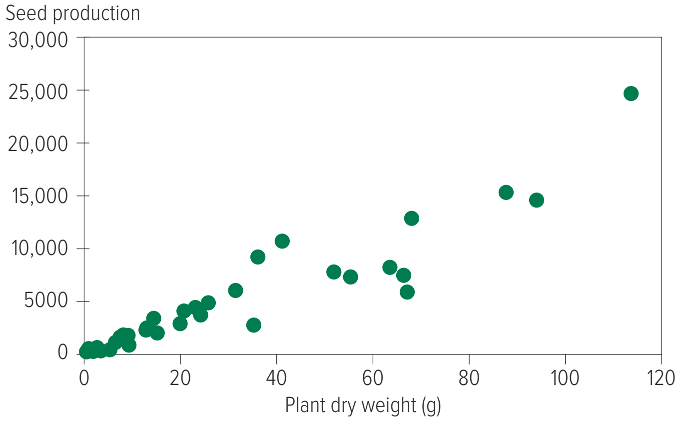
Wireweed is poorly competitive in wheat. Competition trials indicated no reduction in wheat yield from wireweed in 2017 and 2019 (Figure 7). Yield was reduced by five to 21 per cent in 2018 because the wireweed emerged in June, which was earlier than other years. In the other two years, initial emergence was in August (2017) and July (2019). Late, staggered emergence is common for wireweed. Delayed emergence results from the cold requirement to remove seed dormancy.

Figure 5: Effect of burial depth and duration on seedbank persistence averaged over two populations of wireweed from WA. Vertical bars indicate the standard error of the mean.



Source: DPIRD

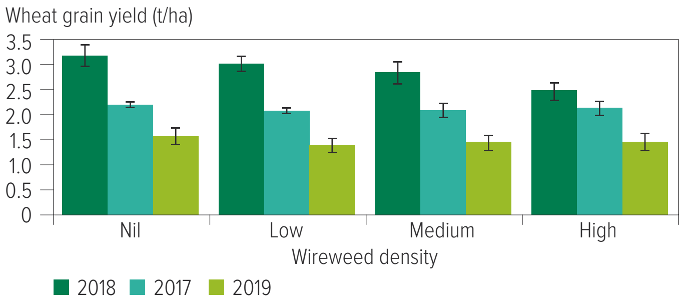
Figure 6: The dry weight and seed production of individual wireweed plants.



Source: DPIRD

Crops that have an initial two to three weeks of weed-free growth are highly competitive. As wireweed is a prostrate species, it has little competitive impact on crop growth and yield in those years where it does not have initial emergence until July or August.

Figure 7: Wheat yield at increasing densities of wireweed (with wireweed density assessed at 17 weeks after crop emergence) at Wongan Hills, WA, from 2017 to 2019. The low, medium and high-density plots had 1, 4 and 11 plants/m² in 2017, 4, 23 and 59 plants/m² in 2018, and 6, 37 and 80 plants/m² in 2019. Vertical bars indicate the standard error of the mean.



Source: DPIRD

References and further reading

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KEY CONTACTS

Catherine Borger
Department of Primary Industries and Regional Development
0467 816 082
catherine.borger@dpird.wa.gov.au

P Level 4, 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604
T 02 6166 4500 **E** grdc@grdc.com.au
www.grdc.com.au