Western Region

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Canola

Western Region

August 2015

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Start here for answers to your immediate canola crop management issues

What variety should I grow?

What's the latest thinking on optimum sowing rate?

How do I approach canola nutrition?

What approach should I take to weed control in my canola crop?

What pre-emergent herbicide control options do I have?

How do I control aphids in canola?

Should I choose swathing or direct heading?

Key Management Issues for Canola in the Western Region

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NO TILL

Use no-tillage as it stores more **soil moisture** than conventional fallows

Ensure heavy stubble **does not cover the plant line** as it will impede canola establishment

P Phosphate nutrition for canola is very important. Canola can respond to phosphorus on soils where wheat does not

N Use similar rates of nitrogen on canola as you would for high protein wheat in the same soil

10 20 30 40 50

Where conditions allow, aim to drill seed through the main seed box to **1.5–3 CM** deep and **UP TO 5 CM** in self-mulching clays

Grow **several varieties** to **spread harvest timing** and the **risk of unfavourable events** e.g. moisture stress and frost

Consider **HERBICIDE TOLERANT VARIETIES** e.g. triazine tolerant (TT) RoundupReady® or Clearfield® where weeds are a problem

Canola is best followed with a **WINTER CEREAL,** as disease levels (e.g. crown rot) should be reduced and AM* (Arbuscular Mycorrhiza, previously known as VAM) is not a high requirement with these crops

SOW

Mid/late maturing spring varieties **10 APRIL TO 5 MAY**

Short season varieties **20 APRIL TO 15 MAY**

Target density **<20** plants per square metre

APHIDS

Recent seasons have seen high levels of aphids in spring, monitor aphid levels in autumn and spring to reduce the impact of virus transmission and crop stress from feeding.

If choosing to windrow prior to harvest this should start when **40-60%** of seeds have changed colour to red, brown or black.

ESTABLISHMENT FLOWERING PODDING SWATHING

Monitor crops for insect pests during the **critical times.** Take account of **BENEFICIAL INSECT NUMBERS** when making decisions on control options

Swathed crops should be ready to harvest **5-14 DAYS** after swathing depending on the weather.

The moisture content of the grain should be **8%** or less.

Front page image: Harvesting canola at Corrigin, WA. Photo: Evan Collis Photography

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SECTION A

Introduction

A.1 Crop overview

Western Australia (WA) is the major canola-growing state in Australia, producing about 40% of the nation's 2.7 million tonnes each year.

The majority of WA canola is exported, generating ~$0.6 billion for the state's economy each year. The Netherlands, Belgium, Germany and Japan are WA's largest export canola markets.

Canola from WA is renowned for its high oil content, with the state consistently achieving higher oil contents than the rest of the nation. [1]

A.1.1 History of canola

Canola refers to the seed and oil that is produced by several cultivars of the rape plant, generally cultivars of either rapeseed (*Brassica napus* L.) or field mustard/turnip rape (*Brassica rapa* subsp. *oleifera*, syn. *B. campestris* L.). [2]

Rapeseed oil was produced in the 19th Century as a source of a lubricant for steam engines; however, it was less useful as food for animals or humans because of high levels of erucic acid and glucosinolates, chemical compounds that significantly lower the nutritional value of rapeseed for animal feed.

Canola was developed in Canada in the early 1970s by traditional plant-breeding techniques to reduce significantly the levels of erucic acid and glucosinolates that were found in the parent rapeseed plant. The name 'canola' is a contraction of 'Canadian' and 'ola' (meaning oil). [3]

In the 1970s, intensive breeding programs in several countries including Australia produced high-quality varieties that were significantly lower in the two toxicants. Varieties termed 'canola' must meet specific standards on the levels of erucic acid and glucosinolates. They must yield oil low in erucic acid (<2%) and meal low in glucosinolates (total glucosinolates 30 μmol/g toasted oil-free meal)

1 DAFWA. Canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/crops/grains/canola

2 Canola. Wikipedia, http://en.wikipedia.org/wiki/Canola

3 CanolaInfo (2015) Where does canola come from? CanolaInfo, http://www.canolainfo.org/canola/where.php

(CODEX International Food Standards 1999), and are often referred to as 'double low' or 'double zero' varieties. [4]

Australian canola typically contains <10 µmol/g of glucosinolates, 43–45% oil, and 38–40% protein in oil-free meal. [5]

Canola now dominates the consumption markets for oil and meal (Figure 1). Production of high erucic acid rapeseed is confined to production under contract for specific industrial uses, including environmentally friendly lubricants. [6]

In addition to varieties from the traditional *B. napus* and *B. rapa* species, cross-breeding of multiple lines of *B. juncea* has enabled this mustard variety to be classified as a canola-type variety by lowering both erucic acid and glucosinolates to the market standards. [7]

Figure 1: Canola is now a major oilseed industry, providing national economic benefits in employment, processing, manufacturing and exports.

A.1.2 Canola in Australia

Rapeseed was first trialed in Australia in the early 1960s and grown commercially in 1969, following the introduction of wheat delivery quotas. The first commercial seed, of the variety Target, was imported from Canada in 1967 by Meggitt Ltd.

4 OGTR (2002) The biology and ecology of canola (*Brassica napus*). Office of the Gene Technology Regulator, http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/content/canola-3/$FILE/brassica.pdf

5 AEGIC. Australian grain note: canola. Australian Export Grains Innovation Centre, http://www.australianoilseeds.com/oilseeds_industry/quality_of_australian_canola

6 CanolaInfo (2015) Where does canola come from? http://www.canolainfo.org/canola/where.php

7 Canola. Wikipedia, http://en.wikipedia.org/wiki/Canola

Early varieties were not well adapted to Australian conditions, being Canadian in origin. Canadian plant breeders had developed varieties much lower in erucic acid than Target and Arlo, but they were also lower in yield, so never became popular in Australia. For the same reason, the first ‘double low’ varieties were not widely grown in Australia. The varieties available were also quite susceptible to blackleg, and farmers suffered increased disease losses. The growth of the industry was being limited by a lack of suitable varieties.

The first rapeseed-breeding program in Australia was set up in Victoria in 1970, followed by WA and New South Wales in 1973. Their initial objectives were to develop varieties that were blackleg-resistant and low in erucic acid and glucosinolates while maintaining or increasing yields. Blackleg became a major problem in the early 1970s, and the disease was soon widespread. In WA, where the disease was most severe, yield losses of up to 80% resulted in plantings crashing from 49,000 ha in 1972 to 3,200 ha in 1974.

Although resistant varieties were developed, the WA industry did not produce significant quantities of canola again until the early–mid 1990s. The first Australian varieties were Wesreo (released 1978) and Wesway (released 1979), which were low-erucic-acid, blackleg-resistant varieties from WA. In Australia, canola is used to denote varieties with erucic acid level <2% and total glucosinolates <40 µmol/g. The first canola-quality *B. napus* varieties to be released were Wesroona, in WA in 1980, and Marnoo, from Victoria in 1980. Marnoo was higher yielding and had much lower glucosinolate levels than earlier varieties and so became a popular variety, particularly in Victoria.

However, Marnoo’s limited blackleg resistance was a handicap in New South Wales. Growers there had been growing mainly Span, and quickly adopted Jumbuck (*B. rapa* variety, released 1982) because of its better yield, quality and disease resistance. In 1987, with the release of Maluka and Shiralee (both *B. napus*) from New South Wales, high-quality canola varieties became available. These were the first varieties to combine canola quality with blackleg resistance and high yields. They also resulted in a trend back to *B. napus* varieties.

The first hybrid canola, Hyola 30, was released by Pacific Seeds in 1988, followed by Hyola 42 in 1991. Triazine-tolerant (TT) canola was first commercialised with the release of the variety Siren in 1993. Siren was late maturing with low yield and oil content but was useful where crucifer weeds reduced the chances of success with canola. New TT varieties rapidly followed, both early (Karoo and Drum) and mid-season (Clancy and Pinnacle) maturity. This led to the rapid adoption of TT canola across Australia, especially in WA.

The TT varieties continue to have a yield disadvantage of 10–15%, and about 3–5% lower oil content than conventional varieties, but they are accepted by farmers because they allow canola to be grown where it could not previously.

Since the early 1990s, canola production has extended into lower rainfall areas in all states, even where rainfall is as low as 325 mm/year. This expansion has caused plant breeders to select earlier maturing varieties, with the release of Monty in 1998 and

Mystic in 1999. Early-maturing varieties currently have lower oil contents than mid-season types and often have slightly lower resistance to blackleg; however, further work is being conducted to improve these types. [8]

The first imidazolinone-tolerant (Clearfield®) variety was released in 1999, further expanding weed-control options. Genetically modified glyphosate-tolerant varieties, incorporating the Roundup Ready® trait, were grown commercially for the first time in 2008 in New South Wales and Victoria. High oleic, low linolenic acid varieties were grown commercially for the first time in 1999. These varieties differ from conventional canola in the fatty acid profile of the oil, which increases its uses, especially for deep frying. [9]

A.1.3 Domestic production

Australian canola production has averaged ~1.4 Mt/year, ranging from 512,000 t to 2.46 Mt. The total Australian oilseed crush capacity is ~1.1 Mt, with much of this in the eastern states. Some 550,000–650,000 t of canola is crushed annually, with the main export markets for surplus seed being Japan, Pakistan, Bangladesh, China and the European Union.

The vast majority of canola oil is used in the food industry: about one-third in spreads and cooking oil, and two-thirds in the commercial food-service sector (Figure 2). About 20–25% of Australian canola oil is exported. Canola meal, the main byproduct of crushed canola, is used as a high-protein feed for intensive livestock, mainly in the pig, poultry and dairy industries.

Figure 2: Most of Australia's canola oil is used in the food-service sector.

The challenge for growers and the industry over the next few years will be to continue to improve productivity by adopting best practice management and being responsive to climate variability to ensure a stable supply of high-quality oilseed for domestic

[8] B Colton, T Potter. History. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0010/2701/Chapter_1_-_History.pdf

[9] D McCaffrey (2009) Introduction. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

and international markets. [10] Table 1 shows production in four states for 2013–14 and estimated production for 2014–15.

Table 1: Canola production in New South Wales, Victoria, South Australia and Western Australia
Sources: industry estimates, GIWA, PIRSA

	Final 2013–14		Estimate 2014–15	
	Harvested area (ha)	Production (t)	Area planted (ha)	Production (t)
NSW	600,000	900,000	550,000	750,000
Vic	400,000	700,000	400,000	700,000
SA	300,000	500,000	280,000	450,000
WA	1,180,000	1,800,000	1,250,000	1,750,000
Total	2,480,000	3,900,000	2,480,000	3,650,000

A.1.4 Canola in the western region

Canola has become an important crop in WA, with production in 2013 being 1.8 Mt, worth just over $1 billion to the state's economy (Figure 3). Nearly all WA canola production is exported, predominantly into Asia for human use and to Europe for biofuels. The Department of Agriculture and Food WA has a strong research, development and extension program for canola, with a focus on developing profitable agronomic packages and overcoming pest and disease constraints. [11]

Production

Canola is WA's third largest crop after wheat and barley, with production increasing to well over 1 Mt over the past 5 years on the back of rising world demand and prices. WA is the leading Australian state for canola production, accounting for ~40% of the nation's 5-year average production of 3.4 Mt.

The state has a reputation for producing canola with a high oil content, often 2–4% above that of other states. [12]

[10] D McCaffrey (2009) Introduction. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[11] J Paterson, I Wilkinson (2015) Western Australian canola industry. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/canola/western-australian-canola-industry

[12] J Paterson, I Wilkinson (2015) Western Australian canola industry. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/canola/western-australian-canola-industry

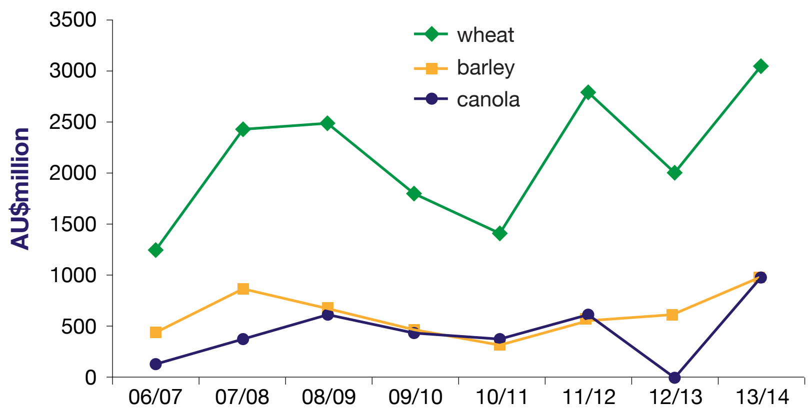


Figure 3: Relative value of production (AU$ million) of Western Australian wheat, barley and canola industries.

As well as being profitable in its own right, canola has become the most important break crop in WA cereal production systems, overtaking lupin because of better prices and better weed-control options.

Canola in WA is grown under sustainable farming systems that can be certified to meet sustainability criteria required to access the European Union markets.

Both conventional and genetically modified canola varieties are grown in WA, with strict segregation in the supply chain allowing the two systems to co-exist. [13]

Exports

Western Australia exports nearly all of the canola it produces, accounting for 40–50% of the nation's total canola exports and ~7% of global exports.

The value of WA canola exports has increased 5-fold since 2000, with a 5-year average of $440 million/year. The major markets for WA canola are South Korea, Japan, Netherlands, Malaysia and Germany. [14]

Processing

Two locally based canola crushers operate and both are small by international industry standards. These are at Pinjarra and Kojonup. Between the two local crushers, ~60,000 t of canola seed is processed per year, representing ~8% of the state's total canola production. [15]

A.1.5 Hybrids

A hybrid is a plant created by cross-pollinating male and female parents of different inbred lines. A hybrid has the benefit of heterosis (hybrid vigour). Hybrid canola generally has higher yield potential than traditional, inbred, open-pollinated varieties.

[13] J Paterson, I Wilkinson (2015) Western Australian canola industry. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/canola/western-australian-canola-industry

[14] J Paterson, I Wilkinson (2015) Western Australian canola industry. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/canola/western-australian-canola-industry

[15] J Paterson, I Wilkinson (2015) Western Australian canola industry. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/canola/western-australian-canola-industry

This improved yield is achieved through a combination of superior traits such as larger seeds, leading to early vigour, and better stress tolerance. However, hybrid seed should never be retained for sowing because it will not produce true copies of the original hybrid plant. [16]

Although the first canola hybrid was released in 1988, only recently have hybrids been grown on a large scale. Since the introduction of Roundup Ready and Imidazolinone Tolerant (IT) hybrid canola into Australia, seed companies have focussed more on these hybrids, at the expense of open pollinated triazine tolerant (TT) varieties. This places a dramatic increase in seed costs on growers which is likely to restrict further expansion of the canola growing area and is likely to decrease the area sown to canola in the lower rainfall higher risk areas of WA's grain growing area.

The major global producers are China, the European Union, Canada and India. Canada is the major exporter and Japan and the European Union are the major importers. Australian canola competes with Canadian product in the international marketplace. Canola is the third most important winter grain crop in Australia, behind wheat and barley. [17]

[16] GRDC (2010) Growing hybrid canola. GRDC Canola Fact Sheet, August 2010, https://www.grdc.com.au/~/media/D4B939DB8790453FB2D6CBD04CA11B78.pdf

[17] D McCaffrey (2009) Introduction. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

SECTION 1

Planning/Paddock preparation

1.1 Paddock selection

In addition to early preparation and good crop management, success with canola cropping depends on careful paddock selection. The major considerations when selecting a paddock to grow canola in rotation with other crops are:

- soil type
- potential disease problems
- previous herbicide use
- broadleaf weeds

Choosing more reliable and weed-free paddocks is the best option (Figure 1). It is desirable to soil-test prior to sowing the crop and to continue to manage broadleaf and grass weeds prior to sowing.

When considering the rotation, using crops such as wheat or barley prior to sowing canola will allow for increased broadleaf control through more herbicide options and increased crop competition. Well thought out weed control can have significant benefits, especially where problem weeds are difficult to control in canola. [1]

Many growers are now growing canola to control weeds not able to be controlled in wheat. This is through use of Roundup Ready or Triazine Tolerant (TT) varieties.

DAFWA: Canola Diagnostic Tool

[1] P Parker (2009) Crop rotation and paddock selection. Ch. 4. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 1: Choosing more reliable and weed-free paddocks is the best option for canola. (Photo: Evan Collis Photography)

1.1.1 Soil types

Canola is adapted to a wide range of soil types. Whilst sandy soils can grow canola successfully, particularly in areas with winter dominant rainfall, canola is best adapted to red-brown earths and clay soils. These soils generally have higher organic matter and inherent fertility. Canola has a high requirement for Nitrogen that will need to be met by fertilizer application in soils of lower fertility. Canola will perform best on neutral to alkaline soils, with good tilth. Paddocks with a uniform soil type will permit more even sowing depth and seedling emergence and more even crop ripening.

Research paper: Climate and Soils

Avoid growing canola where the following problems occur:

Hardpans

Although canola is a tap-rooted plant, it is not strong enough to penetrate some tight hardpans and can still suffer from 'J' rooting problems. Paddocks should be checked 12 months in advance by using a soil probe or by digging a small pit to visually assess a suspected problem and determine the depth of working or ripping that may be required to break up any hardpan.

Crusting soils

The surface of a soil can crust after rainfall and reduce plant establishment if it is poorly structured with low organic matter levels, or a sodic clay that disperses after wetting. The use of gypsum and/or stubble retention on hard-setting sodic clay soils may improve seedling emergence and early growth.

Acid soils

Canola is more susceptible to low pH and aluminium (Al) toxicity than most other crops. If you expect the pH in calcium chloride ($CaCl_2$) to be <5.0, have the prospective canola paddock soil-tested in the previous season. If acidic subsoil is suspected, take split samples of soil depths 0–10 and 10–20 cm. Where a pH($CaCl_2$) <4.7 is combined with exchangeable Al level of ≥3%, do not grow canola before obtaining specific advice. Other indicators of acidity problems are poor growth in barley, or if oats and triticale grow better than wheat. Consider using lime when the topsoil pH($CaCl_2$) drops to <5.0.

Sodic subsoils

Soils with a sodic clay subsoil of low permeability become waterlogged when rainfall exceeds their infiltration capacity. A sodic subsoil problem can be identified by a simple soil testing procedure (dispersion test) backed up by laboratory chemical analysis. Avoid these soils unless they have a good depth of well-drained topsoil, which allows for adequate root growth even after heavy rainfall. Use of raised beds has been a successful strategy for reducing the impact of waterlogging in high-rainfall areas of south-western Western Australia. [2]

More information

Canola best practice management guide for south-eastern Australia

1.2 Rotations and paddock history

Canola can reduce but not eliminate the incidence of some cereal root and crown diseases, such as crown rot and take-all. Research has shown canola to be the most effective winter crop for reducing levels of crown rot in subsequent wheat crops. [3]

Canola is not a host for arbuscular mycorrhizal fungi (AMF) and will result in lower levels following the crop. This may disadvantage subsequent crops that are highly dependent on AMF, particularly if environmental conditions and progressive fallows have also reduced AMF levels. Crops with a reliance on AMF include faba beans and chickpeas.

Research has shown that wheat yield increases of ~0.6–1.0 t/ha can be expected when following canola compared with following wheat.

2 P Parker (2009) Crop rotation and paddock selection. Ch. 4. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

3 L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

Figure 2: Canola has benefits for subsequent cereal crops as it can reduce the incidence of some cereal root and crown diseases.

No-tillage, which retains more stubble, is increasing the carryover of many of the main cereal diseases, such as crown rot. Canola fits well into this system by allowing an additional season for cereal stubble breakdown to occur, therefore reducing the carryover of disease.

Ideally canola should not be included in the rotation more frequently than one in every four years. This reduces the potential for canola disease build-up and also allows for rotation of herbicide and weed control tactics. The use of triazine-tolerant (TT), imadozoline-tolerant (IT or Clearfield), Roundup and Triazine Tolerant (RT) canola systems and Roundup Ready (RR) canola systems can also be used strategically as for hard to control weeds.

When planning cropping systems on the farm consider placement of future crops in relation to potential insect pest host crops. Rutherglen bugs may be present in large numbers on canola stubble around harvest time. [4]

1.2.1 Profitable paddock rotations in WA's wheatbelt

Crop rotations in Western Australia's wheatbelt are heavily dominated by 4 crop types and pasture, with around 94% of farm paddocks using some combination wheat, canola, lupins, barley or pasture.

Canola is a part of 53% of rotations in the southern wheatbelt and 30% of northern wheatbelt rotations after 3 years of DAFWA trial measurements (2010-12).

[4] L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

Common rotations

The most popular individual rotation across the 3-year dataset is currently wheat/wheat/wheat, accounting for 18%. Wheat/wheat/canola (15%) and wheat/canola/wheat (16%) rotations combined account for 31% of paddock rotations.

When wheat/lupin/wheat (15%) along with wheat/wheat/lupin (3%) are added to this mix almost 70% of all paddock rotations are accounted for within these 3 crop types.

The rotations can be further broken down if we split the data in the north and south of the wheatbelt. There are significant differences between the prevalence of different rotations across the state, with the most obvious example being the previously mentioned wheat/wheat/wheat rotation which accounts for 25% of all paddocks monitored in the north, whilst only 5% of those in the south.

Rotation profitability

The appearance of canola in the most profitable rotations should leave little doubt as to the reasons behind the rapid uptake of canola across the state. Equally, all but 2 of the 8 most profitable 3-year sequences have at least 2 years of wheat which supports the idea that the ability to get tight wheat rotations into the system being a key driver of profitability for much of the wheat belt. However, as most paddocks in this system area on rotations of 4 or more years it is too early to draw too many conclusions in terms of overall profitability.

Looking at the most popular rotations we can identify whether or not there are any significant differences between a wheat/wheat/wheat rotation when compared to a wheat/canola/wheat rotation. Looking at the third year wheat component of these rotations it doesn't appear as though there is any significant difference in either average fertiliser costs or the range of fertiliser costs, coming in at an average $85/ha (i.e. $28 - $115/ha) and $87/ha (i.e. $28–$121/ha) respectively.

As we would expect after 3 years of wheat, there does appear to be a difference in chemical costs. The WCW rotations have an extremely narrow range, with 18 of 21 samples being between $6 and $33/ha. The WWW rotations on the other hand were largely between $24 and $56/ha, with the average cost being approximately 25% higher than WCW rotations. It is likely that at least part of this differential can be explained by the difference in Take-all and Rhizoctonia concentrations between sequences (Table 1), specifically the impact of canola on reducing disease concentration.

Table 1: Disease concentration by rotation in focus paddocks

PDK Sequence	n	Rhizo 2010	Rhizo 2013	% of initial	TA 2010	TA 2013	TA% of initial
Wheat/Wheat/Wheat	21	3.4	18.4	547	0.5	1.2	257
Wheat/Canola/Wheat	19	40.2	11.2	28	1.8	1.5	80
Wheat/Wheat/Canola	16	4.4	1.7	38	1.4	1.8	135

Weed numbers also play a key role in explaining this difference in chemical costs. As with disease there is a significant difference between the two rotations, with average

More information

[Profitable paddock rotations: Is the choice of break crop costing you money?](#)

[Profitable crop and pasture sequencing 2013 trial report](#)

[Over the bar with better canola agronomy](#)

[Canola best practice management guide for south-eastern Australia](#)

[Crown rot in winter cereals](#)

weed numbers declining by 40% over the 3 years in Wheat/Canola/Wheat rotations, and increasing by 374% for Wheat/Wheat/Wheat rotations (Table 2).

Table 2: Weed numbers by rotation in focus paddocks

PDK Sequence	n	Weeds Per m Sq 2010	Weeds Per m Sq 2012	% of initial
Wheat/Canola/Wheat	21	20.9	12.5	60%
Wheat/Wheat/Wheat	19	12.6	47	374%

Current paddock rotations are dominated by five main choices, and whilst the secondary reasons for crop rotation choice may differ from year to year (ranging from controlling weed pressure, being used as a disease break, or as a nitrogen injection), the primary reason is always long term rotational profitability.

Canola's role in the system has increased dramatically over time, with Focus Paddock project data suggesting it has a place in 53% of rotations in the south of the wheatbelt and 30% in the north. The reasons for its inclusion appear obvious with the weed and disease data presented in combination with its profitability.

In many locations, particularly in the lower rainfall zones, tightness of wheat in the rotation appears to be the primary goal, and wheat/wheat/wheat rotations are common. Whilst currently this system does appear to be among the most profitable, the fourth year performance may drastically alter the overall profitability of varying rotations, especially where fallow is a part of the system. [5]

1.3 Herbicide plant-back periods

Canola is particularly susceptible to a range of residual herbicides. Under dry seasonal conditions or in alkaline soils, residues from a herbicide applied to a previous pulse or cereal crop can persist into the next cropping season. For example, the sulfonylurea group (e.g. chlorsulfuron, sulfosulfuron) used in cereal crops have a canola plant-back period of 24–30 months. Similarly, some herbicides registered in pulse crops can have plant-back periods ranging from 9 months (simazine) to 24 months (flumetsulam) to 34 months (imazethapyr). The use of these herbicides can therefore restrict crop options and prevent the sowing of canola for up to 3 years. The use of various herbicide-tolerant (TT or Clearfield®) canola varieties coupled with their companion herbicides (triazines or imidazolinone herbicides) can restrict crop-selection options in the following year. Plant-back periods are provided on herbicide labels for sensitive crops under these conditions. [6]

Plant-back periods do not begin until there has been a significant rainfall event.

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

5 http://www.giwa.org.au/pdfs/2014/Not_Presented_Papers/Hagan%20James%20-%20Profitable%20paddock%20rotations%20Is%20the%20choice%20of%20break%20crop%20costing%20you%20money%20PAPER%20-%20EOI36%20DR.pdf

6 P Parker (2009) Crop rotation and paddock selection. Ch. 4. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[Soil behaviour of pre-emergent herbicides in Australian farming systems: a reference manual for agronomic advisers]

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods, as is the case for sulfonylureas (chlorsulfuron) (see Table 3). Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate heading or under 'Protection of crops etc.' in the 'General Instructions' section of the label. [7]

Table 3: Residual persistence of common pre-emergent herbicides, and noted residual persistence in broadacre trials and from paddock experience [8]

Sources: CDS Tomlinson (Ed.) (2009) The pesticide manual (15th edn), British Crop Protection Council; Extoxnet, http://extoxnet.orst.edu/; California Department of Pesticide Regulation Environmental Fate Reviews, www.cdpr.ca.gov/

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than triasulfuron
Diuron	90 (range 1 month–1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed, long-lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane
Atrazine	60–100, up to 1 year if dry	High. Has had observed, long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	60 (range 28–149)	Medium–high. 1 year residual in high pH soils. Has had observed, long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	6.5–139	High. Has had observed, long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed, long-lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.)
Stomp® (pendimethalin)	40	Medium. 3–4 months residual
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed, long-lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and prosulfocarb; however, weed control persists longer than with prosulfocarb

More information

[Australian Pesticides and Veterinary Medicines Authority]

[Using pre-emergent herbicides in conservation farming systems]

[Weed control in winter crops]

[Sulfonylurea spray contamination damage to canola crops]

[7] B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

[8] B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

More information

Canola best practice management guide for south-eastern Australia

DAFWA: Dry seeding- more wins than losses

1.4 Seedbed requirements

Seed–soil contact, especially under dry conditions, is crucial for helping moisture to diffuse into the canola seed. Emergence of canola seedlings can be reduced by the formation of soil crusts in hardsetting, sodic or dispersing soils. Sodic or dispersing soils that surface-seal will reduce the emergence of canola seedlings.

A firm, moist seedbed provides uniform seed germination and rapid seedling growth. Adequate soil moisture at the seedling and elongation stages promotes the development of a strong, healthy plant less prone to lodging and with maximum leaf growth by the end of July. [9]

1.5 Soil moisture

Soil moisture is vital for both germination and emergence. Canola must absorb a high percentage of its weight in water before germination begins. It will germinate when the seed moisture content has risen to approximately 24%.

Water absorption is a passive process. The ability of seeds to absorb water depends on the difference in water potential between the seed and the surrounding soil. Seeds can absorb water even at very low soil-water potentials, but low water potentials may induce secondary dormancy.

Seed size influences the rate of water absorption. Small seeds have a high surface-to-volume ratio, which means that less time is required to absorb adequate moisture for germination.

In soils with a low moisture content, the germination rate will be lower and emergence slower (Table 4).

Table 4: Effect of soil moisture content on final emergence percentage and days to 50% emergence

Source: Modified from Canola Council of Canada (2003)

Total soil water content (% weight)	Final emergence percentage	Days to 50% emergence
18%	82%	9
15%	59%	12
13%	45%	13
11%	4%	–

The trial was established in a growth chamber at constant day–night temperatures of 8.5°C–10°C. In summary:

- The higher the total soil water content, the higher the final germination percentage.

[9] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

- The higher the soil water content, the quicker the time to 50% seedling emergence. [10]

Water is essential for plant growth. Adequate soil moisture:

- promotes root growth
- promotes a large, abundant leaf area
- helps plants to retain their leaves longer
- lengthens the flowering period
- increases the numbers of branches per plant, flowers forming pods and seeds per pod
- increases seed weight and seed yield

Moisture stress is more important during podfill than at the vegetative stage. However, too much or too little water at any growth stage reduces yield potential. Factors that may limit yield include:

- the amount of moisture stored in the soil over summer
- the rate and duration and timing of rainfall during the growing season
- the ability of the soil to absorb water, store it, and make it available for plants

More information

[Is there a place for canola on irrigation?](#)

[Yield of wheat and canola in the high rainfall zone of south-western Australia in years with and without a transient perched water table](#)

Modifying some of these factors can improve moisture availability and efficiency of water use.

When soil water and nutrients are abundant, the balance of root to stem and leaf growth typically shifts in favour of stem growth at the expense of roots. When water is limited, the opposite usually occurs. Roots account for ~25% of plant dry matter at stem elongation in moisture-stressed canola, compared with ~20% in unstressed plants.

1.5.1 Moisture stress during rosette formation and elongation

Canola has limited ability to withstand severe drought. To avoid dehydration, the plant closes its stomata and rapidly sheds leaves.

Moisture stress during the early vegetative stages reduces the ability of stomata to conduct carbon dioxide and therefore slows photosynthesis. This in turn reduces leaf area expansion and dry matter production. It also limits root growth, which reduces nutrient uptake. More severe water deficits inhibit photosynthesis because of cell and chloroplast shrinkage.

This is important in seasons with dry winters. It is also important in low-rainfall areas where the period of crop growth is restricted at the start of the season by lack of rainfall and at the end of the season by water deficits and high temperatures.

[10] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

Plants under early-season moisture stress will usually recover normal growth with subsequent rainfall or irrigation. Stressed plants are able to recover leaf area, form flowers, set pods and fill seeds when water becomes available, but with hastened development rates, crops have early maturity and lower yields. The worst time for drought stress in canola is during stem elongation or flowering.

Long periods of drought will reduce yields more than frequent, short periods of drought. The impact will be greatest on coarse-textured soils and shallow soils with low water-storage capacity.

Adequate soil moisture tends to lengthen the number of days to maturity by up to 10 days. Additional soil moisture will result in no further increase in yield and may cause yield reductions through poor soil aeration and/or increased lodging and diseases. [11]

infocus

1.5.2 How much moisture is enough to successfully establish April-sown canola?

Key messages

- The criteria for successful wet sowing are that rainfall should connect with deeper soil water or one should allow for evaporation till the next effective rain, especially under dry and warm conditions.
- For dry sowing, the maximum allowable rainfall was estimated at about 5 mm for sandy, 8 mm for loamy and 10 mm for clay textured soils, failing which a day or two after the rain (depending on evaporation rate) should be allowed before dry seeding.
- For the first 15 days after stress, daily seedling mortality under water deficit conditions was about 2% more than the usual mortality (about 0.8%) under unstressed conditions.
- Since additional branching can offset mortality losses, a low plant population of the early sown canola can still be sufficient for maximum yield, especially in low yielding seasons.

Aims

Dry sown and early wet sown canola crops are increasing in Western Australia. Both present an opportunity to maximise yield but are accompanied by major risks of seed and seedling mortality due to early drought conditions.

Economic losses could be substantial if a dry sown crop was sown 'too wet' (i.e. with enough soil water present to germinate but not to establish the plants); and conversely, a wet sown crop was sown too dry. Hence, this paper intends to highlight

11 J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

moisture considerations relevant to this issue and provide some indicators that farmers might use in making educated decisions.

Method

We used two years' data, a literature review and common knowledge on soil-plant water relations to estimate the maximum allowable and minimum required rainfall in order to successfully avail a dry or a wet sowing opportunity, respectively.

The field experiments were conducted at Kellerberrin (2011, 2012) and Merredin (2011). The Kellerberrin experiments were unreplicated and the Merredin experiment contained four replicates.

In 2011, canola was dry sown followed by irrigation to create a moisture gradient. For the 2012 experiments, sowing was done after irrigation. Irrigation levels in 2011 ranged from 15 mm to 52 mm with increments of 2.5 mm while 5 mm increments were used in 2012.

Plants were counted twice a week till the season/rains started. Seedling mortality per day was calculated as percentage of the maximum emerged counts.

For modelling purposes, dry and wet sown criteria of plant available water (PAW) were used as proposed by Abrecht and Robertson (unpublished) and soil specific PAWC limits as proposed by Burk and Dalgliesh (2008) and Oliver (2010).

Results

Results are presented for plant mortality and then for rainfall requirements to suit dry or wet sowing.

Emergence

The percentage of plant emergence increased progressively with increasing irrigation (up to 30 mm). Secondly, we observed two situations, one in Merredin 2011 when no further emergence took place after the break of the season and the other at Kellerberrin in 2012 where a second cohort of emergence was noticed on a water-repellent sandy textured soil (Figure 3). This suggested that smaller amounts of irrigation at Merredin evaporated too soon resulting in pre-emergent mortality. In contrast, owing to the non-wetting nature of the sandy textured soil at Kellerberrin (2012), such small irrigation amounts were insufficient to wet up the seedbed thoroughly resulting in some seed surviving. These saved seeds germinated at the next rains (break of the season). Such a bimodal germination pattern on non-wetting sands can perhaps provide buffering to a dry sown crop against false or partial breaks while sowing on other soils with limited rainfall (and limited moisture in the seedbed) will put germinating seedlings to high lethal risk.

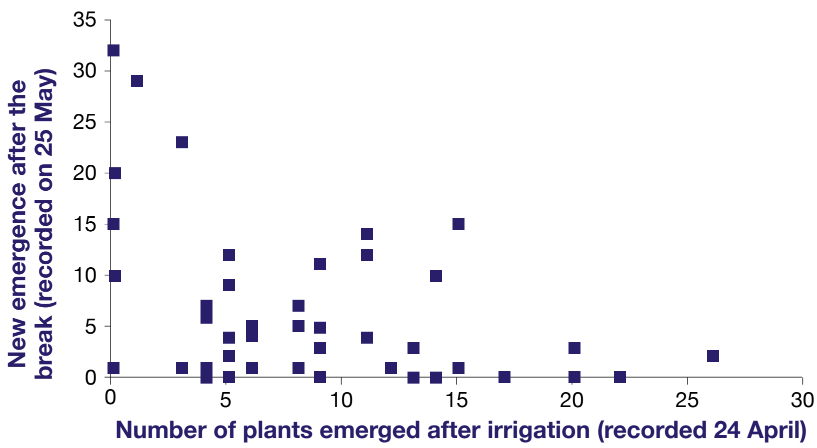


Figure 3: New plants emerged after break of the season at spots where initial emergence (after irrigation) was low at Kellerberrin 2012.

Note that new emergences (y-axis) are more where only few could emerge (x-axis) in the first instance and vice versa.

Survival of the emerged seedlings

Of the four experiments, seedling mortality due to water deficit was not noticeable at Merredin 2011 and either of the Kellerberrin 2012 sites irrespective of the emergence percentage and irrigation level. For example, the points on 1:1 line in Figure 4 imply no mortality from max count date (x-axis) to the last count date (y-axis) for any of the treatments.

To understand this, soil moisture levels were compared with seedling mortality. In all the three sites where mortality rate per day was similar among irrigation treatments, we found plenty of moisture at 20 cm for all treatments and it had connected with the stored moisture underneath (Figure 5). In contrast, Kellerberrin 2011 had clearly two irrigation categories, less than and more than 35 mm irrigation, which coincided with seedling mortality and moisture at 20 cm depth (Figure 6); notably, in comparison to 35 mm, the 25 mm irrigation treatment had less moisture in the 10-20 cm zone and suffered much higher seedling mortality.

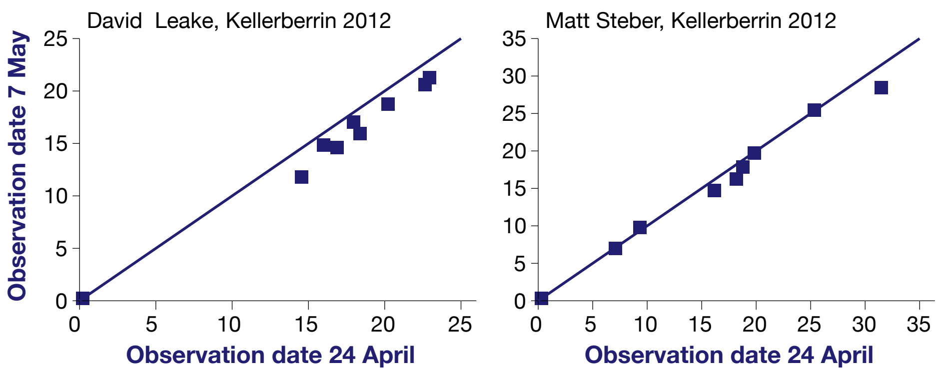


Figure 4: Change in plant density at two sites in 2012.

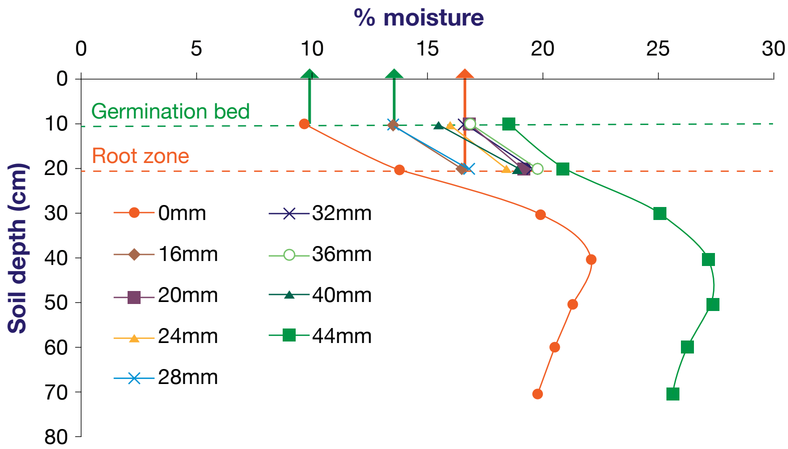
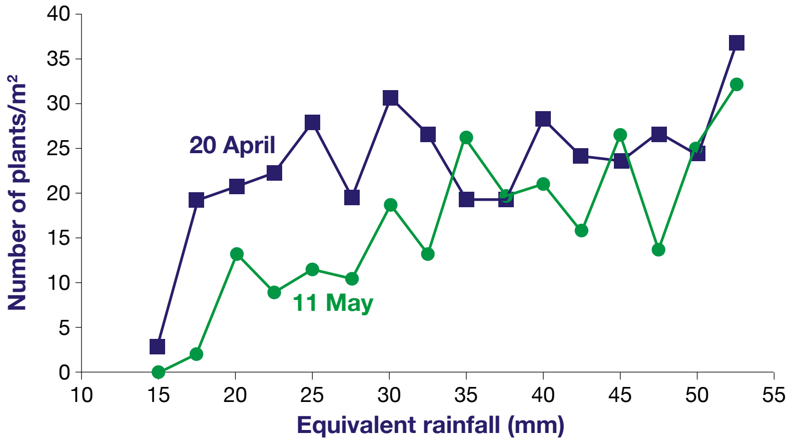


Figure 5: Soil moisture on heavy land at Kellerberrin (2012). To avoid cluttering in the figure, moisture data below 20 cm has not been shown for treatments between nil and 44 mm. Note that even the lowest irrigation level had plenty of moisture at 20 cm (root zone) depth.



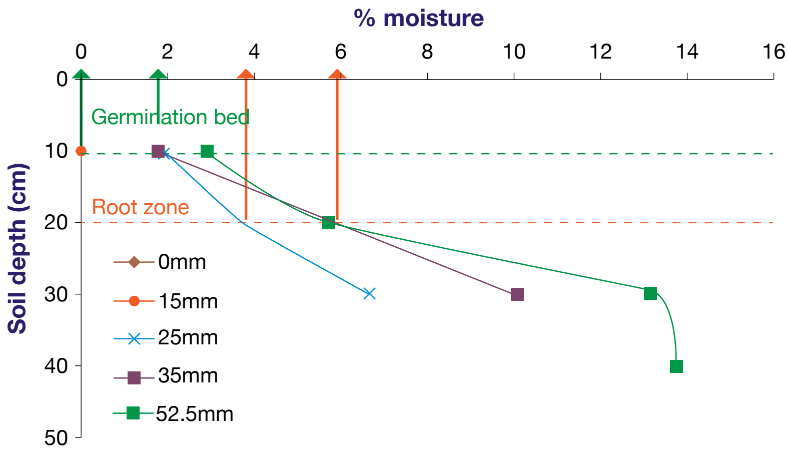


Figure 6: Changes in plant density with time of a 6 April sown canola crop and soil moisture at different irrigation levels. Note that moisture at 20 cm (root zone) depth was lower for 25 mm irrigation compared to 35 mm and above.

How much rainfall?

For a dry sowing, soil moisture must not be more than 30% of PAWC (Table 5). Preliminary calculations reveal that this corresponds to about 4 mm of rainfall on sandy textured soils to a maximum of about 10 mm on clay loam. This implies that dry sowing should be deferred to such a time that moisture in excess of this level gets evaporated.

Duration of this waiting period would vary according to evaporation rate but the estimation of actual evaporation rate from pan evaporation rate (as available from meteorology websites) can be challenging. Determination of actual evaporation rate from soil relative to the pan evaporation rate is complex and is a function of soil moisture percentage, soil type, stubble cover and some other farm practices. From simultaneous consideration of these factors it appears that actual evaporation from soil under most WA conditions should lie from half to three-fourths of the pan evaporation.

Table 5: Estimated maximum allowable rain (mm) on a dry surfaced soil for dry sowing#

$ The significance of 30% PAWC is that this is the approximate water availability above which water is not limiting for plant growth and development

#Falls in excess of this must be allowed to evaporate the difference before dry sowing can be started.

	Soil layer	Depth range (cm)	PAWC$	Sand	Sandy loam	Clay loam
Criterion 1	Seed bed	0-10	< 10%	1.1	1.7	2.3
Criterion 2	Top soil	0-20	< 30%	4.4	6.8	9.9

For wet sowings, more experimental data is needed to model minimum water requirements for early sowing. Nonetheless, following observations from Kellerberrin 2011 (Figure 7) should assist in decision making.

- The mortality rate was higher with less water applied (e.g. compare 25 with 52.5 mm irrigation).
- The mortality rate changed with time. For example, it was higher after 20 April for the moderately stressed treatments (20 and 25 mm) compared to higher irrigation treatments (30 and 52.5mm).
- Average daily evaporation rate for April 2011 at Kellerberrin was 5.4 mm.

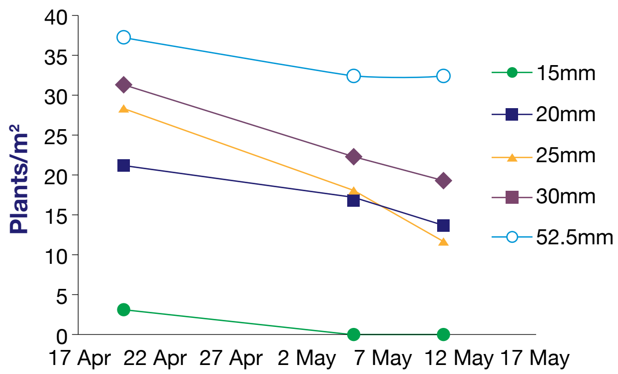


Figure 7: Repeated plant counts for different irrigation levels applied on 6 April to a dry sown crop in Kellerberrin 2011.

Conclusion

For dry sowing, soil type differences exist for maximum acceptable rainfall. Any rain in excess of these limits must be allowed to evaporate before seeding, failing which there will be economic losses due to seed and fuel costs besides the lost opportunity costs in the event of re-seeding.

For wet sowing, plant survival and soil moisture comparison clearly demonstrated that it is not just the availability or the depth to which moisture is available at the time of seeding; it is important that there is sufficient moisture in the seedbed (0-10 cm) for the duration of germination to achieve good plant numbers and adequate deeper moisture to sustain them (10-20 cm and preferably beyond). The best seeding situation is when rainfall reaches stored moisture underneath. [12]

1.6 Yield and targets

Canola has traditionally yielded approximately half of what wheat would yield in the same situation. Said another way it achieves only half the water use efficiency of that of wheat (kg of grain per mm of water available).

More recently with improved varieties and the agronomy and management of the crop many growers are now targeting 50% of typical wheat yields.

As discussed in Section 2, varieties vary in yield performances. However, several generalisations can be made:

- TT varieties will often perform less well than conventional, Clearfield or Roundup Ready varieties as there is a fitness penalty integral to breeding herbicide tolerance. This is often referred to as yield drag and quoted as up to 15% compared to conventional varieties. However some agronomists believe this is over-estimated in some regions and it must be remembered that the TT tolerance allows control of weeds that could otherwise not be controlled. TT varieties often have less seedling vigour which can hinder establishment and this can have ramifications through to harvest.
- Hybrid varieties generally have higher yield potential than open pollinated varieties. This is achieved through the hybridization process, enabling coupling of strong and desirable traits from the parent varieties. Many breeding or seed companies are also investing greater effort into hybrid varieties as gains are easier and quicker to achieve as well as ensuring seed sales each year.
- GMO varieties, specifically Round Up Ready or glyphosate-tolerant varieties, promise improved yield potential and performance but at present these varieties are achieving only average performance, not withstanding weed management benefits.

In setting yield targets or expectations, growers also need to take into account sowing date, seasonal conditions (particularly rainfall and fallow moisture) and disease and pests. In southern regions Blackleg, and more sporadically Sclerotina, can impact

[12] D. Sharma, C. Peek, G. Riethmuller and D. Abrecht, (2013), How much moisture is enough to successfully establish April-sown canola. Department of Agriculture and Food, Western Australia

More information

DAFWA Seasonal Climate Outlook

Grain marketing—wheat, canola and barley outlook

Agribusiness Outlook 2015

Canola agronomy research in central NSW

Irrigated canola - Management for high yields

Growing hybrid canola

heavily on crop performance but the northern region does not seem to experience the same level of disease, particularly Blackleg, so this should not in many cases be too much of a yield barrier.

Pre-seeding planning to manage frost risk in WA

1.6.1 Seasonal outlook

DAFWA's Season Climate Outlook (SCO) is a monthly newsletter that summarises climate outlooks for the next three months produced by DAFWA's Statistical Seasonal Forecast (SSF) system specifically for the Western Australian wheatbelt, and by the Australian Bureau of Meteorology. It provides a review of recent climate indicators, including ENSO (El Niño Southern Oscillation), the Indian Ocean Dipole, the Southern Annular Mode, as well as local sea surface temperature and pressure systems. At appropriate times of year it also includes an overview of the rainfall outlook for the growing season produced by the SSF. [13]

1.6.2 Fallow moisture

Like wheat, canola will benefit from stored subsoil moisture, particularly in marginal cropping areas where winter and spring rainfall is unreliable. Manage fallows efficiently to maximise the amount of moisture at sowing. [14]

1.6.3 Nitrogen- and water-use efficiency

Nitrogen fertiliser can increase the water-use efficiency (WUE) of early-sown canola. The additional N enables the crop to cover the ground quicker and develop a dense leaf canopy, resulting in reduced soil evaporation and better WUE. [15]

A University of Adelaide study in 2013 of canola under different water regimes with N showed that grain yield was mainly driven by biomass production. It also revealed that the timing of N had little impact on yield; however, split application improved oil content.

Canola crops extracted water to 60–80 cm, and addition of N increased the drying of the profile by maturity but had little effect on total water use relative to nil N. Both N-use efficiency and WUE were improved by additional water availability. [16]

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13 https://www.agric.wa.gov.au/newsletters/sco

14 L Jenkins (2009) Crop establishment. Ch. 5. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

15 P Hocking, R Norton, A Good (1999) Crop nutrition. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0013/2704/Chapter_4_-_Canola_Nutrition.pdf

16 A Riar, G McDonald, G Gill (2013) Nitrogen and water use efficiency of canola and mustard in Mediterranean environment of South Australia. GRDC Update Papers, 13 February 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Nitrogen-and-water-use-efficiency-of-canola-and-mustard-in-South-Australia

1.6.4 Estimating maximum yield per unit water use by location and nitrogen

Researchers propose a three-step procedure to derive the 'slope' parameter representing maximum yield per unit water use accounting for N and location.

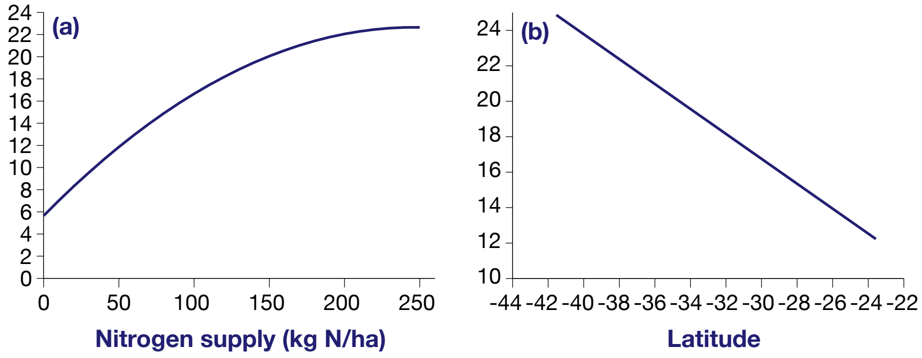

Figure 8: Maximum yield per unit water use (kg/ha.mm) as a function of (a) nitrogen and (b) location.

Step 1

Use the data in Figure 8a to account for the effect of N on maximum yield per unit water use. For severely limited crops (N supply <50 kg N/ha), maximum yield per unit water use would be about 5–6 kg grain/ha.mm. For crops with abundant N supply (>200 kg N/ha), the parameter approaches 24 kg grain/ha.mm. For intermediate N supply, maximum yield per unit water use can be estimated graphically using this curve.

Step 2

Use the line in Figure 8b to correct for location. For a latitude of –41.5° (Launceston, the southernmost location in this study), maximum yield per unit water use would be ~24–25 kg grain/ha.mm. For a latitude of –23.5° (Emerald, the northernmost location), maximum yield per unit water use would be ~12 kg grain/ha.mm. For intermediate locations, maximum yield per unit water supply can be estimated graphically using the line in Figure 8b.

Step 3

Select the lowest value from steps 1 and 2. For example, if we want to estimate the maximum yield per unit water use for Dalby (latitude –27.1°) with intermediate N supply (100 kg N/ha), the location correction would return 14.7 kg/ha.mm and the N correction would return 16.6 kg/ha.mm. We therefore select the lowest value, 14.7 kg/ha.mm, as a benchmark for this combination of location and N supply. [17]

[17] V Sadras, G McDonald (2012) Water use efficiency of grain crops in Australia: principles, benchmarks and management. GRDC Integrated Weed Management Hub, http://www.grdc.com.au/GRDC-Booklet-WUE

Table 6: Water-use efficiency based on total biomass (WUEdm) or grain yield (WUEgy) of different crops

Water-use efficiency is based on the biomass or yield per mm of crop water use. Values are mean and range.

Crop	Region	WUEdm (kg/ha.mm)	WUEgy (kg/ha.mm)	Source
Canola	Victoria	24.0 (17.1-28.4)	6.8 (4.7-8.9)	Norton and Wachsmann 2006
Canola*	NSW		13.4	Robertson and Kierkegaard 2005
Chickpeas	Western Australia	16.0 (11.1-18.3)	6.2 (2.6-7.7)	Siddique et al. 2001
Lentils		12.7 8.5-16.7)	6.7 (2.4-8.5)	
Lupins		17.3 (9.3-22.3)	5.1 (2.3-8.3)	
Faba beans		24.2 (18.7-29.6)	10.4 (7.7-12.5)	
Peas		26.2 (17.6-38.7)	10.5 (6.0-15.9)	
Vetch		18.2 (13.4-22.4)	7.5 (5.6-9.6)	
Chickpeas	Tel Hadya, Syria	13.7 (9.4-18.1)	3.2 (2.1-5.2)	Zhang et al. 2000
Lentils		8.7 (5.0-14.2)	3.8 (1.9-5.5)	
Wheat	South Australia	36.1 (21.2-53.1)	15.9 (9.2-23.2)	Sadras et al. (unpublished)
	South-east Australia		9.9 (max =22.5)	Sadras and Angus 2006

*Based on simulated estimate of crop water use

More information

Water use efficiency of grain crops in Australia

Nitrogen and water use efficiency of canola and mustard in South Australia

Nitrogen use efficiency in canola

Water-use efficiency of canola in Victoria

There are intrinsic differences in the WUE of crops (Table 6), with wheat more water-use efficient than grain legumes or canola, in terms of both total biomass production and grain yield. Differences in the composition of the grain—it is more energy efficient to produce starch than oil or protein—partially explain the higher grain yield per unit water use of wheat compared with oilseed crops and pulses.

Further, canola and the grain legumes are grown at lower plant densities and/or have less vigorous seedlings than wheat, contributing to greater early losses of moisture through soil evaporation, and hence to lower WUE. The amount of winter growth made by the crop is therefore an important factor in determining crop WUE. [18]

1.7 Potential disease problems

Blackleg is the major disease of canola in Australia and can significantly reduce yields, especially in higher rainfall districts. Research has shown that 95–99% of blackleg spores originate from the previous year's canola stubble.

Spores can travel >1 km on the wind but most travel shorter distances, so selecting a paddock as far away as possible from the previous season's canola stubble will help to reduce disease pressure. Where possible, a buffer distance of 500 m is recommended.

On larger farms, it may be possible to implement a system of block farming whereby blocks of several paddocks of a particular crop type are rotated around the farm to maintain an adequate buffer distance. Reducing canola stubble by raking and burning

[18] V Sadras, G McDonald (2012) Water use efficiency of grain crops in Australia: principles, benchmarks and management. GRDC Integrated Weed Management Hub, http://www.grdc.com.au/GRDC-Booklet-WUE

provides only limited benefits in reducing the disease level because not all of the infected stubble and old roots are destroyed.

Use of blackleg-resistant varieties in combination with an appropriate fungicide treatment, if necessary, is the best way to minimise yield losses. Careful paddock selection can also assist in reducing the impact of another potentially serious canola disease, Sclerotinia stem rot (caused by *S. sclerotiorum*).

Sclerotinia stem rot - Managing the disease in 2013

Sclerotinia stem rot is an intermittent problem in many canola-growing districts, particularly northern regions of WA. It has a wide host range of broadleaf plants and weeds, including lupins, chickpeas, field peas, faba beans, sunflowers, cape weed and Paterson's curse. Growing canola after any of these crops or in paddocks that have had large populations of these weeds can increase the risk of Sclerotinia stem rot, especially when canola is grown under irrigation or in higher rainfall areas. [19]

More information

AGWEST Plant Laboratories for seed and plant testing

For more information, see GrowNotes Section 9, Diseases.

Sclerotinia infection occurs when there is rainfall around petal drop but only when those petals have Sclerotinia spores on them. Predicting infection is difficult but fungicides can be applied to combat the infection. The economic benefits of this approach in the western region are questionable.

1.8 Nematode status of paddock

Canola is considered moderately susceptible to *Pratylenchus neglectus, P. quasitereoides* and *P. penetrans*.

More information

Variety choice and crop rotation key to managing root lesion nematodes

For more information, see GrowNotes Section 8. Nematodes.

Testing soil is the only reliable way to determine whether root-lesion nematodes are present in a paddock. Before planting, soil tests can be carried out by PreDicta B (SARDI Diagnostic Services) through accredited agronomists, to establish whether crops are at risk and whether alternative crop types or varieties should be grown. Growing-season tests can be carried out on affected plants and associated soil; contact local state departments of agriculture and PreDicta B. [20]

To organise testing and sending of soil samples, visit the PreDicta B website.

[19] P Parker (2009) Crop rotation and paddock selection. Ch. 4. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[20] GRDC (2015) Root-lesion nematodes. GRDC Tips and Tactics, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

SECTION 2

Pre-planting

More information

NVT 2015 canola mudmaps

NVT variety brochures

Current canola variety guide for Western Australia

WA's hybrid canola demand growing

FAQ

2.1 Varietal performance and ratings yield

The main features to consider when selecting a variety are maturity, yield, oil content, herbicide tolerance and blackleg resistance. Early-maturing varieties are generally more suited to lower rainfall areas, and mid-season types are suited to medium and higher rainfall growing areas. [1]

2.1.1 Varieties for WA

The vast majority (87%) of the Western Australian (WA) canola crop is triazine-tolerant (TT). The area of Roundup Ready® (RR) canola increased from 8% to 13% in 2013–14 (Table 1). The most popular canola varieties grown in 2013–14 were Crusher TT, ATR-Stingray, ATR-Cobbler, Hyola® 404RR and ATR-Snapper. These five varieties made up >70% of the area sown to canola in the 2013–14 season (Table 2). [2]

The 2014 growing season was very kind to the mid–long maturity groups. Clearfield® (imidazolinone-tolerant) and RR varieties continue to demonstrate a yield advantage over the TT group.

Roundup Ready®–TT (RT) varieties were in the National Variety Trials (NVT) program for the second year and their performance was a very close second to benchmark hybrids from the TT group, which indicates that this chemistry group should be used only for its herbicide agronomic traits. TT hybrids have demonstrated some yield benefit over open pollinated lines, although this is not consistent.

More information

Canola National Variety Trial Results 2014

The financial reward from the oil bonus has shown benefit with some varieties, but oil content remains the second selection criterion, with yield still the greatest influencing factor on profit. [3]

1 L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.nvtonline.com.au/wp-content/uploads/2013/03/Crop-Guide-Canola-Northern-NSW-Planting-Guide.pdf

2 J Bucat (2014) 2015 Canola guide for WA,. Department of Agriculture and Food Western Australia., Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

3 M Davey (2015) Canola National Variety Trial results 2014. GRDC Update Papers, 20 April 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/04/Canola-National-Variety-Trial-Results-2014

More information

[Genetically modified canola: a resource guide](#)

[Canola talk](#)

[SEPWA 2014 all trials in the Esperance port zone](#)

Table 1: Canola herbicide systems in Western Australia: percentage of area planned to be sown under different herbicide systems

Data courtesy of CBH Group. Conventional canola has no specific herbicide tolerance

Herbicide system	2012–13	2013–14
Triazine-tolerant	87	83
Roundup Ready®	8	13
Clearfield	4	3
Conventional	1	1

Table 2: Canola varieties in WA: percentage of area sown

Data courtesy of CBH Group. TT, Triazine-tolerant; RR, Roundup Ready®; IT, imidazolinone-tolerant (Clearfield®); CC, conventional canola with no specific herbicide tolerance

Variety	Group	11/12	12/13	13/14
Crusher TT	TT	1.9	21.3	23.0
ATR-Stingray	TT	0.4	7.9	19.3
ATR-Cobbler	TT	41.3	29.6	14.6
Hyola® 404 (RR)404RR	RR	0.3	3.4	7.4
ATR-Snapper	TT	0.1	2.7	6.7
Telfer	TT	2.7	4.4	5.1
ATR-Gem	TT		0.4	3.8
Jackpot TT	TT		0.4	3.3
Pioneer® 43Y23(RR)	CLRR		0.4	1.9
Tanami	TT	8.2	5.0	1.4
Pioneer® 45Y86(CL)	IT			1.0
GT Cobra	RR		1.1	0.9
Nuseed® GT-50	RR			0.9
Thunder TT	TT	6.6	3.2	0.9
AV Garnet	CC	0.5	0.6	0.9
ATR-Stubby	TT	2.0	1.9	0.7
Pioneer® 44Y84(CL)	CLIT	1.3	0.9	0.6
GT Viper	RR		0.6	0.5
Tornado TT	TT	3.8	2.0	0.5
ATR Beacon	TT	1.7	1.3	0.5
Thumper TT	TT		0.0	0.5
Hyola® 559TT	TT			0.5
Tawriffic TT	TT	2.6	1.2	0.4
Other		26.6	11.7	4.7

2.2 Agzones

Agzones have been developed to group together environmental regions that give similar crop performance. The six Agzones are shown in Figure 1:

- Agzone 1 is the northern medium- and high-rainfall area including Mingenew and Northampton.
- Agzone 2 is the northern-central medium-rainfall area including Coorow, Northam and Wagin.

More information

Growing western canola

Getting the good oil on the right canola for your region

Selecting canola varieties for Western Australia

- Agzone 3 is the southern-central high- and medium-rainfall areas including Williams and Kojonup.
- Agzone 4 is the north-central low-rainfall area east of Mullewa and Merredin.
- Agzone 5 is the southern low- and medium-rainfall area including Newdegate, Scaddan and Salmon Gums.
- Agzone 6 is the south-coast high-rainfall area including Wellstead, Munglinup and Gibson. [4]

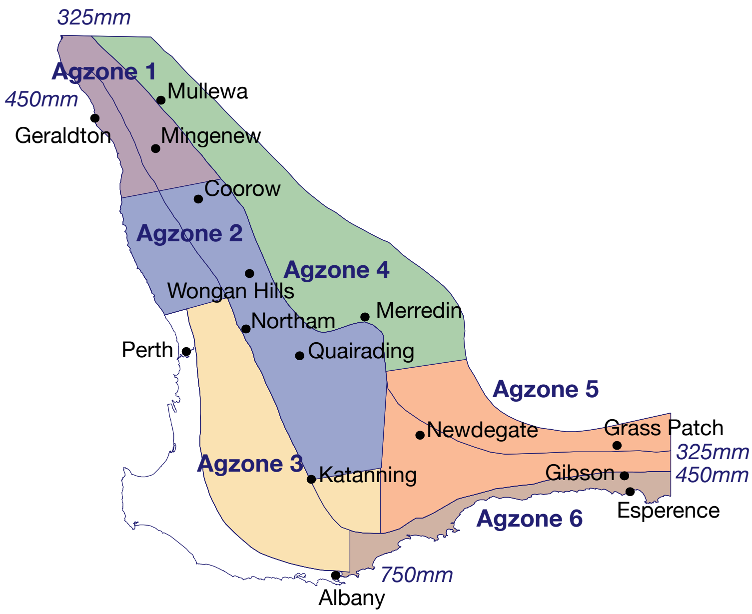

Figure 1: Agzones of Western Australia. (Source: DAFWA)

2.3 National Variety Trials Project yield and oil information

There are two series of NVT trials for canola: early-maturity series and mid-maturity series. Early-maturity trials are conducted where these varieties are needed—in northern areas and in the lower rainfall parts of central and southern areas (across Agzones 1–5). Mid-maturity trials are in the medium- and high-rainfall parts in central and southern areas (in Agzones 2, 3, 5 and 6).

Representatives from breeding companies nominate the series in which their varieties are tested. Many varieties are in both early- and mid-maturity trials.

Yield data are presented as predicted yield. Predicted yields are derived from long-term, multi-environment trials from 2009 to 2013. Results for TT and TT-RR canola are presented in Table 3 (early-maturity series) and Table 4 (mid-maturity series); likewise, RR canola results are in Tables 5 and 6, and Clearfield® canola in Tables 7 and 8. Predicted yield of each variety is presented relative to a 'standard' variety. For example, in Table 3, the TT variety ATR-Stingray has a predicted yield of 1.08 t/ha in the early maturity NVT trials in Agzone 1. The predicted yield of ATR-Bonito is 138%

4 J Bucat (2014) 2015 Canola guide for WA, Department of Agriculture and Food Western Australia., Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

of ATR-Stingray's yield in the same zone; therefore, the predicted yield of ATR Bonito can be calculated as 1.49 t/ha.

Oil data presented are the average oil percentage for each variety. The number of trials for each variety is shown in each yield table. Note that data are less reliable where there are only a few trials. [5]

For further information about long-term yields or individual NVT trial results, refer to NVT online at nvtonline.com.au.

Table 3: NVT trials (2009–13) early-maturity triazine-tolerant (TT) canola and TT-Roundup Ready® (RR) canola

GY, Predicted grain yields as a percentage of ATR-Stingray; oil is expressed as average percentage for that variety; n, number of trials

	Agzone 1			Agzone 2			Agzone 3			Agzone 4			Agzone 5		
ATR-Stingray (t/ha):	**1.08**			**1.72**			**1.68**			**0.68**			**1.45**		
	GY	**Oil%**	**n**	**GY**	**Oil%**	**n**	**GY**	**Oil%**	**n**	**GY**	**Oil%**	**n**	**GY**	**Oil%**	**n**
ATR-Stingray	100	42.5	7	100	43.0	4	100		2	100	42.3	2	100	43.0	13
ATR-Bonito	138	40.8	3	92	44.4	3				112	43.8	2	98	46.0	7
ATR-Cobbler	124	42.7	8	81	40.4	3	90		3				87	40.0	12
ATR-Gem	133	40.2	3	92	45.6	3				99	43.2	2	91	45.3	7
ATR-Snapper	127	44.5	6	91	43.7	2	97		2				94	43.4	9
ATR Wahoo													87	46.7	2
Crusher TT	127	37.3	3	98	44.5	3							96	42.6	9
Hyola® 450TT													99	47.8	4
Hyola® 555TT	143	41.2	3	103	42.0	3							98	40.8	4
Hyola® 559TT	158	41.1	3	99	46.6	3							98	46.4	6
Jackpot TT	136	40.5	2										82	42.4	2
Sturt TT(b)	134	42.2	5	92	42.4	4	101		2	110	41.9	2	97	43.6	10
Tanami	109	40.8	4										83	36.8	6
Telfer	88	42.6	9	85	41.7	3	90		3	93	41.9	2	91	43.3	13
Thumper TT													83	42.8	5
TT + RR															
Hyola® 525RT				95	47.3	2							98	47.4	2

[5] J Bucat (2014) 2015 Canola guide for WA,. Department of Agriculture and Food Western Australia., Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

Table 4: NVT trials (2009–13) mid-maturity triazine-tolerant (TT) canola and TT-Roundup Ready® (RR) canola

GY, Predicted grain yields as a percentage of Crusher TT; oil is expressed as average percentage for that variety; n, number of trials

	Agzone 2			Agzone 3			Agzone 6		
Crusher TT (t/ha)		1.79			2.40			2.03	
	GY	Oil%	*n*	GY	Oil%	*n*	GY	Oil%	*n*
Crusher TT	100	42.4	15	100	43.0	13	100	43.5	9
ATR-Bonito	101	43.2	14	98	45.9	6	99	46.4	5
ATR-Cobbler	84	42.5	28	78	42.6	14	69	44.1	11
ATR-Gem	95	43.7	18	96	45.7	9	97	45.7	7
ATR- Snapper	93	45.4	18	87	46.1	9	79	46.6	8
ATR-Stingray	94	43.3	25	93	44.1	12	91	45.3	10
ATR-Wahoo	95	42.6	12	94	45.2	6	97	45.6	5
Hyola® 450TT	93	45.1	7	101	46.5	3	99	46.7	2
Hyola® 555TT	97	42.1	20	103	43.4	13	102	43.8	11
Hyola® 559TT	100	43.7	12	105	45.9	8	102	45.6	6
Hyola® 650TT	95	45.8	2	106	46.4	3	105	45.5	2
Hyola® 656TT	97	43.9	2	103	44.2	6	103	43.9	4
Jackpot TT	91	41.0	7	96	46.4	3	97	45.5	3
Sturt TTⓓ	93	41.8	19						
Tanami	72	39.9	12	67	40.3	5	57		2
Telfer	80	42.9	28	73	43.9	4	58	44.9	4
Thumper TT	84	44.9	8	91	44.6	13	95	45.6	10
TT + RR									
Hyola® 525RT	92	45.3	5				94	46.4	2

Table 5: NVT trials (2009–13) early-maturity Roundup Ready® (RR) canola

GY, Predicted grain yields as a percentage of Hyola® 404RR; oil is expressed as average percentage for that variety; n, number of trials

	Agzone 1			Agzone 2			Agzone 3			Agzone 4			Agzone 5		
Hyola® 404RR (t/ha)		1.95			1.81			1.96			0.87			1.58	
	GY	Oil%	*n*	GY	Oil%	*n*	GY	Oil%	*n*	GY	Oil%	*n*	GY	Oil%	*n*
Hyola® 404RR	100	44.8	5	100	45.7	4	100		2	100	44.6	2	100	45.5	4
GT Cobra	74	43.2	5	94	43.9	4	87		2	82	41.5	2	90	44.2	4
GT Viper	55	43.5	5	86	43.4	3	79		2	72	41.5	2	85	44.5	4
Hyola® 400RR				94	48.1	2									
Hyola® 500RR				99	47.0	2									
Hyola® 505RR	86	44.1	4	93	45.4	4							88	46.1	3
IH30 RR	89	40.7	3	95	45.2	3				89	43.1	2	93	45.8	2
IH50 RR				96	44.0	3	86		2				89	42.3	4
Nuseed GT-41	84	40.9	3	100	45.1	3				95	41.8	2	100	48.0	2
Nuseed GT-50	87		2	99	46.6	2									
Pioneer® 43Y23(RR)	104	42.4	5	98	43.3	4	97		2	97	41.9	2	96	43.9	4
Pioneer® 44Y24(RR)	88	40.0	3	100	44.9	3				91	41.6	2	97	45.3	2

Table 6: NVT trials (2009–13) mid-maturity Roundup Ready® (RR) canola

GY, Predicted grain yields as a percentage of Hyola® 404RR; oil is expressed as average percentage for that variety; n, number of trials

	Agzone 2			Agzone 3			Agzone 6		
Hyola® 404RR (t/ha)		**1.96**			**2.65**			**2.16**	
	GY	**Oil%**	*n*	**GY**	**Oil%**	*n*	**GY**	**Oil%**	*n*
Hyola® 404RR	100	45.4	19	100	46.9	7	100	46.8	8
GT Cobra	91	43.4	16	89	45.5	6	91	45.2	7
GT Viper	85	43.7	15	79	45.0	4	76	45.8	5
Hyola® 400RR	97	46.3	4				103	46.8	2
Hyola® 500RR	101	45.0	3	104	47.2	2	107	47.0	2
Hyola® 505RR	90	45.9	13	98	47.9	7	99	46.4	8
IH30 RR	97	42.6	8						
IH50 RR	89	42.0	14	94	44.6	6	95	44.1	7
Nuseed GT-41	100	42.8	10	94	45.3	2	96	45.4	5
Nuseed GT-50	103	44.0	11	101	45.3	6	106	45.1	7
Pioneer® 43Y23(RR)	103	41.6	10	106	44.2	4	105	44.6	5
Pioneer® 44Y24(RR)	100	43.2	16	101	44.6	6	104	44.7	7
Pioneer® 45Y22(RR)	91	42.8	21	99	45.8	8	104	44.7	9

Table 7: NVT trials (2009–13) early-maturity Clearfield (CL) canola

GY, Predicted grain yield as a percentage of Pioneer® 44Y84(CL); oil is expressed as average percentage for that variety; n, number of trials

	Agzone 1			Agzone 2			Agzone 5		
Pioneer® 44Y84(CL) (t/ha)		**1.69**			**1.59**			**1.32**	
	GY	**Oil%**	*n*	**GY**	**Oil%**	*n*	**GY**	**Oil%**	*n*
Pioneer® 44Y84 (CL)	100	40.5	3	100	45.8	2	100	43.9	4
Archer	99		2	97	45.7	2	92	44.5	2
Carbine	88	39.9	3	104	46.0	2	104	43.8	3
Hyola® 474CL	82	41.1	3	108	45.4	2	104	45.0	3
Hyola® 575CL	84	41.5	3	109	45.4	2			
Pioneer® 43C80(CL)	66	39.7	2				96	42.8	3
Pioneer® 43Y85(CL)	77	38.3	3	103	45.1	2	102	43.9	3
Pioneer® 44Y87(CL)	86		2	106	44.4	2	104	43.2	2

Table 8: NVT trials (2009–13) mid-maturity Clearfield (CL) canola

GY, Predicted grain yields as a percentage of Pioneer® 44Y84(CL); oil is expressed as average percentage for that variety; n, number of trials

	Agzone 2			Agzone 3			Agzone 6		
Pioneer® 44Y84(CL) (t/ha)	1.79			2.40			1.88		
	GY	Oil%	*n*	GY	Oil%	*n*	GY	Oil%	*n*
Pioneer® 44Y84 (CL)	100	45.4	12	100	44.8	11	100	44.9	8
Archer	95	41.7	3	105	45.1	9	108	44.1	4
Carbine	101	45.1	7	99	44.8	9	100	44.6	5
Hyola® 474CL	89	44.9	7	102	44.0	9	107	44.3	6
Hyola® 575CL	91	43.8	8	103	44.3	10	110	43.9	7
Hyola® 577CL	91	45.1	2	101	45.9	3	110	46.0	2
Pioneer® 43Y85(CL)	89		3						
Pioneer® 44Y87(CL)	101	40.9	2	102	40.6	3	104	42.2	2
Pioneer® 45Y86(CL)	101	45.5	9	106	45.1	10	109	44.8	7
Pioneer® 45Y88 (CL)	100	42.6	4	106	43.0	6	113	43.5	4

2.4 Commercial and agronomic information

2.4.1 Open-pollinated and hybrid canola

Open-pollinated canola has relatively uniform genetics within a population and is ~75% self-pollinating, so each generation mostly retains the characteristics of the population. Retained seed is suitable to use for seeding.

Hybrid seed is produced by controlled cross-pollination of two distinctly different parent lines, which produce hybrid seed (F1). Hybrids may show better performance than either parent because of hybrid vigour.

Retaining seed from hybrids leads to variability in the next crop (F2) and has negative effects on plant vigour, uniformity of plant height, uniformity of flowering, blackleg resistance, lodging resistance, oil levels and their combined effects on yield. [6]

Blackleg rating

Blackleg information is provided in Tables 9, 10 and 11. See the GRDC Fact Sheet *Blackleg Management Guide* for further information about the importance of blackleg ratings, resistance groups and management of blackleg. [7]

More information

What is Roundup Ready canola?

Genetically modified (GM) canola

All Roundup Ready® canola is genetically modified, including varieties that are also triazine-tolerant (RT). [8]

[6] J Bucat (2014) 2015 Canola guide for WA. Department of Agriculture and Food Western Australia, Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

[7] J. Bucat (2014) 2015 Canola guide for WA. Department of Agriculture and Food Western Australia, Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

[8] J. Bucat (2014) 2015 Canola guide for WA, Department of Agriculture and Food Western Australia, Bulletin June 2014, https://www.agric.wa.gov.au/sites/gateway/files/Canola%20variety%20guide%202015.pdf

Table 9: Triazine-tolerant (TT) canola and TT-Roundup Ready® (RR) canola commercial and agronomic information

OP, Open pollinated. Maturity information provided by licensees. Maturity key: V, very; E, early; M, mid; L, late (maturity range: VE, E, EM, ME, M, ML, LM, L, VL). Blackleg data provided from the GRDC 2014 Blackleg Management Guide. Blackleg rating key: R, resistant; MR, moderately resistant; MS, moderately susceptible; S, susceptible; VS, very susceptible. Jockey® seed dressing contains fluquinconazole. Blackleg resistance group refers to the different combinations of blackleg resistance genes carried by each variety

Variety	Licensee	Release year	Type	Maturity	2014 blackleg rating		Blackleg resistance group
					Bare seed	+ Jockey®	
TT							
ATR-Bonito	Nuseed	2013	OP	EM	MR	R-MR	
ATR-Cobbler	Nuseed	2007	OP	E			
ATR-Gem	Nuseed	2011	OP	EM	MR	R-MR	A
ATR-Snapper	Nuseed	2011	OP	EM			
ATR-Stingray	Nuseed	2011	OP	E	MR	R	C
ATR-Wahoo	Nuseed	2013	OP	ML	MR	R-MR	A
Crusher TT	Pacific Seeds	2010	OP	M	MR-MS		A
Hyola® 450TT	Pacific Seeds	2013	Hybrid	ME	R	R	ABD
Hyola® 555TT	Pacific Seeds	2010	Hybrid	ME	R		D
Hyola® 559TT	Pacific Seeds	2012	Hybrid	M	R	R	
Hyola® 650TT	Pacific Seeds	2014	Hybrid	ML	R	R	E
Hyola® 656TT	Pacific Seeds	2012	Hybrid	ML	R	R	ABD
Jackpot TT	Pacific Seeds	2011	OP	M			
Sturt TTA(Ⓓ)	NPZA	2012	OP	E	MS		
Tanami	NPZA	2006	OP	VE			
Telfer	NPZA	2008	OP	VE			
Thumper TT	Pacific Seeds	2011	OP	ML	R		E
TT-RR							
Hyola® 525RT	Pacific Seeds	2014	Hybrid	M	R-MR	R	ABD

Table 10: Roundup Ready® (RR) canola commercial and agronomic information

OP, Open pollinated. Maturity information provided by licensees. Maturity key: E, early; M, mid. Blackleg data provided from the GRDC 2014 Blackleg Management Guide. Blackleg rating key: R, resistant; MR, moderately resistant. Jockey® seed dressing contains fluquinconazole. Blackleg resistance group refers to the different combinations of blackleg resistance genes carried by each variety

Variety	Licensee	Release year	Type	Maturity	2014 blackleg rating		Blackleg resistance group
					Bare seed	+ Jockey®	
GT Cobra	Nuseed	2011	OP	EM	R-MR		A
GT Viper	Nuseed	2011	OP	E	MR		
Hyola® 400RR	Pacific Seeds	2014	Hybrid	E	R		ABD
Hyola® 404RR	Pacific Seeds	2010	Hybrid	EM	R-MR		ABD
Hyola® 500RR	Pacific Seeds	2014	Hybrid	M	R		ABD
Hyola® 505RR	Pacific Seeds	2010	Hybrid	ME	R		
IH30RR	Bayer	2014	Hybrid	E	R-MR	R	AB
IH50RR	Bayer	2012	Hybrid	M	R-MR	R	A
Nuseed GT-41	Nuseed	2012	Hybrid	EM	R-MR	R	ABF
Nuseed GT-50	Nuseed	2012	Hybrid	M	R-MR		ABF
Pioneer® 43Y23(RR)	Pioneer®	2012	Hybrid	E	R-MR	R	
Pioneer® 44Y24(RR)	Pioneer®	2013	Hybrid	EM	R-MR	R	C
Pioneer® 45Y22(RR)	Pioneer®	2011	Hybrid	M	MR	R	C

Table 11: Clearfield (CL) canola commercial and agronomic information

OP, Open pollinated. Maturity information provided by licensees. Maturity key: E, early; M, mid. Blackleg data provided from the GRDC 2014 Blackleg Management Guide. Blackleg rating key: R, resistant; MR, moderately resistant; MS, moderately susceptible. Jockey® seed dressing contains fluquinconazole. Blackleg resistance group refers to the different combinations of blackleg resistance genes carried by each variety

Variety	Licensee	Release year	Type	Maturity	2014 Blackleg rating		Blackleg resistance group
					Bare seed	+ Jockey®	
Archer	Heritage Seeds	2012	Hybrid	M	MR-MS	R-MR	
Carbine	Heritage Seeds	2012	Hybrid	EM	MR-MS	R-MR	A
Hyola® 474CL	Pacific Seeds	2011	Hybrid	ME	R		BF
Hyola® 575CL	Pacific Seeds	2010	Hybrid	M	R		BF
Hyola® 577CL	Pacific Seeds	2013	Hybrid	M	R	R	
Pioneer® 43C80(CL)	Pioneer®	2008	OP	E			
Pioneer® 43Y85(CL)	Pioneer®	2012	Hybrid	E	MR	R-MR	A
Pioneer® 44Y84(CL)	Pioneer®	2010	Hybrid	EM	MS	MR	A
Pioneer® 44Y87(CL)	Pioneer®	2013	Hybrid	EM	MR	R-MR	A
Pioneer® 45Y86(CL)	Pioneer®	2012	Hybrid	M	MR-MS	R-MR	AB
Pioneer® 45Y88(CL)	Pioneer®	2013	Hybrid	M	R-MR	R-MR	A

More information

www.nvtonline.com.au

www.agric.wa.gov.au

2.4.2 Oil

Canola was developed from rapeseed to produce an oilseed crop with improved nutritional composition. The aim was to produce a crop that had low levels of glucosinolates in the meal and low levels of erucic acid in the oil. [9]

Oil is extracted by mechanically crushing the seed. The oil is then processed by using heat and/or chemicals. Approximately 73% of canola in Australia is processed by addition of solvents, 25% by expeller treatment and 2% by cold-pressing.

The seed typically has an oil content of 35–45%. Oil content is generally expressed as a percentage of the whole seed at 8% moisture content. The oil contains:

- 10–12% linolenic acid (omega-3)
- <0.1% erucic acid
- 59–62% oleic acid
- 12–22% linoleic acid

[9] R Mailer (2009) Grain quality. In Canola best practice management guide for eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Canola oil is high in unsaturated fats (93%) and has no cholesterol or trans-fats. It has the lowest saturated fat content (7%) of any common edible oil. When canola is processed to form canola oil, all traces of protein are removed to the residue, which becomes the seed meal. [10]

2.4.3 Seed meal

The seed meal is what is left over after the oil is removed. It contains proteins, carbohydrates, minerals and fibre. The exact composition of seed meal depends on the oil extraction method. The protein content varies each season and increases as the oil content decreases. Typically, seed meal consists of 36–39% protein, 1.5–2.0% fat, 11–13% fibre and <10 µmol glucosinolate/g.

The minimum protein content of seed meal, as determined by the Australian Oilseeds Federation (AOF) is 36%, measured at 12% moisture. [11]

2.5 Planting seed quality

2.5.1 Seed size

Canola seeds are smaller than other grains such as wheat, barley or lupins. They weigh only 3 mg each. The 1000-seed weight of canola is typically 3–6 g. Seed size varies according to the growing conditions. There are also varietal differences. Generally, hybrid varieties have larger seeds however it is not always reflective with the seed that is supplied to growers from production crops.

Seed size plays an important role in crop establishment. Larger seeds produce seedlings that are more vigorous and give improved crop establishment. There is also an interaction with sowing depth (Table 12). Larger seeds establish more plants, particularly if sown at depth of ≥3 cm. [12]

Table 12: Effect of seed size and sowing depth on plant establishment (no. of plants/m²) of canola
Source: Kathi Hertel, unpublished data, NSW DPI [13]

Seed size (mm)	Sowing depth (cm)			
	4.5	3.0	1.5	Mean
>1.7	41.7	64.2	77.0	61.0
1.4–1.7	26.6	43.2	73.3	47.7
<1.4	23.0	33.0	78.5	44.8
Mean	30.5	46.8	76.3	

[10] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[11] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[12] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[13] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

Similar plant numbers established when seeds were sown at depth of 1.5 cm, regardless of seed size. Larger seeds (>1.4 mm) established more plants when sown at 3.0 and 4.5 cm deep.

2.5.2 Diagnosing poor-quality seed in canola

Poor-quality seed can affect germination rates and market quality (Figure 2). It can be due to small seed or damage by harvest, storage, long-term storage of seed coated with fungicide, weather or environment. [14]

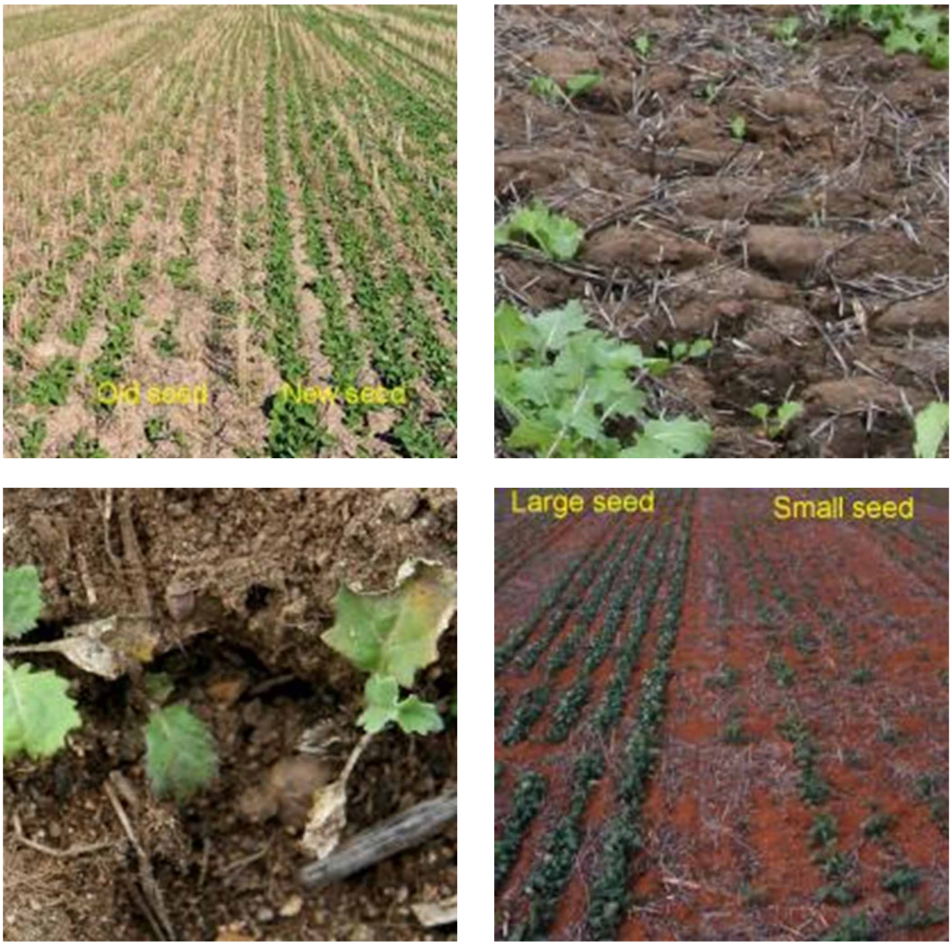

Figure 2: Effects of seed quality on canola establishment. (Photos: DAFWA)

What to look for

In the paddock, look for reduced germination and/or weak seedlings that may be uniformly affected across a paddock, or more pronounced in rows or areas that are less favourable for germination and early growth.

Signs in individual plants:

- seeds that swell but fail to germinate
- seed that germinates but resulting seedlings are malformed or too weak to reach the surface

[14] DAFWA (2014) Diagnosing poor quality seed in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-poor-quality-seed-canola

- weak seedlings after emergence
- broadleaf seedlings with broken roots, cotyledons or growing points [15]

What else could it be?

Deep seeding of canola can also cause reduced emergence and weak seedlings. It can be confirmed by measuring seeding depth. [16]

Where did it come from?

Poor seed quality may arise from:

- small seed (<1.8 mg) being less resilient than large seed
- poor storage where seed is exposed to moist and hot conditions
- old seed (canola seed quality declines faster than for cereals)
- frost-affected grain
- green sappy grain that has been harvested too early
- insect-damaged grain [17]
- Seed collected from areas dessicated with glyphosate

More information

Diagnosing poor quality seed in canola

GIWA past events: Blackleg in canola seed

Management strategies

Poor seed quality can be managed by germination testing of 1000 seed weight and not using seed weighing <1.8 mg.

How can it be monitored?

Grain that is being retained for seed should be germination tested. [18]

For expert help, consult AGWEST Plant Laboratories (+61 (0)8 9368 3721).

2.5.3 Retaining seed

A Department of Agriculture and Food Western Australia (DAFWA) trial investigated options for improving production from retained, hybrid and open-pollinated canola seed: grading harder, buying new seed, increasing the seed rate, mixing retained and new seed, or no action.

At Grass Patch, retaining seed of CB Telfer from a dry harvest in 2012 resulted in small seed. This seed was then graded by a commercial cleaner and further graded with 1.85-mm slotted sieve in an attempt to achieve a higher proportion of large seeds. If the crop was sown at 2 kg/ha, the highest yields of CB Telfer in 2013 were obtained by purchasing fresh seed from the seed company. However, if the seeding rate was increased to 4 kg/ha, then grower-retained seed produced similar grain yield

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[15] DAFWA (2014) Diagnosing poor quality seed in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-poor-quality-seed-canola

[16] DAFWA (2015) Deep seeding in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/deep-seeding-canola

[17] DAFWA (2014) Diagnosing poor quality seed in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-poor-quality-seed-canola

[18] DAFWA (2014) Diagnosing poor quality seed in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-poor-quality-seed-canola

and equal gross margins to purchased seed. Thus, addressing issues with small seed in canola by increasing the seed rate appears feasible.

Hybrids are yet to prove superior in lower rainfall areas in Western Australia. At Grass Patch in 2013, the older TT hybrid variety was not as productive as the open-pollinated TT variety CB Telfer. However, the treatments in that experiment were designed using a scenario of a grower who had decided to grow hybrids and then retain seed from the F1 seed crop. (Growers buy first-generation hybrid seed (F1); F2 seed is the subsequent generation.) The results showed that if growers retained F2 hybrid seed and sowed it at the same rate of 2 kg/ha as F1 seed purchased from the seed company, they would lose yield and would be financially worse off than purchasing new F1 seed. However, if they increased the seed rate of the F2 hybrid to 4 kg/ha or made mixes of F1 and F2, then some of the loss in performance could be overcome. Farmers need to ensure that they have the legal right to retain and grow F2 seed prior to undertaking such operations.

Results summary:

- In dry years, open-pollinated canola can produce small seed in low-rainfall areas. Sowing the small seed at a low seeding rate of 2 kg/ha reduced yield, and farmers could benefit by increasing the seeding rate to 4 kg/ha in the following year or purchasing fresh seed.
- Grading small seed hard was not as reliable as increasing the seeding rate to 4 kg/ha.
- F2 hybrid seed produced lower yields than F1 seed unless seeding rates were increased to 4 kg/ha or mixes were made with F1 seed.
- Hybrid TT was less productive than open-pollinated TT canola.

Comparisons to retaining CB Telfer and sowing at 2 kg/ha:

- Grading seed over a 1.85-mm slotted sieve did not increase plant establishment; the only reliable way to improve plant numbers was to increase seed rate.
- Compared with using the grower-retained CB Telfer seed and sowing it at 2 kg/ha, only the strategies of purchasing new CB Telfer seed and sowing it at 2 or 4 kg/ha and purchasing the new hybrid variety (name not disclosed) and sowing it at 4 kg/ha increased grain yield.
- The extra expenses incurred resulted in no treatment producing higher returns than the farmer-retained CB Telfer seed sown at 4 kg/ha.

Comparisons to retaining hybrid TT seed and sowing at 4 kg/ha:

- F1 hybrid seed is relatively expensive at $24 to $35/kg for IT, RR and TT Hybrid seed, $43/kg for RT Hybrid seed; therefore, seeding rates are usually relatively low, at ~2 kg/ha.
- If growers were to retain hybrid TT seed and sow the F2 at 2 kg/ha, they would lose yield and be financially worse off than buying fresh F1 seed.
- Because F2 hybrid seed cost is reduced to ~$2/kg, growers are more likely to increase seeding rate to 4 kg/ha, in which case, yields and returns similar to F1 sown at 2 kg/ha could be achieved.

More information

Estimating the size of retained canola seed

Retained canola seed options at Grass Patch, 2013

BCG trial details: retaining hybrid canola

Testing retained sowing seed of hybrid canola over a range of rainfall zones

Testing retained sowing seed of hybrid canola over a range of rainfall zones (Adelaide)

Growing hybrid canola Fact Sheet

More information

Canola establishment; does size matter?

Canola re-seeding: is it worth it?

- A mix of 25% F1 and 75% F2 was not quite as productive as 100% F1 seed, but might be more productive than 100% F2 seed. [19]

2.5.4 Canola establishment

Check the seed size every year; it can vary depending on how well the seed crop finished in the previous spring.

For *Brassica napus* varieties, the range is 250,000–350,000 seeds/kg for open-pollinated varieties and 150,000–260,000 for hybrids. Table 13 shows the large difference in plant establishment rates for a given seeding rate between open-pollinated varieties and hybrids. [20]

Table 13: Number of plants established per m² from different sowing rates and establishment percentages of open-pollinated varieties based on 290,000 seeds/kg and hybrids based on 175,000 seeds/kg

Sowing rate (kg/ha)	Establishment percentage					
	40%	50%	60%	70%	80%	90%
Open-pollinated						
2.0	23	29	35	41	46	52
3.0	35	44	52	61	70	78
4.0	46	58	70	81	93	104
5.0	58	73	87	102	116	131
Hybrid						
2.0	14	18	21	25	28	32
3.0	21	26	32	37	42	47
4.0	28	35	42	49	56	63
5.0	35	44	53	61	70	79

Canola re-seeding: Is it worth it?

Trials conducted by DAFWA demonstrated that it was not worth re-seeding canola. April-sown plots at only 5 plants/m² produced yields equal to or greater than May-sown plots at 5–30 plants/m². Over a number of years, DAFWA trials show canola producing 60–80% of maximum yield at ~5 plants/m², and 80–90% at 10 plants/m².

Low plant numbers sown early therefore appears to be an acceptable approach, although weed control may be compromised.

Canola is often the first crop sown each autumn. Because the small seed is best suited to shallow seeding, it is susceptible to drying soil conditions. If growers do not receive a good break or decent follow-up rains, they may need to consider reseeding 2–3 weeks later. The important question for growers is whether they should leave their low-density crop (<10 plants/m²) or reseed (Figure 3).

19 DAFWA (2015) Retained canola seed options at GrassPatch, 2013. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/retained-canola-seed-options-grass-patch-2013-13ed19?page=0%2C2

20 L Jenkins (2009) Crop establishment. In Canola best practice management guide for eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 3: Low-density (<5 plants/m²) plot at Salmon Gums.

In 2014, DAFWA conducted a series of trials with plots sown before or at the break of season with plant densities of 5, 10, 15 and 30 plants/m² compared to plots sown 3 weeks later with densities ranging from 5 to 60 plants/m². At this time, some plots were included that were sown over the top of earlier sown, low-density plots.

The most successful trial in this series was at the Northern Agri Group's (NAG) main trial site at Ogilvie. The first sowing time of Pioneer® 43Y23RR was on 29 April with establishment ~90% of target. The second sowing time was 16 May, when conditions were actually drier and less favourable than at the April sowing; consequently, establishment was ~40% of target. At this site, the resown plots were in offset rows and seeds were 'tickled in' to reduce damage to the earlier sown plants, with only 13% of these plants establishing, and no extra yield produced (see Figure 4).

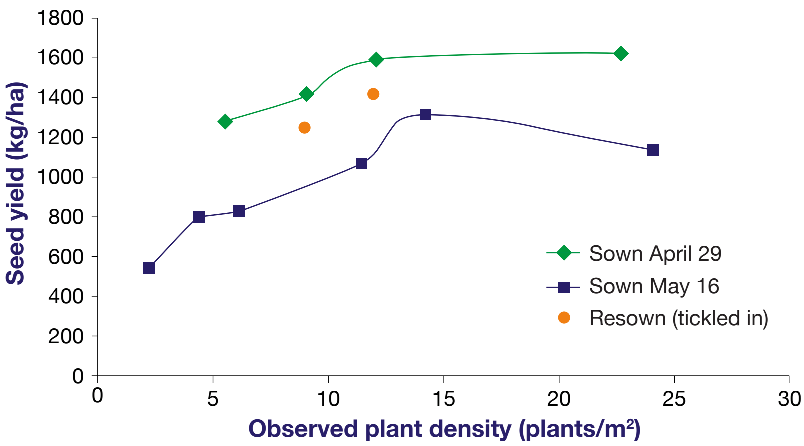


Figure 4: Time of sowing density and reseeding of canola at Ogilvie in 2014—GRDC-funded DAFWA trial at Northern Agri Group's main trial site.

As expected, the April-sown plots outyielded plots sown in May at every comparable plant density. In addition, April-sown plots that had only 5–10 plants/m² produced yields equal to or greater than later plots sown at higher densities. Over several years, canola has produced 60–80% of maximum yield at ~5 plants/m² and 80—90% at 10 plants/m² in DAFWA trials.

From a yield perspective, low plant numbers sown early appears an acceptable approach as long as insects are under control. However, weed control may be compromised at these low densities. For example, in a DAFWA plant-density trial at the Liebe site in 2013, more ryegrass panicles were observed in TT canola when the crop density was <20 plants/m^2, whereas in RR hybrid plots, no such effect of plant density was found. This indicates that with a competitive variety (e.g. RR hybrid) and effective herbicides such as glyphosate, low crop densities are less of an issue than when using less competitive crops (e.g. TT canola) combined with–in this instance at least—a less effective herbicide system (see Figure 5). [21]

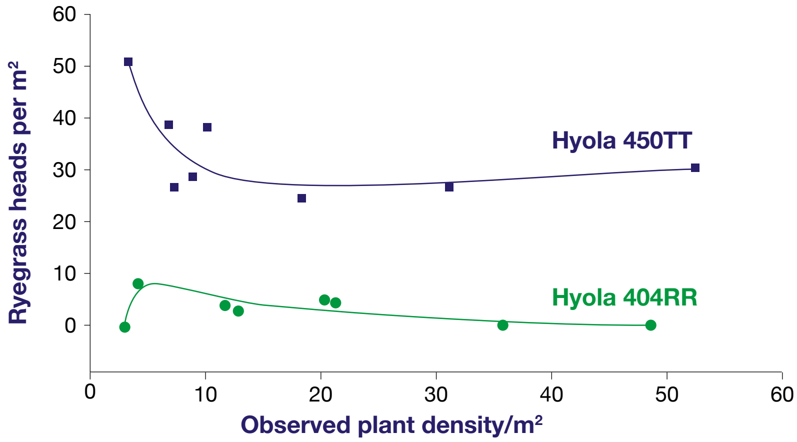


Figure 5: Ryegrass panicles (expressed as % of maximum) of TT and RR canola at North Miling (Liebe main trial site) in 2013—GRDC-funded DAFWA trial 13WH12.

2.5.5 Seed germination and vigour

Seed quality is important for good establishment. Canola seed should have a germination percentage >85%. Planting high-quality seed is essential for rapid, even crop establishment.

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if the seed is undamaged, stored correctly, and from a plant that has had adequate nutrition.

Seed moisture content, age of seed, seed size and germination percentage all contribute to seed quality. There can be substantial differences in the performance of commercial certified seed lots from different sources, and these differences can be as great as differences among varieties.

Several factors can greatly affect germination, including seed size, seed handling and harvest timing. [22]

The larger the seed, the larger the cotyledon and the lipid reserves. Although seed size does not affect germination, larger seeds have earlier and faster emergence than medium-sized and small seeds. This is because larger seeds germinate more rapidly

[21] DAFWA (2015) Canola re-seeding: is it worth it? Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/canola-re-seeding-it-worth-it

[22] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

More information

[Improved canola establishment, yield and oil with large seed on sandplain soil in Western Australia]

and produce longer roots than smaller seeds. Under adequate moisture, medium-sized seeds will emerge in 5–6 days.

Seed size is usually measured by weighing 1000 grains; this is known as the 1000-seed weight. The 1000-seed weight differs among varieties and from season to season. As a result, sowing rates should be altered according to seed weight to achieve the desired plant population. [23]

Harvest timing

The timing of swathing can also affect germination. If the crop is not swathed at the correct time, seed development can stop, resulting in unripe seeds with reduced germination ability.

Seed chlorophyll

High levels of seed chlorophyll can reduce seedling vigour and increase seedling mortality. Chlorophyll levels <35 mg/kg are desirable. Canola seed harvested from plants suffering frost or severe moisture stress during seed-filling may have elevated chlorophyll levels.

Seed handling

Germination can also be affected by seed-handling procedures. Care needs to be taken when harvesting canola seed to ensure that it is not cracked. Cracking can reduce germination. [24]

2.5.6 Seed storage

The aims of storage are to preserve the viability of the seed for future sowing and to maintain its quality for market. Canola is more difficult to store than cereals because of its oil content. The oil content makes canola more prone to deterioration in storage. For this reason, canola should not be stored on-farm for more than one summer.

The rate at which canola deteriorates in storage depends on:

- storage temperature
- seed moisture content
- seed oil content
- relative humidity
- storage time
- percentage of green or immature seeds in the sample
- amount of weathering after physiological maturity

[23] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[24] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

Monitoring of seed moisture of canola is necessary during storage because a moisture content of 6.0–8.5% can be unsafe, depending on the seed oil content (Figure 6).

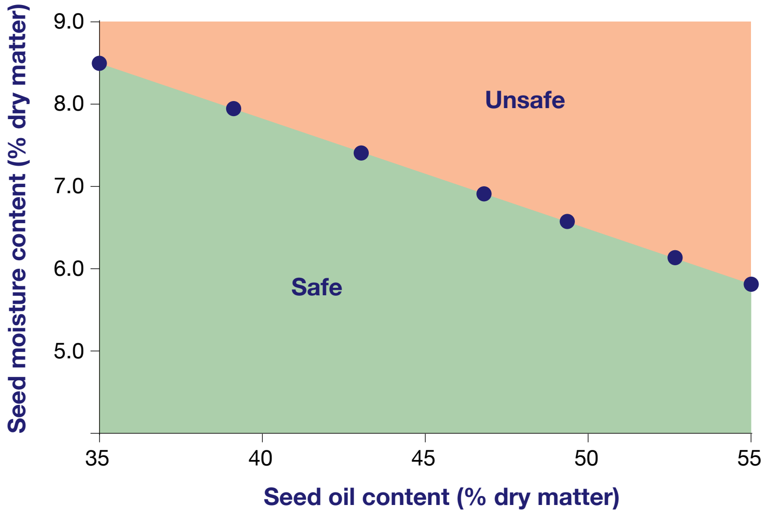


Figure 6: Potential unsafe storage limits for Australian canola varieties at 60% equilibrium relative humidity and 25°C. (Source: http://www.australianoilseeds.com/__data/assets/pdf_file/0006/4110/Oilseeds_Flyer.pdf)

High temperatures or moisture levels can cause a number of reactions in the seed, resulting in:

- increased levels of free fatty acids, causing off-flavours in the oil
- oxidation and browning reactions, which taint the oil
- changes to the oil profile of the seed, due to reactions involving chlorophylls, carotenoid pigments, flavonoids and phenols

Canola should be stored at ≤8% moisture and at temperatures <25°C (and preferably <20°C).

Safe storage limits are determined by the oil and moisture content of the seed. Canola falling into the potentially unsafe area above the line in Figure 6 should not be stored for any length of time unless appropriate action is taken, such as lowering the moisture content and seed temperature. [25]

2.5.7 Safe rates of fertiliser sown with the seed

Canola seedlings are particularly sensitive to damage from close proximity to fertiliser. Larger seeds are less prone to damage. [26]

Nitrogen and starter (N and phosphorus, P) fertilisers can affect germination and reduce establishment if sown in contact with canola seed. Seed can be affected in a number of ways:

[25] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[26] GRDC (2011), Fertiliser toxicity fact sheet. http://www.grdc.com.au/GRDC-FS-FertiliserToxicity

- toxic chemical effects from ammonium vapour, most likely from urea and ammonium phosphates (e.g. mono- and di-ammonium phosphate, MAP and DAP)
- osmotic or salt effects due to high concentrations of salts produced from soluble fertiliser dissolving in water (both N and P)
- seed desiccation from direct moisture absorption by fertiliser in very dry soil

Fertiliser applied at high rates is best separated from the seed at sowing, by banding. The risk of seed damage from fertiliser increases:

- with narrow sowing tines or discs, particularly at wider row spacing, where fertiliser becomes more concentrated close to the seed (Table 14)
- in more sandy soils
- in partially wet soils that are drying
- in dry soils

More information

Care with fertiliser and seed placement

Fertiliser toxicity

Table 14: Amounts of nitrogen (kg N/ha) that can be sown with canola seed, as determined by calculations of seedbed utilisation

Source: Jim Laycock, Incitec Pivot, adapted from 'Fertiliser management in direct seeding systems'. Better Crops 81(2), 1997

	25-mm seed spread (e.g. discs, knife-point)			50-mm seed spread		
Row spacing:	**15 cm**	**22.5 cm**	**30 cm**	**15 cm**	**22.5 cm**	**30 cm**
Seed bed utilisation:	**17%**	**11%**	**8%**	**33%**	**22%**	**17%**
Light (sandy loam)	10	5	0	20	15	10
Medium–heavy (loam–clay)	15	10	5	30	20	15

Figure 7 shows the approximate safe rates of P that can be sown with the seed using DAP fertiliser (18% N). Seedbed utilisation (Figure 7, *x*-axis) takes into account the width of the seed row and the row spacing. In dry soils, the amounts shown in the graph should be halved. [27]

More information

Canola best practice management guide for south-eastern Australia

Canola irrigated: GM—SQ

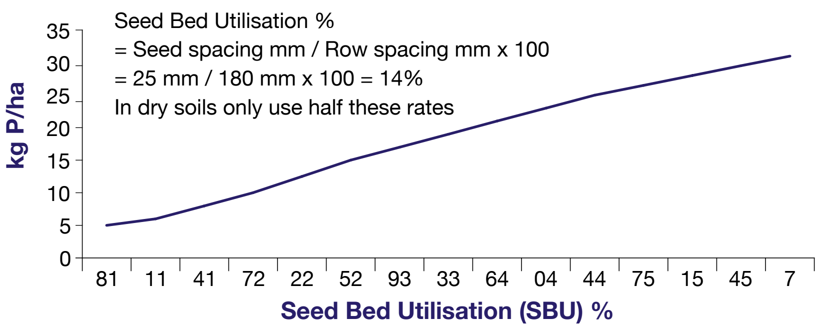


Figure 7: Approximate safe rates of phosphorus with seed when using di-ammonium phosphate under good soil-moisture conditions.

[27] R Mailer (2009) Grain quality. In Canola best practice management guide for eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard)) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Birchip Cropping Group (BCG) trials in 2012 at Sea Lake, Victoria, showed that applying urea with the seed, even deep-banded, could affect establishment and slow growth and development.

More information

BCG trial details: are canola and nitrogen good 'seed bed' fellows?

Key points included:

- There was no advantage in applying nitrogen at sowing (deep-banded).
- The effects of seed burn on canola are much greater on sandier soils than clay. Dry soils are also more susceptible than wet soils; if applying up-front N, rates should not exceed 10 kg N/ha (22 kg/ha urea) on 30-cm spacing, and seed should be separated by at least 3–4 cm from the N fertiliser. [28]

[28] BCG. Are canola and nitrogen good 'seed bed' fellows? Trial Details, Birchip Cropping Group, http://www.bcg.org.au/view_trial.php?trial_id=874&src=

SECTION 3

Planting

3.1 Seed treatments

3.1.1 Insecticide treatments

Imidacloprid products, such as Gaucho® 600 or Picus, are registered for use on canola seed, for seedling protection against low pressure redlegged earth mite, blue oat mite and aphids.

These chemicals work through repellency and anti-feeding action, rather than by directly killing earth mites or aphids. They will protect emerging seedlings for 3–4 weeks after sowing. As well as the direct effects of controlling aphids, the use of imidacloprid may also reduce the incidence and spread of aphid-transmitted virus diseases during this period. This product can be applied only by registered operators. All seed companies can supply seed pre-treated with imidacloprid. Fipronil (e.g. Cosmos®) is registered for control of redlegged earth mite in canola. It should be used as part of an integrated pest management approach to redlegged earth mite. Newer insecticide seed treatments include Poncho® Plus and Cruiser® Opti but growers should consult the APVMA at www.apvma.gov.au for up to date information.

Fipronil can be applied either on-farm or off-farm by a contractor or seed company. [1]

3.1.2 Fungicide treatments

Fluquinconazole products (e.g. Jockey®) can be used in high-risk situations as a seed dressing to help minimise the effects of blackleg disease. These products may shorten the hypocotyl length of canola. To avoid the possibility of reduced emergence, do not sow treated seed deeper than 20 mm or in soils prone to crusting. Ensure that treated seed is sown in the season of treatment.

Fludioxonil + metalaxyl-M (Maxim® XL) is a fungicidal seed dressing that provides seedling suppression of blackleg as well as protection against seedling diseases caused by *Pythium* spp. and *Rhizoctonia solani*. It will not cause shortening of the hypocotyl or affect seed viability.

Flutriafol products (Impact®) are in-furrow fungicide treatments that are mixed and sown with the granular or liquid fertiliser to assist in minimising the effects of blackleg

[1] L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

More information

[Oilseeds WA: Assessment of fungicide efficacy against blackleg disease]

[DAFWA research paper: Evaluation of fungicides for the control of downy mildew]

[Bayer CropScience product details]

disease. In situations of high blackleg pressure, research has shown flutriafol products to be superior to other fungicides for controlling blackleg disease. [2]

3.2 Time of sowing

The optimum sowing time for spring varieties is a compromise between sowing too early, which may increase the risk of frost damage, early droughting if follow up rains do not occur until late May and lodging, and sowing too late, which increases the risk of the crop undergoing seed development in increasingly hot and dry conditions, reducing the yield potential and oil content of the grain.

The optimum sowing window using early mid to mid/late maturing spring varieties normally falls in the window from April 10th to May 5th. For short seaon varieties, this window normally falls in the period from April 20th to May 15th.

New research is happening in the south coast and great southern canola growing areas, looking at whether winter canola varieties can also be used. Winter varieties have a vernalisation requirement (a period of exposure to cold temperatures) before they will change from vegetative to reproductive growth ie they won't flower until they have received this period of cold.. Therefore it is envisaged that they could be sown even earlier than April, maybe as early as February (or even the previous spring). This may result in two added benefits; 1- stock feed over summer and autumn, as well as water use over these periods, thereby decreasing the winter waterlogging risk in prone areas.

In general, sowing at the earliest time within the optimum window pays off in several ways. Earlier sown crops:

- generally have higher seed and oil yields because the crop finishes under cooler, moister, conditions (a premium is paid for oil content >42%);
- allow for better coordination of sowing and harvesting, because these operations for canola are well ahead of wheat;
- grow faster initially and so compete better with weeds; and
- may have fewer problems with seedlng insect pests.

[2] L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 1: Canola seed in bunker stockpile. (Photo: AM Photography)

Figure 2: Canola takes longer to establish than cereals due to its small seed size. (Photo: Rebecca Jennings)

Because canola seed is very small (Figures 1 and 2), it takes longer to establish than cereals. Late sowing into cold soils further reduces plant growth, making canola seedlings more vulnerable to disease, insects, slugs and other constraints.

Late sowing also results in canola maturing when the weather is typically warmer and drier. Hot weather during the flowering–podset stages may cause pod abortion, fewer seeds per pod, and reduced oil content.

In general, sowing later to avoid frost is not a good strategy; canola flowers for 4–6 weeks and can usually compensate for aborted flowers if frosts occur at early–mid flowering. Canola is most susceptible to frost during late flowering–early podfill, when a heavy frost can destroy immature seeds. Canola usually tolerates frosts better than cereals do.

Late-sown paddocks must be carefully selected and prepared for canola; in higher rainfall areas, poorly drained paddocks may be at greater risk from waterlogging with later sowings.

The optimum time to sow may depend on a range of factors, but the relative maturity of a variety is important. Mid- and mid–late-maturing varieties should be sown early in the recommended sowing window for a particular region, and early-maturing varieties sown later.

More information

DAFWA paper: Modelling sowing time response of canola in the northern wheatbelt of Western Australia

WANTFA Time of sowing trial

Early sowings maximise yield potential and oil content, but sowing too early increases the risk of frost damage during the late flowering and pod-filling stages. Sow midseason varieties from early May and early-maturing varieties from mid-May.

In paddocks known to have high frost risk, sowing should be delayed further.

Canola usually flowers for 4-6 weeks, and frost damage is greatest if it occurs towards the end of flowering and through pod filling. Early-maturing varieties sown at the beginning of May would be subject to frosts in the late flowering and pod-filling stages, whereas midseason varieties sown at this time will flower and fill pods later, reducing the risk of frost damage.

More information

DAFWA paper: Agronomic performance of new open-pollinated and hybrid canola cultivars to time of sowing in Western Australia

DAFWA/UWA paper: Environmental impact on canola yield and oil

GRDC: Over the bar with better canola agronomy

DAFWA presentation: Modelling sowing time response of canola in the northern wheatbelt of Western Australia

DAFWA research: Scoping early sown canola in Western Australia

The small seeds of canola need to be sown ideally no more than 5 cm deep in self-mulching clays (2–3 cm in red soils) into well-prepared, moist seedbeds.

Good seed–soil contact, to help ensure uniform establishment, is aided by the use of rollers, cultipackers and press-wheels. The crop is suited to conventional and no-till systems.

Heavy stubble loads may reduce emergence, and should not be left over the sowing row. Triazine-tolerant (TT) varieties are less vigorous; therefore, planting methods are more critical for even establishment. [3]

3.2.1 DAFWA/UWA trials

The Department of Agriculture and Food Western Australia (DAFWA) and the University of Western Australia (UWA) evaluated three times of sowing (starting from the break of the season with two subsequent sowings at 2-week intervals) and various fungicide treatments for the management of blackleg in canola. The trials were conducted at four different locations: East Chapman, Merredin, Wongan Hills and Mt. Barker. [4]

3 L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

4 R Khangura, M Barbetti. Management of blackleg of canola by manipulating time of sowing in combination with fungicides. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0015/4506/Manipulating_blackleg_time_of_sowing,_fungicides_WA.pdf

Blackleg severity was significantly reduced when the sowing was delayed until the first or second week of July; however, there were yield penalties due to the shortened growing season. All of the fungicide treatments substantially reduced blackleg at all locations and yields were improved with most of the fungicide treatments at all locations except East Chapman.

3.3 Retained seed

There has been some grower interest in retaining hybrids from one season to the next, as they have traditionally done with open-pollinated (OP) varieties. Retaining hybrids to the second generation (F2) will produce seed of inconsistent traits and quality. Depending on how different the parental lines were from each other in certain traits, the F2 generation may vary greatly from the original seed. Such differences may occur in herbicide tolerance, blackleg resistance and maturity (see GRDC Fact Sheet: Growing hybrid canola). Those differences may greatly affect the overall yield and financial returns to growers to the point that the initial savings from retaining the seed are outweighed.

3.4 Targeted plant population

Carry out crop establishment counts within 4 weeks of emergence to review the success of the sowing operation and to help decide whether the seed rate or equipment needs to be adjusted for next year's crop. The impact of establishment pests (such as earth mites, aphids, slugs or soil-dwelling pests) can also be assessed at this time.

For narrow row spacing (up to 30 cm), use a square quadrat (0.25 m^2). For a wider row spacing, a 1-m ruler placed along the row is more convenient. Count as many sites as possible (minimum of 20) across an area widely representative of the whole crop.

Plant population, which is determined by sowing rate, germination percentage and establishment percentage, is an important determinant of biomass at flowering and therefore of yield (Figure 3).

More information

BCG trial details. Timing is everything: barley and canola time of sowing

Hart Field-Site Group: Canola growth and development—impact of ToS and seasonal conditions

GRDC Media: Scope to reap rewards from early sowing

More information

FAQ

GRDC Fact Sheet: Growing hybrid canola

GrowNotes Canola West Section 2. Pre-planting

DAFWA: Estimating the size of retained canola seed

DAFWA: Retained canola seed options at Grass Patch, 2013

Hart Field-Site Group: Retaining hybrid canola seed 2013

GRDC Update-Papers: Turning sowing times on their head with winter habit canola and wheat

GRDC Update Papers: Canola growth and development—impact of time of sowing and seasonal conditions

More information

[DAFWA: 2015 WA agribusiness crop updates: sowing canola in wide rows could save growers money]

[DAFWA: Canola response to plant density at Mingenew, 2014]

[WAFarmers: Canola variety guide available for 2015 cropping season—DAFWA]

[SEPWA: All trials in the Esperance Port zone]

[Mingenew–Irwin Group: Spring field day booklet 2014]

[DAFWA: Canola response to plant density at Mullewa, 2013]

[DAFWA: Canola plant density trials list]

[DAFWA: Canola response plant density Chapman Valley, 2013]

[DAFWA: Other canola agronomy trials list]

Figure 3: Canola stand well established near Geraldton. (Photo: Cox Inall Communications)

Crops with low plant densities tend to yield poorly. Low-density crops can compensate with increased pod and seed production per plant; however, they are more vulnerable to disease, pests, weed competition and environmental stress.[5]

Evenness of plant population, both within the row and across the paddock, is more important than having an ideal population. Where plant populations are low, plants compensate by producing extra branches. For most canola-growing regions, the recommended seeding rate for *Brassica napus* canola is 3–4 kg/ha.

Many growers have reduced this rate to 2 kg/ha but only after they have gained considerable experience in the skills and machinery refinements required to produce consistent establishment of the crop under a range of seasonal conditions. The trend towards hybrids with superior seedling vigour over OP varieties is allowing experienced growers to reduce seeding rates to as low as 1.5–2.0 kg/ha. Excessively high seeding rates (e.g. 6–8 kg/ha) cause crops to grow too tall with weak spindly stems, making them susceptible to lodging in the spring as flowering and pod development occur.

It is advisable to sow at a rate 1.0–1.5 kg/ha higher than normal when seedbed conditions are not ideal, such as when sowing late into cold, wet soils or no-till sowing into dense stubbles. Within the recommended plant-population range, it is better to have too many canola plants than too few, although high plant densities have been linked to an increased incidence of the disease Sclerotinia stem rot.

Typically, about 40–60% of sown seeds establish as plants. However, if conditions are very favourable, establishment can be as high as 80%. Check the seed size every year; it can vary depending on how well the seed crop finished in the previous

[5] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

spring. For *B. napus* varieties, the range is 250,000–350,000 seeds/kg for OP varieties and 150,000–200,000 for hybrids. Table 1 shows the large difference in plant establishment rates for a given seeding rate between OP varieties and hybrids. [6]

Table 1: Number of plants established per m² from different sowing rates and establishment percentages of open-pollinated canola varieties based on 290,000 seeds/kg, and hybrid canola based on 175,000 seeds/kg

Sowing rate (kg/ha)	Establishment percentage					
	40%	50%	60%	70%	80%	90%
Open-pollinated canola						
2.0	23	29	35	41	46	52
3.0	35	44	52	61	70	78
4.0	46	58	70	81	93	104
5.0	58	73	87	102	116	131
Hybrid canola						
2.0	14	18	21	25	28	32
3.0	21	26	32	37	42	47
4.0	28	35	42	49	56	63
5.0	35	44	53	61	70	79

More information

GRDC: Over the bar with better canola agronomy

NSW I&I/Delta Agribusiness/Rural Management research: Canola variety x row spacing x plan population trial

GRDC Update Papers: Wide row canola why bother

Increasing the sowing rate increases competition between plants, creating thinner main stems and fewer, less productive branches.

Reducing the sowing rate creates plants with thicker main stems and more branches, delays leaf-area development, reduces biomass at flowering, and ultimately reduces yield. [7]

3.4.1 Determining target density

To work out the seeding rate, consider the desired result. What is the target plant density, or how thick should the canola crop be? Rainfall is a guide to target density. Table 2 presents the suggested target crop densities for Western Australia.

Cost of seed is another important consideration, the lower density targets of hybrid canola are primarily due to the higher seed cost compared with OP canola. The target density should not be <20 plants/m². [8]

6 L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

7 L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

8 J Bucat, M Seymour (2015) Information for the canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/information-canola-seeding-rate-calculator?page=0%2C0

Table 2: Suggested target crop density (plants/m²) for canola varieties—use the higher target density to combat weeds

Rainfall zone	Hybrid	Open-pollinated
Low (250–325 mm)	20–25	30–40
Medium (325–450 mm)	25–40	35–50
High (450–550 mm)	30–40	40–60

Beware of reducing the seeding rate too much with expensive hybrid seed. It is good to have a safety margin in case of mites, depth variation, fertiliser toxicity or other unforeseen establishment problems.

3.4.2 Use a higher plant density to combat weeds

It may pay to increase the target density to ensure good crop competition with weeds. Make the most of canola and use it as a true break crop by using all of the integrated weed management (IWM) strategies. A high plant density is one such tool. Weed seedset accelerates where canola densities are <20 plants/m². Where there is a high weed burden, target high crop densities to boost crop competition with weeds and help to combat weed seedset.

Although there is no economic yield advantage in having a crop that is too thick, there are generally no yield penalties, especially for growers in the medium- and high-rainfall zones. Results from 18 DAFWA density trials over 3 years and all rainfall zones showed only one trial where yields were severely reduced as density increased. This was in 2013 at Mullewa, where dry conditions and continual aphid attack droughted out canola at crop densities >20 plants/m². In the other experiments, canola densities >60 plants/m² and up to 110 plants/m² produced yields similar to lower densities. However, high-density crops may be more prone to disease or lodging.

3.4.3 Field establishment

Establishment of canola is highly variable. Field establishment (or paddock establishment) is the proportion of viable seeds that emerge and grow (Figure 4) compared with the number sown. Commonly, only half of the canola seeds sown emerge and contribute to the final crop yield.

Seeding conditions are the major factor affecting field establishment. Establishment is best in warm, wet conditions. In cold conditions, emergence is slower and establishment is reduced. Establishment is also reduced in dry conditions. If sowing into marginal moisture, increase the seeding rate to compensate for the seeds that will not emerge.

Accounting for differences in field establishment can be the most important factor in calculating seeding rate. The seeding rate of medium-sized hybrid seed is 1.9 kg/ha under excellent conditions but 2.6 kg/ha when seeding dry and >5 kg/ha if the dry seeding is followed by a tough start to the season.

The precision of the seeder affects establishment if some seeds are sown too deep. Establishment can be reduced further by fertiliser toxicity, high stubble loads, insect attack or diseases such as Pythium or Fusarium root rot. Hybrid varieties tend to have better establishment than OP varieties.

A guide to the expected field establishment is provided in Table 3. [9]

Figure 4: Canola cotyledon. (Photo: J. Bucat, DAFWA)

Table 3: Expected field establishment (%) for canola varieties

Seeding conditions	Open-pollinated	Hybrid
Excellent; warm and wet	65	80
Reasonable; just enough moisture	50	65
Dry-sown; good opening rains within 10 days	45	60
Dry-sown; tough start (non-wetting or hard-crusting soil, marginal break)	10–35	20–45

3.4.4 Seed size or number of seeds per kilo

The bigger the seed, the fewer seeds per kg and the higher the seeding rate required. A change in seed size can cause a marked change in seeding rate. The seeding rate changes from 1.7 to 2.9 kg/ha where seed is changed from a small hybrid seed (285,000 seeds/kg) to large hybrid seed (170,000 seeds/kg), assuming 65% field establishment (as would be expected under reasonable seeding conditions) and a target of population of 30 plants/m^2.

Although you receive more seeds per dollar with small seed, large seed is more robust for good crop establishment. Refer to Table 4 for a guide to the common range of seed size of commercial hybrid and OP seed in Western Australia. [10]

[9] J Bucat, M Seymour (2015) Information for the canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/information-canola-seeding-rate-calculator?page=0%2C0

[10] J Bucat, M Seymour (2015) Information for the canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/information-canola-seeding-rate-calculator?page=0%2C0

Table 4: Common seed size range for hybrid and commercial open-pollinated seed

	Small	Medium	Large
Hybrid			
Seed size (mg)	3.51	4.88	5.88
No. of seeds per kg	285,000	205,000	170,000
Open-pollinated			
Seed size (mg)	2.86	3.22	4.00
No. of seeds per kg	350,000	310,000	250,000

Variation between and within varieties is a normal part of our canola industry. The seed size of canola is determined by genetics and the environment. Hybrids generally have bigger seeds. However, the environment can have an overriding effect on seed size.

Different seed lots of any variety may have quite different seed sizes if they are produced from different source crops. It is important to find out the size of the seed being planted this year. The number of seeds per kg for your seed lot will be provided on the seed bag, and/or available from the seed supplier. [11]

3.4.5 Germination

The germination percentage is the proportion of viable seed in the seed lot. Each seed lot sold has a germination test. This information is available from the seed supplier. Commercially available seed generally has a high germination, >90%.

Retained seed should be germination-tested by a laboratory, such as AGWEST Plant Laboratories (+61(0)8 9368 3721). Otherwise, do a germination test at home. [12]

3.4.6 Calculating seed requirements

To calculate seeding rate, decide on the number of plants per m² (the target density), estimate the field establishment, and determine the seed size (or no. of seeds/kg) and germination percentage.

Use the DAFWA online Canola seeding rate calculator or a hand-held calculator to obtain the seeding rate. [13]

The formula is as follows:

$$\text{Seeding rate} = \frac{\text{(target density (plants/m}^2\text{) x 10,000)}}{\text{(field establishment\% x seeds per kg x germination\%)}}$$

Inputs are: 30 plants/m² target density; 205,000 seeds/kg; expected field establishment 65% (use decimal format, 0.65) (sowing hybrid into reasonable seeding

[11] J Bucat, M Seymour (2015) Information for the canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/information-canola-seeding-rate-calculator?page=0%2C0

[12] J Bucat (2015) Canola germination test. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/canola-germination-test

[13] J Bucat (2015) Canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/canola-seeding-rate-calculator-0

conditions); germination test result 95% (use decimal format, 0.95); 10 000 m^2 in 1 ha. Therefore:

$$\text{Seeding rate} = \frac{(30 \times 10{,}000)}{(0.65 \times 205{,}000 \times 0.95)} = 2.4 \text{ kg/ha}$$

Be prepared to change the seeding rate at seeding time if conditions are better or worse than the field establishment you have used in your seeding rate calculation.

Seeding rate example tables

Table 5 provides examples of seeding rates for hybrid and OP canola varieties at various rates of seed establishment and with different seed sizes.

Table 5: Seeding rate (kg/ha) for hybrid canola varieties with 30 plants/m^2 target and 95% germination, and open-pollinated varieties with 40 plants plants/m^2 target and 95% germination

	Small	Medium	Large
Hybrid seed			
Seed size (mg)	3.51	4.88	5.88
No. of seeds/kg	285,000	205,000	170,000
80% Field establishment (excellent condition)	1.4	1.9	2.3
65% Field establishment (reasonable conditions)	1.7	2.4	2.9
60% Field establishment (dry seeding)	1.8	2.6	3.1
30% Field establishment (dry seeding, tough start)	3.7	5.1	6.2
Open pollinated seed			
Seed size (mg)	2.86	3.22	4.00
No. of seeds/kg	350,000	310,000	250,000
65% Field establishment (excellent condition)	1.9	2.1	2.6
50% Field establishment (reasonable conditions)	2.4	2.7	3.4
45% Field establishment (dry seeding)	2.7	3.0	3.7
20% Field establishment (dry seeding, tough start)	6.0	6.8	8.4

3.4.7 Make a better decision next year

Assess the success rate this year so that you can make a better decision next year. It is good to know the actual plant density. If the target density was higher than expected, then the field establishment was better than estimated. The seed rate may be reduced, under similar seeding conditions.

Conversely, if the target density was lower than expected, the field establishment must have been lower than estimated. Was there a clear reason for this? Or was it just what can be expected of the machinery type? Consider increasing the seeding rate for the following season. Monitor the establishment in different paddocks in each season.

To assess crop density, count the average number of plants per 1-m row and the row spacing;

$$\text{Crop density (plants/m}^2\text{)} = \frac{(\text{average number of plants per 1-m row} \times 100)}{(\text{row spacing (cm)})}$$

More information

DAFWA: Canola seeding rate calculator

Pacific Seeds: Canola seed planting rate calculators

Pioneer: Canola seed rate calculator

For example, plant density is 24 plants/m^2 where there is an average of 6 plants per 1-m row and 25-cm row spacing.

Calculate field establishment by rearranging the seeding rate calculation;

$$\text{Field establishment} = \frac{\text{(crop density (plants/m}^2\text{) x 10,000)}}{\text{(seeding rate (kg/ha) x seeds per kg x germination\%)}}$$ [14]

3.5 Row spacing

Canola was traditionally sown on 15-cm row spacing, but the adoption of stubble retention and no-till farming systems has resulted in a trend to wider row spacing and the possibility of inter-row sowing using GPS guidance systems.

Experiments in southern New South Wales have shown that widening row spacing in canola does appear to reduce yield when the row space is increased to 35 cm. [15] Plant densities as low as 15 plants/m^2, if consistent across a paddock, can still result in profitable crops when sown early and plants have time to compensate. Seed size varies between and within varieties and hybrids. Check seed size to calculate the correct number of seeds to be sown per m^2.

Establishment can be significantly reduced by sowing too deep, sowing late into cold, wet soils, and no-till-sowing into dense stubble. Use the higher seed rate, consider sowing the seed at a shallower depth, or select a variety or hybrid with high vigour in these situations. Hybrids are generally more vigorous than OP varieties, primarily because of larger seed size. Where seed is retained on-farm, grade the seed and keep the largest seed for sowing.

High plant densities, combined with suitable environmental conditions, can increase the risk of Sclerotinia stem rot during flowering. High plant densities can also increase the risk of moisture deficit during grainfill in dry spring conditions, potentially reducing yields. [16]

3.5.1 DAFWA trials at Binnu—wide rows

In GRDC-funded DAFWA trials, canola grown in wide rows (44–60 cm) in the northern region yielded well enough compared with narrow rows (22–30 cm) to consider this sowing option. This means that agronomic packages can be refined for wide rows. Results indicate that wide rows are better suited to warmer climates and shallower soil types where drought during grainfill is more severe.

[14] J Bucat, M Seymour (2015) Information for the canola seeding rate calculator. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/information-canola-seeding-rate-calculator?page=0%2C2

[15] J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[16] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

More information

[DAFWA: Canola row spacing Binnu 2014 trial report]

[GRDC Update Papers: Wide row canola why bother]

[GRDC Media: Scope to reap rewards from early sowing]

[GRDC Media: Assess soil moisture before sowing early canola]

Growers involved in these trials consider other aspects as well as yield to be important: reduced fuel costs at seeding (~30%), better stubble handling and improved crop safety of incorporated-before-sowing (IBS) herbicides.

Key findings:

- Canola grown in wide rows (50–60 cm) yielded well enough to consider this row spacing an option.
- Canola plants were able to compensate for being sown in wide rows—biomass similar to narrow rows.
- We may be able to reduce input costs, seed and fertiliser by refining the production package in wide rows.
- Wide rows offer benefits of reduced fuel costs at seeding, easy stubble handling and safety of IBS herbicides. [17] [18]

3.5.2 Managing low plant establishment

More information

[DAFWA: Canola re-seeding: is it worth it?]

[GRDC Update Papers: Canola establishment; does size matter?]

Although plant populations as low as 20 plants/m^2 can still produce good yields, such crops are more susceptible to weed competition. In addition, the variable pod development on these plants makes timing of windrowing difficult to determine, especially if germination has been staggered. At <15 plants/m^2, the crop is likely to be patchy and lower yielding. Before re-sowing or abandoning a crop, always check with an experienced agronomist or grower, because plants can compensate remarkably well and the yield potential may be equal to or higher than a better established but later sown crop. [19]

3.6 Sowing depth

Where conditions allow, aim to drill seed through the main seed box to 1.5–3 cm deep and up to 5 cm in self-mulching clays. Where there is moisture below 1.5–3 cm, a reduced but viable establishment may still be achieved by sowing deeper, provided large seed is sown. This strategy can be used to sow some of the crop on time in seasons of good summer rainfall followed by drying surface seedbeds in autumn. Success with this strategy depends on soil type, soil structure and the amount and timing of follow-up rainfall. [20]

Sowing depth has a major influence on seedling vigour, which subsequently affects seedling establishment and crop performance. A sowing depth of 1.2–2.5 cm is ideal.

[17] M Harries, M Seymour (2015) Canolarow spacing Binnu 2014 trial report. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/canola-row-spacing-binnu-2014-trial-report

[18] M Harries, M Seymour, C Pinkney, K Suckling, B Cripps, R Ford (2015) Wide row canola why bother; a summary of a series of small plot and farmer trials and farmer experiences. GRDC Update Papers, 25 February 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Wide-row-canola-why-bother

[19] L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[20] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Deep seed placement increases the risk of failed emergence. Deeper sowing reduces light availability, and the hypocotyl (the shoot that emerges from the seed) responds to this by elongating, reducing the chance of seedling emergence. Seeds planted >2 cm deep or into >5 t/ha of stubble develop elongated hypocotyls. This elongation depletes the seed reserves more quickly than in seeds with shorter hypocotyls. The longer hypocotyls are also thinner, with decreased tissue density, and are more susceptible to mechanical damage and collapse.

More information

GRDC: over the bar with better canola agronomy

DAFWA: Deep seeding canola

Plants with longer hypocotyls have smaller root systems, less leaf area from an early stage, and less leaf and root biomass. Leaves are slower to expand, which reduces dry matter. As a result, plants that allocate more resources to the hypocotyls at the expense of leaves and roots have lower relative growth rates. [21]

This effect can contribute to slower growth of plants in surface-mulch treatments, and the slower growth can be compounded by low temperatures.

3.7 Seed placement

Sow canola seed into the soil, rather than dropping it on the soil surface and harrowing it in; drilled seed is more accurately placed in contact with moisture and will germinate more uniformly. In marginal rainfall areas, drilling seed to a pre-determined depth is the only sowing method recommended.

On heavy clay soils, growers have had success with moisture-seeking points, press-wheels, rubber-tyred rollers and trailing cultipackers. Deep-furrow planting, which allows sowing into subsurface moisture through the dry surface soil, is a proven technique in these soils, where rainfall is summer dominant and surface seedbeds are often dry at sowing time. When deep-furrow planting, it is critical that moist soil is firmed around the seed but only 2–3 cm of moist soil is covering the seed.

On lighter, sandier, non-wetting soils, the use of moisture-seeking points in conjunction with 'V' shaped press-wheels can give acceptable results. When sowing into wet soils, take care to avoid a smearing action by the moisture-seeking points, which could reduce crop emergence.

Broadcasting seed through the combine small-seed box is unreliable and usually results in staggered germination. Band-seeding is more suited to high-rainfall areas. Thoroughly clean out the seeder after sowing to prevent seed residue from contaminating other crops sown later in the season. [22]

21 L Jenkins, R Brill (2013) Improving canola profit in central NSW: effect of time of sowing and variety choice. GRDC Update Papers 25 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Improving-canola-profit-in-central-NSW-effect-of-time-of-sowing-and-variety-choice

22 R Mailer (2009) Grain quality. Ch. 2 In Canola best practice management guide for eastern Australia. (EdsD McCaffrey, T Potter, S Marcroft, F Pritchard)) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

3.8 Sowing equipment

Canola can be sown by using no-till techniques or sown into a well-prepared, cultivated seedbed. When sowing into cereal stubble, ensure that straw and header trash is pushed away from the sowing row. Stubble covering the row can reduce canola emergence and early plant growth to reduce yield significantly. Use rollers, cultipackers or press-wheels to improve seed–soil contact where appropriate, ensuring that the pressure applied by these devices is low. [23]

Sow seed through the main seed box or small-seed box of standard wheat-sowing equipment. The air-seeder or combine should be in good condition and the level adjusted (from side to side, front to back, and tine to tine) to ensure sowing at a uniform depth. Regulate groundspeed to avoid tine bounce, which will cause an uneven sowing depth. Diffusers are fitted to the sowing tines of air-seeders to stop seed from being blown from the seed row. A maximum sowing speed of 8–10 km/h is suggested for most soils.

Several options are available to level the seedbed and help to compact moist soil around the seed. These include the use of press-wheels or a rubber-tyred roller, coil packers (flexi-coil roller), or trailing light harrows or mesh behind the planter. Knifepoints with press-wheels are the preferred option. Avoid heavy harrows with long tines because they can disturb seed placement.

The seed box on most modern air-seeders and combines can be calibrated for low seeding rates. Check calibrations from year to year, because seed size can change and affect actual sowing rate.

Checklist for sowing equipment:

- Ensure accurate calibration for sowing rate.
- Ensure even wear of points for accurate seed placement.
- Use narrow points to reduce ridging.
- Keep front and rear rows of tines level.
- Sow slower rather than faster, to avoid overly shallow depth, seed bounce, or increased soil throw by tines, which effectively result in front-tine seed being sown too deep.
- Ensure level ridges behind the seeder. If using harrows, heavy harrows may be too severe and finger harrows too light.
- Avoid seed–fertiliser mixes that contain excess rates of nitrogen. [24]

23 J Edwards, K Hertel (2011) Canola growth and development. PROCROP Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

24 L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

3.8.1 Alternative sowing techniques

The use of wider row spacing to conserve moisture in low-rainfall areas has seen an expansion of the areas in which canola is grown. Other techniques, such as dry sowing, aerial sowing and the use of raised beds, have been further refined, and these can reduce sowing delays caused by unseasonably dry or wet conditions. [25]

[25] L Jenkins (2009) Crop establishment. Ch. 5 In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

SECTION 4

Plant growth and physiology

4.1 Canola types

Almost all canola grown commercially in Australia is the Swede rape type of *Brassica napus*. *Brassica juncea* (brown or Indian mustard), which has the same quality as canola, is also grown but in much smaller quantities.

The 10 oilseed rape types grown throughout the world are mainly annual and biennial forms of *B. napus* and *B. campestris*. In Canada, both species are important; in Europe and the Indian subcontinent, *B. napus* is the dominant species. Each species has an optimum set of environmental and growing conditions.

4.1.1 Conventional

The first rapeseed varieties were introduced into Australia from Europe and Canada in 1969. Under Australian conditions, these varieties were late flowering (and so restricted to the higher rainfall zones) and very susceptible to blackleg.

From 1970 to 1988, conventional breeding techniques were used to improve yield, adaptation, blackleg resistance and seed quality (low erucic acid, low glucosinolates). These varieties were based on *B. rapa* (formerly known as *B. campestris*). They had earlier maturity and tolerance to pod shattering.

In 1988 the first varieties were released that combined blackleg resistance with higher yield. These varieties were based on *B. napus* material from Asia and Europe. From this time, there was a complete change of trend to breeding *B. napus* varieties.

Brassica napus is thought to have originated from natural crosses (hybridisation) of *B. rapa* and *B. oleracea*. It is distinguished from other species by the shape of the upper leaves; the lower part of the leaf blade half-grasps the stalk. [1]

More information

DAFWA: Current canola variety guide for Western Australia

Canola National Variety Trial results 2014

4.1.2 Triazine-tolerant canola

Triazine-tolerant (TT) varieties were first commercialised in 1993, with the release of the variety Siren. Genes for tolerance to the triazine group of herbicides were bred into conventional canola varieties. This enabled the control of *Brassica* weeds, which were previously unable to be controlled in standard canola varieties.

1 J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

The TT trait is associated with reduced conversion of sunlight into biomass (i.e. reduced radiation-use efficiency). TT varieties are therefore generally less vigorous as seedlings and produce less biomass than conventional varieties. This results in 10–15% lower yields and 1–3% lower oil contents than in conventional varieties; however, the effective weed control available in these varieties means that actual yield is often higher than in conventional varieties competing with weeds. Another effect of the TT trait is a delay in plant development. [2]

4.1.3 Hybrids

Hybrids were first released in 1988. Hybrid varieties are produced by using controlled pollination of a female parent by a male parent (the source of pollen). The progeny (the F1 hybrid) may contain the best characteristics of both parents, and typically exhibit ‘hybrid vigour’. Hybrid varieties are usually associated with larger seeds, strong seedling vigour and greater biomass production. [3]

4.1.4 Specialty canola: high oleic–low linolenic

Specialty canola varieties were bred by traditional means to increase the content of the monounsaturated fat oleic acid and decrease the level of the polyunsaturated fat linolenic acid in the oil (hence, high oleic–low linolenic (HOLL) canola). This oil from HOLL canola is more stable at higher temperatures and more suited for deep-frying than other canola oils. [4]

4.1.5 Imidazolinone-tolerant canola

Canola varieties have been bred that are tolerant to imidazolinones (IMIs), the active ingredients of herbicides such as OnDuty® and Intervix®. They are grown as part of the Clearfield® production system. IMI-tolerant canola varieties were developed by selection of naturally occurring mutations from conventional canola varieties. Unlike the TT gene, the gene for IMI tolerance is not associated with a yield penalty. [5]

4.1.6 Condiment (Indian) mustard

Condiment mustards are varieties of *B. juncea* grown for their hot, peppery taste. Although related to juncea canola (see below), condiment mustards have different meal and oil qualities. The level of glucosinolates in the meal after crushing is much higher in condiment mustard and is responsible for the hot and spicy taste of table mustard; however, the erucic acid level is sufficiently low to make it suitable for human

[2] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[3] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[4] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[5] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

consumption. The oil has a distinctive 'nutty' flavour. Indian mustard is the preferred oilseed in many parts of South Asia, northern and western China, and eastern Russia. It has a reputation for having greater drought and shattering tolerance than canola. [6]

4.1.7 Juncea canola (*Brassica juncea*)

Juncea canola is the name given to plants bred from *Brassica juncea* to have all of the oil and meal quality specifications of canola. The oil has high levels of oleic acid and low levels of erucic acid, and the meal has low levels of glucosinolates (Table 1). The meal can be substituted for canola meal in animal diets. Juncea canola has the same market end-use as canola.

Juncea canola is being developed as a drought- and heat-tolerant alternative to canola for the low rainfall zone. It also has excellent seedling vigour (similar to that of hybrid canola) and is more tolerant of shattering than canola. Because it is a relatively new crop, breeding, selection and agronomic research have not progressed as far as with canola. The first commercial varieties were grown in 2007.

Table 1: Typical seed quality characteristics for canola, juncea canola and condiment mustard when grown in the low-rainfall zone (source: NSW DPI)

Characteristic	Canola	Juncea canola	Condiment mustard
Oil %	36–42	34–40	34–40
Oleic acid %	57–63	57–63	variable
Linoleic acid %	18–25	18–25	variable
Linolenic acid %	8–13	8–13	variable
Erucic acid %	<1	< 1	1–20
Glucosinolate in meal (μmol/g – 10% MC)	< 30	< 30	110–160
Allyl glucosinolate in meal (μmol/g – 10% MC)	0	< 1	NA

4.1.8 Roundup Ready® canola

Roundup Ready® varieties have been bred by genetic modification technology to be tolerant of the herbicide glyphosate. This allows glyphosate to be sprayed over canola in the early stages of growth without affecting the development of the crop. The first varieties were grown commercially in 2008.

4.1.9 Industrial mustard

Industrial mustard is a *B. juncea* type that is not suitable for either of the edible markets because of its high levels of erucic acid and/or glucosinolates. Industrial mustard is grown for use in several industrial products, including biodiesel.

4.1.10 Winter types for grazing

Unlike the other canola varieties, which are spring types, winter types require a period of cold (vernalisation) before they can flower. This makes them suitable as a dual-

[6] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

More information

[GRDC Ground Cover: Revisiting canola management can lift returns]

[GRDC Update Papers: Canola growth and development—impact of time of sowing (TOS) and seasonal conditions]

[Research paper: Canola: phenology, physiology and agronomy]

[CropPro: Canola crop phenology for advisors]

[OGTR: The biology of Brassica napus L. (canola)]

[GRDC Presentation: Canola physiology, tactical agronomy and simulation]

purpose crop. They can be grazed during winter, then locked up for harvest in late spring. Currently, only one winter type is commercially available. [7]

The life cycle of the canola plant is divided into seven principal stages. By recognising the beginning of each stage, growers can make more accurate management decisions on timing of weed-control operations, introduction and removal of grazing livestock in crops managed as dual-purpose, timing of fertiliser applications, timing of irrigation, and timing of pest-control measures.

Each growth stage covers a developmental phase of the plant. However, the beginning of each stage is not dependent on the preceding stage being finished, which means growth stages can overlap.

The beginning of each growth stage from budding is determined by looking at the main (terminal) stem. In the literature, it is referred to as a decimal code, similar to the Zadoks code for wheat growth stages (Figure 1). [8]

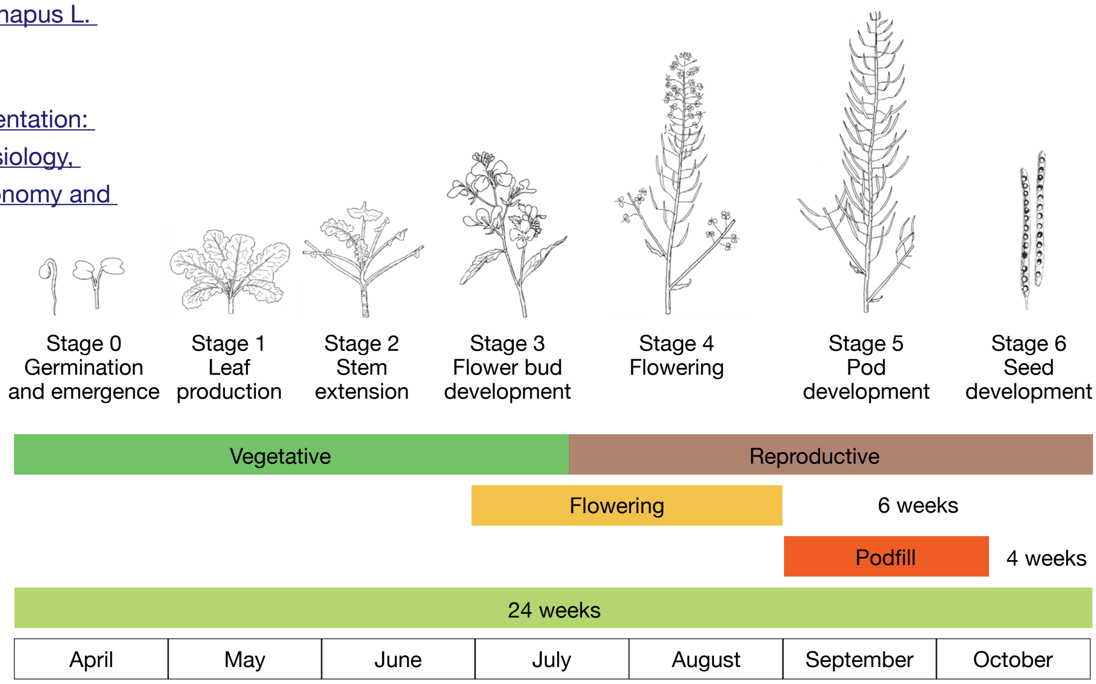


Figure 1: Canola growth stages (Source: NSW DPI)

[7] J Edwards (2009) Introduction. Ch. 1. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[8] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

in focus

4.1.11 Why know about canola development?

- Understanding the drivers behind canola development will help to improve canola management and variety selection.
- Varietal maturity ratings do not always correlate with varietal phenology.
- Early sowing opportunities may provide a means to maximise canola yield, but selection of the correct variety is important.

Despite the success of canola in Australian cropping systems, significant gaps remain in the underlying knowledge of canola physiology and agronomy, a situation exacerbated by its expansion into new areas and the release of new technologies, including vigorous hybrid varieties with herbicide tolerance.

Although growers recognise the high profit potential and the farming-system benefits of canola, a perceived risk of growing canola remains, largely due to the high level of input required (e.g. seed, nitrogen (N) fertiliser, sulfur fertiliser, windrowing). There is a need to determine the level of investment appropriate for these inputs on a regional scale and the agronomic management practices (for example sowing date decisions) that reduce the overall risk and increase the profitability of canola.

Sound, tactical agronomic decisions require improved understanding of the physiology of yield and oil formation in canola, and of how they are affected by variety, environment and management, and the interaction (G x E x M).

Maximising canola yield and profit will be achieved through an increased understanding of canola physiology. This will occur by taking the following steps:

1. Identify the optimum flowering window to minimise heat and frost risk at specific sites.
2. Identify the variety–sowing date combinations that achieve the optimum flowering window.
3. Manage the trajectory of biomass accumulation (of specific varieties) to maximise water-use efficiency, optimise N-use efficiency and minimise the risk of high-input costs (e.g. seed costs, N fertiliser, herbicide types, harvest strategies).

Having optimised these steps, further investigation may reveal specific varietal adaptations that provide yield advantage under specific stress (heat, drought, frost) or provide further G x E x M synergies.

As a first step to improve the understanding of G x E x M interactions in current varieties, CSIRO conducted pre-field-experiment modeling by using the best available information on variety development prior to 2014 trials, and the APSIM model. This modeling explored the potential for planting canola early at locations across Australia and the potential yields to be achieved by planting cultivars with differing maturity

More information

GRDC Update Papers: Canola growth and development—impact of time of sowing (TOS) and seasonal conditions

GRDC Update Papers: Improved understanding of thresholds of armyworm in barley and aphids in canola

Oilseeds WA: Growing western canola

at a range of sowing times. The results show that potential exists for longer season varieties to be planted in locations such as Cummins, South Australia, and to have improved yield potential. However, the opportunity for successful sowing of these varieties occurs in only 15% of years (when sufficient summer rainfall occurs).

The manner in which each canola variety develops can have a large influence on yield, when planted at different times and in different environments. The challenge for researchers is to develop and deliver information on new varieties in a way that is timely and relevant to growers and advisers. Growers and advisers will be able to use this information when selecting a set of varieties suited to the sowing opportunities that most often occur in their district and to capitalise on early or delayed sowing opportunities as the seasons dictate. [9]

4.2 Plant growth stages

4.2.1 Germination and emergence (stage 0 [0.0–0.8])

Emergence occurs after the seed absorbs moisture and the root (radicle) splits the seed coat and the shoot (hypocotyl) pushes through the soil, pulling the cotyledon leaves upward and in the process shedding the seed coat (Figure 2). When exposed to light, the cotyledons part and become green. [10]

After sowing, the seed adsorbs moisture and the various biochemical processes begin, resulting in the production of the first root and shoot. The root grows downward and develops root hairs, which anchor the developing seedling. The hypocotyl begins growing up through the soil, pushing the cotyledons or seed leaves. Emergence takes 6–15 days depending on soil temperature, moisture and sowing depth.

As well as an energy source to fuel the biochemical processes, the developing plant needs oxygen for respiration. Waterlogging results in oxygen being driven from the soil, as well as cooling the soil, resulting in slower growth rates.

At this stage, all of the energy required for the cotyledons to emerge is provided by the seed reserves. Deep sowing, small seed or any other factor that requires the plant to expend more energy in getting the first leaf through to the surface (e.g. crusting) will, apart from delaying emergence, result in weaker and smaller seedlings that may be more prone to weed and pest competition. [11]

[9] A Ware *et al.* (2015) Canola growth and development—impact of time of sowing (TOS) and seasonal conditions. GRDC Update Papers, 10 February 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Canola-growth-and-development-impact-of-time-of-sowing-TOS-and-seasonal-conditions

[10] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[11] Canola crop phenology for advisors. CropPro. http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

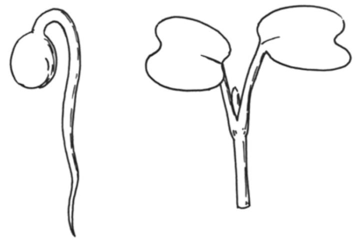


Figure 2: *Canola germination and emergence, stage 0–0.8.*

4.2.2 Leaf production (stage 1 [1.00–1.20])

A well-grown canola plant normally produces 10–15 leaves. Each leaf is counted when most of its surface is exposed to light (Figure 3). Early leaves may drop from the base of the stem before leaf production is complete. [12]

The growing point of canola is above the soil, between the two cotyledons. The exposed growing tip makes canola seedlings more susceptible than cereals to insect damage. At 4–8 days after emergence, the seedling develops its first true leaf. Subsequent leaves are produced at a rate determined by temperature. No definite number of leaves is produced by a canola plant. A canola plant under good growing conditions normally produces 9–30 leaves on the main stem depending on variety and growing conditions.

As the shoots continue to develop, a similar process is happening with the root system. Canola plants have a taproot system. The root system continues to develop, with secondary roots growing outward and downward from the taproot. Root growth is due to cell division and enlargement at the tip of the root. Root development is relatively constant, averaging nearly 2 cm/day as long as good soil moisture exists.

Roots do not grow in search of water or nutrients; they intercept water and nutrients present in the soil pore space that they happen to contact. Factors limiting root penetration through the soil include dry soil, soil compaction, weed competition for moisture and nutrients, salinity and cold soil temperatures. [13]

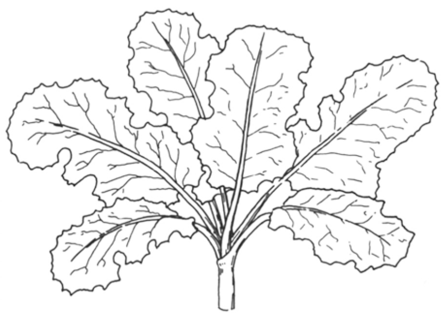


Figure 3: *Canola leaf production, stage 1.*

12 T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

13 Canola crop phenology for advisors. CropPro. http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

4.2.3 Stem elongation (stage 2 [2.00–2.20])

Stages of stem elongation are defined according to how many detectable internodes (minimum length 5–10 mm) are found on the stem (Figure 4). A leaf is attached to the stem at each node. Each internode is counted. A well-grown canola plant normally produces 15–20 internodes. [14]

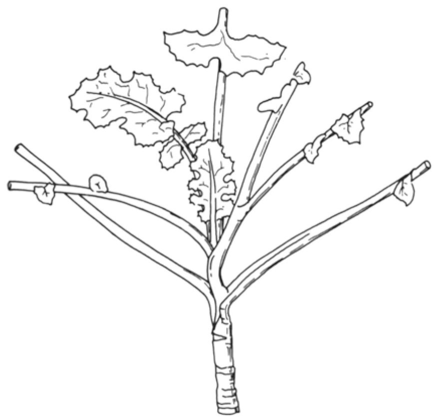


Figure 4: Stem elongation, stage 2.

4.2.4 Flower bud development (stage 3 [3.0–3.9])

Initially, flower buds remain enclosed during early stem elongation and they can only be seen by peeling back young leaves. As the stem emerges, they can be easily seen from above but are still not free of the leaves; this is described as the green bud stage (Figure 5). As the stem grows, the buds become free of leaves and the lowest flower stalks extend so that the buds assume a flattened shape. The lower flower buds are the first to become yellow, signaling the yellowing bud stage. [15]

Figure 5: Canola flower bud development, stage 3.

[14] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[15] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

4.2.5 Flowering (stage 4 [4.1–4.9])

Flowering starts when one flower has opened on the main stem and finishes when no viable buds are left to flower (Figure 6). [16]

Figure 6: Flowering, stage 4.

4.2.6 Pod development (stage 5 [5.1–5.9])

Podding development starts on the lowest one-third of the branches on the main stem and is defined by the proportion of potential pods that have extended to >2 cm long (Figure 7). [17]

[16] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[17] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 7: Pod development, stage 5.

4.2.7 Seed development (stage 6 [6.1–6.9])

Seed development is also seen on the lowest one-third of branches on the main stem (Figures 8, 9). The stages are assessed by seed colour as follows:

- 6.1, seeds present
- 6.2, most seeds translucent but full size
- 6.3, most seeds green
- 6.4, most seeds green–brown mottled
- 6.5, most seeds brown
- 6.6, most seeds dark brown
- 6.7, most seeds black but soft
- 6.8, most seeds black but hard
- 6.9, all seeds black and hard

Seed oil concentration in Australian crops increases through seed development following an 'S'-curve pattern, which starts 20 days after flowering and reaches a plateau ~60 days after flowering, the time when seed dry weight is ~70% of its final value (Figure 10). Final seed oil concentrations usually vary between 30% and 50% (as received). In general, high temperatures during grain filling, terminal water stress, and high N supply depress final seed oil concentration. Variety has a significant impact, with TT varieties typically having lower oil concentrations than conventional varieties because of their less efficient photosynthetic system. The growth stage when the crop is physiologically mature is important and one that growers should learn to recognise. It occurs when the seeds have reached their maximum dry weight and the crop can be windrowed. At this time, 40–60% of seeds have started to change from green to their mature colour (growth stage 6.4–6.5). Seed moisture content is 35–40% and most seeds are firm enough to roll between the thumb and forefinger without being squashed. It is a period of rapid change, when all seeds can develop from translucent to black over a 12-day period. It is important not to windrow too early; windrowing before physiological maturity will reduce yields by 3–4% for each day too early, because of incomplete seed development. Oil content will also be reduced. Canola can be harvested when the moisture content of mature seed is 8%. [18]

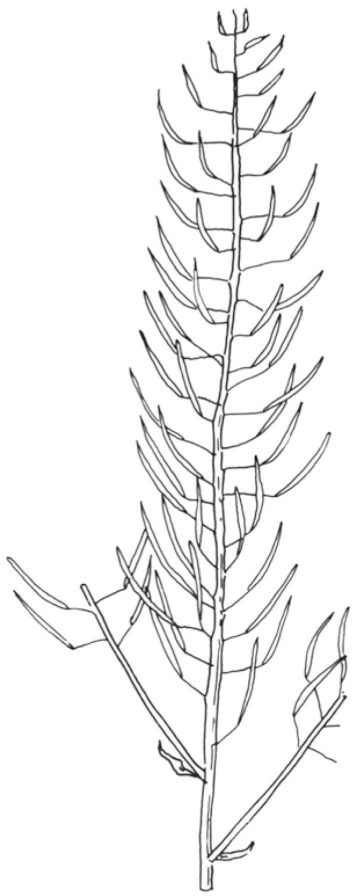


Figure 8: Seed development, stage 6.

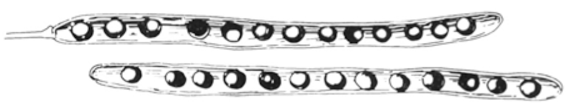


Figure 9: Seed pods.

[18] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

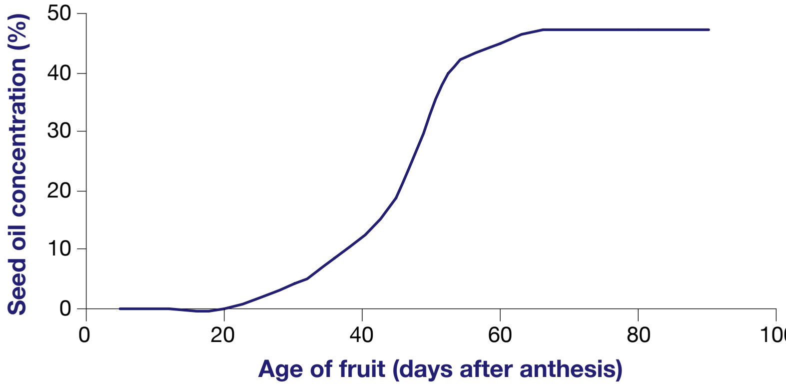


Figure 10: Seed oil concentration in Australian crops increases throughout seed development and reaches a plateau at ~60 days after flowering. (Source: P. Hocking and L. Mason)

4.2.8 Environmental stresses impacting yield and oil content

Frost, moisture stress and heat stress can all have an impact on grain yield, oil content and oil quality. Frost can occur at any time during the growth of the canola plant, but frosts are most damaging when pods are small. Pods affected at this time have a green to yellowish discoloration, then shrivel and eventually drop off. Pods affected later may appear blistered on the outside of the pod and usually have missing seeds (Figure 11).

Figure 11: Frost damage before the watery seed stage results in either missing seeds or very shrivelled seeds. Frost damage at this time may or may not affect oil content. (Photo: T. Potter, SARDI)

Moisture and heat stress are linked, in that the plant will suffer heat stress at a lower temperature if it is also under moisture stress. Flower abortion, shorter flowering period, fewer pods, fewer seeds per pod and lighter seed weight are the main effects, occurring either independently or in combination (Figure 12). [19] Hail damage to pods can also affect seed development (Figure 13).

[19] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Figure 12: Severe moisture stress during pod filling results in seeds being underdeveloped and small. (Photo: D. McCaffery, NSW DPI)

Figure 13: Hail damage may penetrate through the pod wall and affect seed development. (Photo: D. McCaffery, NSW DPI)

4.3 The drivers of plant phenology

4.3.1 Temperature

Temperature influences plant development principally via effects on rate of growth and developmental phases.

Temperature and vegetative growth

Generally, plant vegetative growth increases as temperature increases. There are upper and lower temperature limits at which growth ceases. The lower limit, or base temperature, for growth in Australia is generally accepted as 3°C, although studies have shown a broader range of lower limits from 0°C to 5°C.

Optimal temperature for growth is in the range 20–25°C.

The upper limit is generally regarded as 35°C, but crops have been shown to acclimatise if they have previously been exposed to high temperatures.

The concept of degree-days was developed to quantify the influence of temperature on crop growth and it is used to predict crop growth stage. Degree-days are calculated by taking the daily average temperature (maximum plus minimum divided by 2) and subtracting the base temperature.

For example, if the daily maximum was 20°C and the minimum 10°C, then the average daily temperature was 15°C; after subtracting the base temperature of 3°C, the crop therefore experienced 12 degree-days for growth. [20]

Development of the plant in response to temperature

Germination and emergence

Germination is the process whereby the seed imbibes moisture and produces the first root and shoot, which emerge from the seed coat. The coleoptile (e.g. wheat) or cotyledons (e.g. canola) push through the soil surface and the first leaves appear. Temperature, moisture and oxygen are needed to instigate this process.

An estimate of the time needed for the crop to germinate can be calculated using degree-days, with the range being 80–100 degree-days, or if the soil temperature is 16°C, then ~7 days. [21]

Vegetative growth

Following emergence, the plant then produces leaves at a rate determined by temperature. The appearance of one leaf to the next is a constant in thermal time, accepted as 80 degree-days. This period is also known as the phyllochron. There are variations to this value, influenced by sowing date, but for most crops sown from late April to mid-June, the phyllochron is 80 degree-days.

If the daily mean temperature is 15°C as per the previous calculation, then a leaf will appear every 6.7 days, or if it is cooler and the daily mean is 10°C, then it will take 11.5 days for the next leaf to emerge. This information can be used to predict leaf timing for herbicide operations.

The transformation from vegetative to reproductive growth occurs ~500–800 degree-days after emergence. [22]

Flowering and podfill

High temperatures (>32°C) at flowering will hasten the plant's development, reducing the time from flowering to maturity. High temperatures during flowering shorten the time for which the flower is receptive to pollen, as well as the duration of pollen release and its viability.

High temperature can decrease total plant dry matter, the number of pods that develop, number of seeds per pod and seed weight, resulting in lower yields. Very hot

[20] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

[21] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

[22] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

weather combined with drought and high winds may cause bud blasting, where the flower clusters turn brown and die, resulting in serious yield losses.

Although temperature is the key driver of plant development, the plant's response is modified by vernalisation and daylength. [23]

Vernalisation

Vernalisation is the requirement to be exposed to cold temperatures in order for the reproductive phase to begin. Temperatures of ~0°C are needed to meet this requirement depending on varietal characteristics. Canola varieties that have little or no vernalisation requirement are often referred to as spring types, and temperatures in the range of 7–18°C for brief periods will be sufficient for vernalisation. Canola varieties with strong vernalisation requirements are called winter types, and lower temperatures of 0–7°C for several weeks are needed for vernalisation.

Vernalisation is an adaptation that gives the plant an environmental cue for when is the most suitable time to transform to the reproductive phase, so offering a greater sowing window.

Spring types will simply go through the vegetative phase and transform to reproductive phase based on the temperatures and/or daylength experienced by the plant. [24]

Daylength

Canola develops and flowers more rapidly when grown under long day conditions. Canola is not an obligate-daylength plant (i.e. a plant that will not commence the reproductive phase until a certain daylength requirement is met), but the change to reproductive phase can be delayed if the daylength is too short. Although varieties have differing responses, a daylength longer than ~11 h is required by the canola plant to trigger reproductive development.

This results in an autumn-sown canola crop remaining in the vegetative phase during the winter, accumulating biomass, and, hence, yield potential, as well as delaying flowering until the risk of frosts is reduced. However, early-sown canola may experience the 11-h photoperiod shortly after emergence, which may result in the plant flowering prematurely.

Daylength requirement is a desirable characteristic because it allows flexibility in sowing dates. [25]

What does all this mean?

When growing a canola crop, the aim is to have the crop grow sufficient biomass to flower late enough to reduce the risk of a major frost event, but early enough

[23] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

[24] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

[25] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

to ensure that grainfill is not adversely affected by either moisture or temperature stress. Therefore, the optimum flowering window is generally known for each district. However, getting a crop to flower in this period is not easy, because many variables such as sowing date, seasonal temperatures and available moisture influence crop phenology.

Canola varieties already possess the characteristics that give a reasonable sowing window to allow flowering at the optimal time for maximising grain yields. A key advantage of canola over many crops is the much longer flowering period, so whereas a frost may kill the flowers for that day, there will be new flowers the next day to compensate.

A characteristic such as vernalisation allows canola to be sown at the first opportunity early in the season, and the grower can be confident that it will remain vegetative until its temperature requirements are met for flowering in late spring. In a high-rainfall zone where summer rain is assured, theoretically, spring sowings will remain vegetative until late winter. In lower rainfall areas, the delay to the reproductive phase can mean that flowering occurs too late for the optimum conditions for grainfill.

Similarly, a variety that is sensitive to daylength has a wider sowing window because the vegetative period is extended, developing biomass and yield potential, and the flowering period is delayed until the optimum time. [26]

[26] Canola crop phenology for advisors. CropPro, http://www.croppro.com.au/cb_pages/canola_crop_phenology.php

SECTION 5

Nutrition and fertiliser

FAQ

More information

[GRDC Update Papers: Fertiliser strategies, drones and apps]

[GRDC Update Papers: Shifting investment from nutrients to lime and cultivation on acid soils: is an immediate payback possible?]

[GRDC Update Papers: Managing nutrition on soils that have been treated for water repellence by cultivation]

[DAFWA: Focus paddocks 2014 trial report]

[Research paper: Crop nutrition—canola]

[CSBP Fertilisers: Soil and plant nutrition]

[DAFWA: Crop nutrition—frequently asked questions]

5.1 Crop removal rates

Canola requires high inputs per tonne of grain for the major macronutrients nitrogen (N,), phosphorus (P, K) and sulfur (S) compared with other crops (Table 1). However, on a per-hectare basis, the nutritional requirements of canola and cereals are similar, because yields are usually about half those of wheat. [1]

Table 1: Comparison of the average quantity of major nutrients removed (kg/ha) per tonne of grain and stubble for a range of crops, including canola and wheat

	Nitrogen		Phosphorus		Potassium		Sulfur	
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble
Canola	40	10	7	2	9	26	3.5-5	3.2
Wheat	21	8	3	0.7	5	21	1.5	1.5
Barley	20	7	2.5	0.7	4.5	18	1.5	1.5
Oats	20	7	2.5	0.6	4.5	18	2	1
Lupins	51	10	4.5	0.4	9	16	3	2.5

5.2 Soil testing

In Australia, canola is not recommended for sowing on soils of pHCaCl <4.5, and preferably not <4.7 if exchangeable aluminium (Al) levels exceed 3%. Many soils where canola is grown have a pH <5.0; some have pH as low as 4.0. Although most of these soils were naturally acidic, their acidity has been increased by agricultural activities. The acidity may occur in the surface soil or subsoil, or in both. Soil tests for pH are recommended before growing canola. Samples are taken from the surface (0–10 cm), as well as at depth (10–30 cm) to check for subsoil acidity.

Where the soil pH is ≤5, Al and manganese (Mn) toxicities can be a problem for canola. Aluminium is much more detrimental than Mn because it kills root tips, the sites of root growth. Plants with Al toxicity have a shallow, stunted root system that is unable to exploit soil moisture at depth. The crop does not respond to available nutrients, and seed yield is drastically reduced. Severe Mn toxicity reduces yield because entire leaves become chlorotic and distorted. Mild to severe Mn toxicity is often seen sporadically or in patches and often associated with waterlogged parts of fields. [2]

[1] P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[2] P Hocking, R Norton, A Good (1999) Crop nutrition. In 10th International Rapeseed Congress. GCIRC, http://www.regional.org.au/au/gcirc/canola/p-05.htm

More information

DAFWA: Canola

GRDC Update Papers: Use soil test to inform change from phosphorus build-up to maintenance for more profits

GRDC Update Papers: Economics and management of P nutrition and multiple nutrient decline

IPNI: Nitrogen and sulfur for wheat and canola—protein and oil

GRDC: More profit from crop nutrition

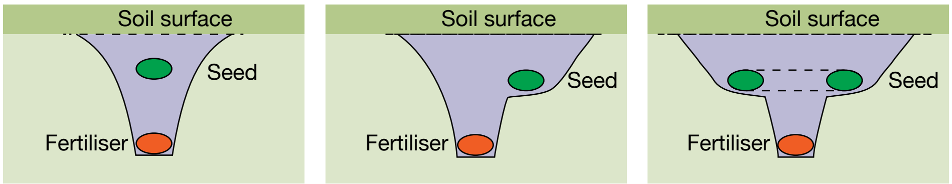
5.3 Nitrogen

Canola has a high demand for N. A canola crop of 1 t/ha will remove ~40 kg N/ha, but the crop will require at least twice this amount. A crop with a targeted yield of ~2 t/ha will require at least 160 kg N/ha. This can be supplied through soil reserves, but additional N fertiliser will be needed in many cases. Depending on the amount of soil N available to the crop, ~80–100 kg/ha of fertiliser N would be needed. In general, a canola crop requires an amount of N similar to a high-protein wheat crop.

Deep soil testing for N and S is recommended for all growers, particularly first-time growers. This will allow N budgeting.

Canola seed is very sensitive to fertiliser burn. No more than 10 kg/ha of N should be in direct contact with the seed at sowing in narrow (18-cm) rows, and proportionally less at wider row spacings. The majority of the N should be either drilled in before sowing or banded 2–3 cm below and beside the seed at sowing (Figure 1). An alternative is to apply N to the growing crop. Application timing should aim to minimise losses from volatilisation; that is, time the topdressing for when the crop has good groundcover and before a rain event. Losses can be high on dry, alkaline soils. [3]

[3] L Serafin, J Holland, R Bambach, D McCaffery (20092005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf



A. Single outlet with centre banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth.
Cons: High draft and breakout force required compared with tillage at seeding depth, seed placement quality variable.

B. Single outlet with side banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth, improved seed placement, good moisture transfer to seed.
Cons: High draft and breakout force required, potentially higher soil and residue disturbance.

C. Dual outlet paired row and ribbon sowing systems
Pros: Sub-seed soil disturbance, fertiliser separation, good seed placement except over centre section, higher seed-bed utilisation.
Cons: High draft and breakout force required, higher soil and residue disturbance influencing seeding depth uniformity.

Figure 1: Three arrangements of split seed and fertiliser banding with tillage below the seeding point that illustrate the different types of seed and fertiliser separation achieved.

The N content of a canola plant (expressed as percentage of dry matter) is highest at the full rosette stage; this is when deficiency symptoms are often visible.

Generally, the older leaves become pale green to yellow, and may develop red, pink or purple colours (Figure 2). Plants will be stunted and the crop will not achieve full groundcover by 8–10 weeks after sowing. Once stem elongation commences, deficiency is then characterised by a thin main stem and restricted branching. This results in a thin and open crop. Flowering will occur over a shorter period, reducing the number of pods per unit area.

Figure 2: Nitrogen deficiency symptoms show as smaller leaves, which are more erect, and leaf colours from pale green to yellow on older leaves and pinkish red on others. (Photo: S. Marcroft, MGP)

Some visual symptoms are similar to other nutrient deficiencies (e.g. P and S), and this can result in incorrect diagnosis. [4] Nitrogen deficiency affects older leaves first, whereas S deficiency affects younger leaves first. [5]

Tissue tests, combined with a good knowledge of the paddock history (including past fertiliser use and crop yields), will assist in an accurate assessment of the most likely deficiency. [6]

DAFWA: Diagnosing nitrogen efficiency in canola

GRDC Update Paper: Getting nitrogen (N) into the crop efficiently and effectively

5.3.1 Estimating nitrogen requirements

Canola is ideally grown in soils of high N fertility, for example, as the first or second crop following a legume crop or two years of legume-dominant pasture. However, paddock fertility is often inadequate, so additional N is required to produce both high yields and good seed quality.

Although canola removes 40 kg N/t grain, the crop can require at least twice this amount of N to produce the yield (referred to as the efficiency factor). This is because the plants must compete for N with soil microorganisms, and some of the N taken up by the plants is retained in the stubble and senesced leaves and roots. A good canola crop will produce twice as much stubble as grain (by weight), giving a harvest index (HI) of about 33%.

The best way to determine a crop's potential N requirement is through a combination of N removal (total N in the estimated grain yield efficiency factor) and the amount of N estimated to be available in the soil, utilising 0-10cm soil (testing for Organic Carbon, Nitrate and Ammonium Nitrogen) and deep soil testing . Whilst not a common practice yet in WA, deep soil tests (to a depth of 60 or 90 cm) can be taken prior to sowing and enable fine tuning of the crops N requirements. They can also be done during the growing season to determine whether topdressing is required.

4 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

5 Diagnosing nitrogen deficiency in canola, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-canola DAFWA (2015) Diagnosing nitrogen deficiency in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-canola

6 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

Example

Available soil N (calculated from deep N test + estimate of in-crop mineralisation) = 125 kg/ha

As a rough 'rule of thumb', the in-crop mineralisation is calculated as:
Growing season rainfall (mm) x organic carbon (%) x 0.15

Fertiliser N required for crop = total N required – available soil N (kg N/ha)
= 200 – 125 kg N/ha
= 75 kg N/ha

Nitrogen requirement calculator

Nitrogen removed in grain = target yield x 40 (kg N/t grain)

Total N required = N removed in grain x 2.5 (efficiency factor of 40%)

More information

GRDC/Federation University: Online Farm Trials research

In the example:
Estimated target yield = 2 t/ha
N removal in grain 2 x 40 kg N/t = 80 kg N/ha
Total N required = 80 x 2.5 kg N/ha
= 200 kg N/ha [7]

5.3.2 Diagnosing nitrogen deficiency in canola

Nitrogen deficiency is the most common nutrient deficiency in canola, especially during cold, wet conditions and in sandy soils in high-rainfall areas. Hybrid varieties can display leaf purpling with adequate nutrient levels (Figure 3).

7 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

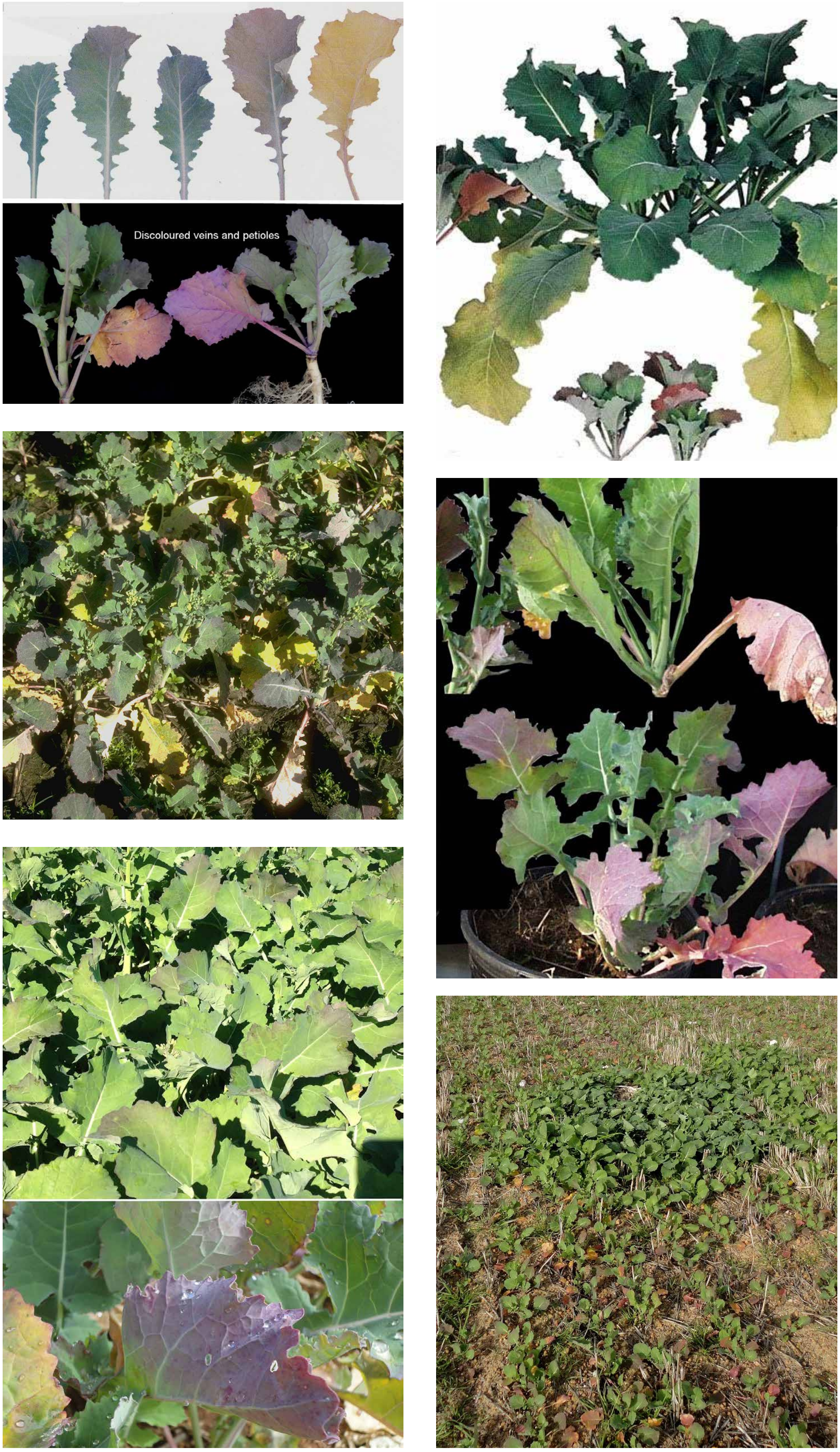


Figure 3: Images of nitrogen deficiency in canola. (Photos: DAFWA)

What to look for

Paddock

- Plants are smaller and less branched with red to purple or yellow leaves.
- Symptoms are worse in wetter seasons, on lighter soil areas and sometimes on non-legume header rows.

Plant

- Mildly deficient plants are smaller with paler green and more erect leaves. Deficient seedlings have reddened cotyledons.
- Oldest leaves develop whitish purple veins and mild purple pigmentation, which starts at the end of the leaf and progresses to the base on both sides of the leaf. (See Table 2 for conditions with similar leaf symptoms.)
- The whole leaf then turns yellow or pinkish purple. Developing leaves are narrow and more erect.
- Established plants that become N-deficient develop yellowing on leaf margins that spreads in toward the midrib between the veins. The midrib becomes discoloured then the leaf dies.
- From stem elongation, the main stem is thinner and branching is restricted. Flowering time and pod numbers are reduced.

What else could it be?

Table 2: Conditions that result in symptoms in canola similar to nitrogen deficiency. Other conditions may include K deficiency or Alternaria.

Condition	Similarities	Differences
Beet western yellow virus in canola	Purple-red colours spreading from end of oldest leaves	Affected plants are stunted rather than smaller and thinner as in N deficiency
Damping off in canola	Reddened cotyledons and older leaves of seedlings	Damping off causes stunted plants with pinched roots or hypocotyls. Often plant death occurs
Sulfur deficiency in canola	Purple leaves	Sulfur deficiency affects younger leaves the most
Phosphorus deficiency in canola	Purplish older leaves	Phosphorus-deficient plants have purpling on leaf margin, then the leaf turns bronze

Where does it occur?

Nitrogen deficiency can occur on most soils but is most common in the following situations:

- cold, wet conditions that slow N mineralisation and uptake of N
- soils with very low organic matter
- after high rainfall on sandy soils, which can result in nitrogen leaching

Management strategies

- Granular or foliar Nitrogen fertiliser can be applied. However with foliar N, a low percentage N can only be absorbed through the leaf, so you will still be reliant on rainfall to move the N into the root-zone. Consider economics. Economics of liquid *v.* solid fertilisers as liquid N is often more expensive per unit of N.

- There is a risk of volatilisation loss from urea or nitrate sources of N. Loss is greatest from dry alkaline soils with dewy conditions, but recent GRDC-funded research shows this may not be as high as traditionally thought. [8]
- The yield potential for canola is established during stem elongation and the budding stage, so all N should be applied before this stage of growth (8–10 weeks).

Tissue test

- Use whole top-of-plant test to diagnose suspected deficiency. Critical N levels vary with plant age and size, but as a rough guide, 2.7% (seedling) to 3.2% (rosette) indicates deficiency.
- Nitrogen soil testing by itself is of little value for most soils.
- Models that combine nitrate, ammonium, soil organic carbon, soil type, and legume history are valuable for N fertiliser calculation.
- Leaf-colour symptoms are not a reliable guide for hybrid varieties. [9]

infocus

5.3.3 Timing of nitrogen for canola in lower rainfall areas in Western Australia

Key messages

In 2013, application of N at seeding or at 4, 8 or 12 weeks after sowing provided similar responses. In low-rainfall areas, as N supply increases, the oil percentage of canola often decreases at a faster rate than grain yield increases. In most instances, Roundup Ready® (RR) canola produced higher grain yields, oil percentage and gross margins.

Timing needs to be drawn out to later full flower timing in many areas that have adequate moisture. There is still a linear response to N at this late timing, especially on higher leaching soils. Much of the research stopped at stem elongation and early flowering as it became too hard to apply the later timing. The data is true for low rainfall environment but not higher rainfall.

Agronomist's view

Aims

The aim was to investigate the N rate and time of application response of canola in lower rainfall parts of Western Australia (WA).

8 G Schwenke (2014) Nitrogen volatilisation: Factors affecting how much N is lost and how much is left over time (2014), GRDC Update Papers, 25 July 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Factors-affecting-how-much-N-is-lost-and-how-much-is-left-over-time

9 DAFWA (2015) Diagnosing nitrogen deficiency in canola. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-canola

Method

Nine experiments were conducted in lower rainfall areas in 2013 and eight in 2014, which compared elite hybrid and open-pollinated (OP) cultivars incorporating triazine-tolerant (TT) and RR herbicide technologies. The 2013 trials are reported. Nitrogen treatments in 2013 included five rates of N (0, 25, 50, 75 and 100 kg N/ha) applied as per schedule in Table 3. Gross margins were calculated taking into account grain and seed prices and herbicide costs for RR and TT varieties, oil bonuses, N fertiliser and application costs, and all other associated input costs.

Table 3: Nitrogen treatments in canola trials in 2013

Total N applied (kg/ha)	Timing of N application(s) (weeks after seeding)	Treatment name (N applied)
0	0	0N
25	0	25N
25	4	0N 25N
25	8	0N 0N 25N
25	12	0N 0N 0N 25N
50	0	50N
50	4	0N 50N
50	8	0N 0N 50N
50	12	0N 0N 0N 50N
50	0 + 4	25N 25N
50	0 + 8	25N 0N 25N
50	0 + 12	25N 0N 0N 25N
75	0 + 4 + 8	0N 50N 25N
100	0 + 4 + 8	25N 50N 25N

Results

Grain yield of canola with no applied N ranged from 0.7 to 1.7 t/ha (mean of both varieties, Table 4). Canola yield and oil percentage responded to applied N at all sites (Table 4). A typical response at Salmon Gums is shown in Figure 4, where oil percentage decreased and grain yield increased with applied N; oil percentage decreased more quickly than grain yield increased, resulting in a flat financial response at rates of applied N >40 kg/ha. Similar responses at other sites resulted in four of nine sites showing no financial gain from applying N.

Grain yield was not affected by time of application of 25 or 50 kg N/ha in eight of nine trials. Oil percentage was not affected by time of application of 25 kg N/ha in eight of nine trials, whereas timing of 50 kg N/ha had a significant effect on oil percentage at the three driest sites (Merredin, Miling North and Salmon Gums). At these sites, applications near flowering (at 12 weeks after sowing) reduced oil percentage in the seed by 0.6–1%, with split applications (25 kg at seeding and 25 kg at 12 weeks after sowing) having less effect than a single application. Despite these reductions in oil percentage with delayed N application, there was little overall effect on timing of N on gross margins (no significant effect in 17 of 18 instances).

In most cases, RR outyielded TT canola and produced higher oil percentages, resulting in higher gross margins for RR in four of nine trials. However, at Salmon

Gums and Merredin, TT canola produced similar yields to RR and therefore had higher gross margins because of lower seed costs.

Table 4: Site details for canola nitrogen (N) application trials in 2013, grain yield (t/ha) with no applied N, 90% of maximum grain yield, and N applied to achieve 90% maximum yield

Location	April to October rainfall (mm)	Organic carbon (%) in top 10cm at sowing	Nitrogen (kg N/ha) in top 30cm at sowing*	N avail.# (kg N/ ha)	Previous crops(2012/ 2011/ 2010)	OP TT and RR hybrid varieties	Grain yield (t/ha) with no applied nitrogen	90% of max GY (t/ ha)	N at 90% of max GY (kg N/ha)
Cunderdin	243	0.86	36	42	barley/ wheat/ pasture	ATR Stingray and Hyola 404RR	0.7	0.9	107
Eradu	280	0.86	80	66	wheat/ wheat/ lupin	ATR Stingray and Hyola 404RR	1.1	1.5	76
Holt Rock	282	1.42	132	71	barley/ barley/ wheat	CB Telfer and Hyola 404RR	1.7	2	52
Katanning	356	2.91	86	139	oats/ lupin/ hay	ATR Stingray and Hyola 404RR	1.5	1.8	60
Merredin	204	0.55	92	60	fallow	CB Telfer and Hyola 404RR	0.8	1	61
Miling North	223	0.47	49	74	wheat/ wheat/ lupin	CB Telfer and Hyola 404RR	0.9	1.1	36
Salmon Gums	217	0.8	31	39	wheat/ barley/ canola	CB Telfer and Hyola 404RR	0.9	1.2	57
Wittenoom Hills	305	1.8	41	104	barley/ wheat/ field pea	ATR Stingray and Hyola 404RR	1	1.5	86
Wongan Hills	227	1.01	150	63	wheat/ pasture/ pasture	ATR Stingray and Hyola 404RR	1.48	1.53	23

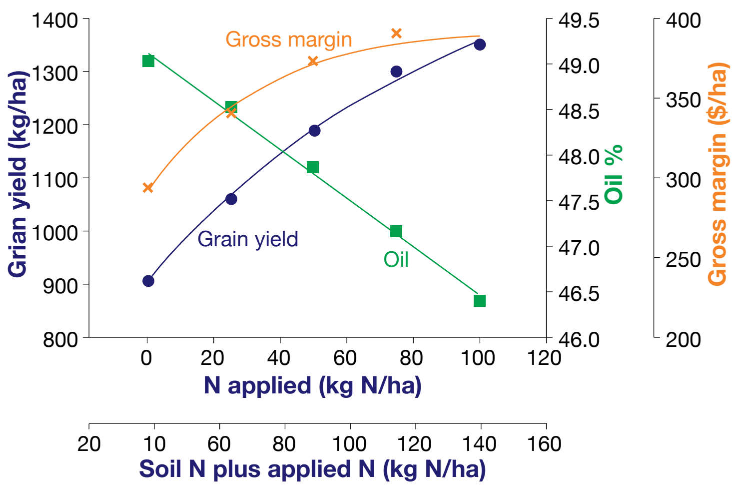


Figure 4: Response of canola grain yield (kg/ha), seed oil (%) and gross margin ($/ha) to increasing nitrogen at Salmon Gums in 2013

Conclusion

In most of the trials conducted in 2013, the timing of N application had no significant effect on grain yield, oil percentage or gross margins. In a few instances, applying N near flowering (12 weeks after sowing) reduced the oil percentage in canola. However, the reductions were often not large enough to reduce gross margins.

It is not common for growers to apply N much later than 8 weeks after sowing. This work suggests that in seasons similar to 2013 with a long soft spring over much of the grain-growing areas, growers can delay their N decisions until early flowering (12 weeks). Thus, farmers can play the season for a few more weeks or 'catch-up' if they missed their regular fertiliser time. [10]

5.4 Phosphorus

More information

GRDC Fact Sheet: Crop Nutrition Phosphorus Management Fact Sheet

Nearly all soils in WA were P-deficient, but continual use of P fertiliser means that acute deficiency in broadacre crops is rare, with the exception of crops on Darling Range gravels. Phosphorus deficiency is often transitory and compounded by dry soil, with symptoms disappearing when topsoil is re-wet following rainfall.

Figure 5: Phosphorus deficiency in canola. (Photo: DAFWA)

What to look for

Paddock

Plants are smaller and less branched, with worse symptoms on higher P-fixing and acidic soils, and in very dry seasons.

Plant

- Deficiency most commonly shows as smaller plants with similar-shaped leaves (Figure 5).
- From stem elongation, the main stem is thinner and branching is restricted.
- Flowering time and pod numbers are reduced.
- Severely deficient plants develop a narrow purple margin of the leaf blade that spreads inwards. (See Table 5 for conditions with similar leaf symptoms.)
- The leaf turns bronze before dying.

10 M. Seymour, S. Sprigg, B. French, R. Malik, J. Bucat and M. Harries (2015), Department of Agriculture and Food Western Australia, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Timing-of-nitrogen-for-canola-in-lower-rainfall-areas-in-WA

What else could it be?

Table 5: Conditions that result in symptoms in canola similar to phosphorus deficiency

Condition	Similarities	Differences
Beet western yellow virus	Purple–red colours on oldest leaves	Purpling spreads down from the leaf end with *Beet western yellow virus* and affected plants are stunted rather than smaller and thinner. Phosphorus-deficient plants will vary with the soil type
Nitrogen deficiency	Purple–red colours on oldest leaves	Symptoms in nitrogen-deficient plants move from the margins to the base with the leaves turning yellow or pink-purple

Where does it occur?

Phosphorus deficiency is a problem on high P-retaining (high Phosphorus Buffering Index (PBI)) soils, particularly in the Darling Range acidic gravels where soil acidity and water repellence markedly reduce P uptake, and in high pH calcareous clay soils.

Dry topsoil can lead to temporary P deficiency on all soils, particularly during early crop growth and on water-repellent soils.

Water-repellent and acidic soils require more P.

Management strategies

Plants have a high requirement for P during early growth. Phosphorus is relatively immobile in the soil; therefore, topdressed or sprayed fertiliser cannot supply enough to correct a deficiency.

Phosphorus is poorly mobile in most soils, but does move on sands with very low P-buffering index (PBI), particularly on coastal plains. Topdressing is effective on these soils, but deficiency is rare.

Root pruning caused by Al toxicity on acidic soils markedly increases P deficiency.

How can it be monitored?

Use soil tests to determine P fertiliser requirements. Soil tests may underestimate available P on very low PBI sands and overestimate it on acidic and water-repellent soils (particularly in the Darling Range).

Use whole-shoot plant tests to diagnose suspected P deficiency, and compare paired good and poor plant samples where possible. Critical plant P levels vary with plant age and size, but as a rough guide, 0.3% (seedling) and 0.25% (rosette) indicate deficiency. [11]

5.4.1 Role and deficiency symptoms

Phosphorus plays an important role in the storage and use of energy within the plant. Lack of P restricts root development (resulting in weaker plants) and delays maturity; both of these affect yield potential and seed oil content, particularly in dry spring

[11] https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-canola DAFWA (2015) Diagnosing phosphorus deficiency in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-canola

conditions. Low P levels also restrict the plant's ability to respond to N. Even a mild deficiency can significantly reduce plant growth without any symptoms. In cases of severe deficiency, the older leaves will often appear dull blue or purple (Figure 6). Phosphorus is a very mobile nutrient within the plant, and if a deficiency occurs, it moves rapidly from older leaves to the young leaves or developing pods.

Figure 6: Phosphorus deficiency shows as distinct pink purpling of the tips and margins of older leaves. (Photo: P. Hocking, CSIRO)

Fertiliser placement

In the soil, P is immobile, so fertiliser should be banded close to the seed at sowing. This ensures that the developing seedling is able to take up a good supply during the early growth stage when requirement for P is at its highest. Many soils (particularly if exchangeable Al is present) are able to tie up P, making it unavailable to plants. Banding the fertiliser can reduce the amount of P tied up because less fertiliser is in contact with the soil than occurs with broadcasting.

Phosphorus fertiliser banded above and below the seed gives better yield responses than P broadcast before sowing. In sandy soils, which are prone to drying in the surface layer, banding some of the fertiliser below the seed at sowing may improve the efficiency of P uptake.

Phosphorus requirements

If a wheat crop responds to P, then a rate at least equivalent should be used when sowing canola at that site. Topdressing is ineffective, so it is important to get the P rate right at sowing. A maintenance application of 7–8 kg P/ha is needed for every tonne of canola you expect to harvest.

If a soil test indicates a high level of soil P, then lower rates of P could be applied. In some situations, where soil P levels are very high, it may be uneconomic to apply P. If more is applied than is removed by the grain, it will be added to the soil P bank and may be available for following crops or pastures to utilise. However, a significant proportion (up to 50%) of applied fertiliser P can ultimately become 'fixed' into organic and inorganic forms that are largely unavailable for crop uptake in the short–medium term but can add to the P pool in the longer term, with a proportion of the P becoming available over time.

Depending on your location, a few laboratory analyses are available for P. The Olsen-P test (bicarbonate test) is often recommended on acid soils, whereas the Colwell-P test is more useful on alkaline clay soils. However, each of these tests measures only a proportion of the P status of a soil. The PBI (P buffering index) is also important because it can indicate how available the soil P is to plants, and BSES-P is recommended as a baseline of the pool P status (easily available and slow-release pools). A qualified soil nutrition advisor will help you to decide which tests are applicable on your soil type.

More information

[EGRDC Update Papers: Economics and management of P nutrition and multiple nutrient decline]

If tests indicate <20 mg/kg, then P is considered marginal to low (depending on soil type and rainfall) and a response is likely. If the soil P level is high (>40 mg/kg), a response to P is less likely, unless the soil is acidic (pHCaCl <4.8) and has a low cation exchange capacity (<5 cmol(+)/kg) or the soil is alkaline pHCaCl >8 and highly calcareous.

5.5 Sulfur

Sandy-textured soils in WA are naturally low in S, and applied S is readily leached from the top 10 cm, especially in high-rainfall areas.

The use of fertilisers containing S somewhat masks the low levels of S present in the soil; however, the introduction of more sensitive crops such as canola and the shift to compound fertilisers that are low in S has increased the frequency of S deficiency seen in crops. High rainfall can leach sulfur from the root-zone early in the growing season, leaving young crops deficient. Other factors that can induce deficiency in crops include subsoil constraints such as acidity, sodicity and hardpan, and the level of N in the soil can limit the crop's ability to access subsoil sulfate.

Compared with wheat, canola crops have a high demand for S. Every tonne of canola grain harvested per hectare uses 10 kg S, compared with 1.5 kg S for wheat. The high demand for S in canola is driven by the high protein content and the presence of S-containing glucosinolates in the seed. The concentration of S in the seed, means high rates of removal from the field—about 3.5 to 5 kg S/t harvested canola grain—especially in high-yielding crops.

Canola also has high within-season demand for S compared with the requirements of wheat. Critical values have been identified for both soil and tissue tests in canola; these suggest that canola has higher S-fertiliser requirements.

The mobile nature of S in the soil, and its capacity to be mineralised through the breakdown of organic matter, makes it difficult to predict reliably when a crop will respond to S application.

A synergistic relationship exists between S, N and P, which affects plant uptake and efficient use of these nutrients. Too much N can induce S deficiency in plants. Grain yields increase when all three nutrients are in sufficient supply and in the correct ratio.

Most of the S present in the soil is bound into organic compounds, but plants can take up only the mineral sulfate form. Cultivation releases S held in the organic matter. In no-till systems, soil organic matter breaks down slowly, releasing mineral S for crop use. Sulfur mineralisation is low in cooler months, as is root exploration, which can cause temporary deficiency in crops, seen as patches that disappear when the soil temperature increases. Mineralisation is higher in the warmer months and under moist soil conditions. Sulfate adsorption occurs in the soil layers below 10 cm, and this can make a significant contribution to crop growth once crop roots have reached the subsoil.

The rate of sulfate leaching is highly variable, depending on seasonal conditions and the water-holding capacity of the soil, and is closely related to the rate of nitrate leaching. These two nutrients are best considered together when planning fertiliser applications at seeding and post-seeding to compensate for their movement down the profile under the current seasonal conditions.

Sulfur nutrition in cropping systems is usually managed through the application of P or N fertilisers containing S. Several fertiliser products are available to growers to supply the crop's S requirements. Gypsum and ammonium sulfate are the most common sources of applied S. Gypsum is often preferred; it contains ~16–18% sulfur, is relatively inexpensive, and unlike ammonium sulfate, it is not acidifying. There are other fertilisers with varying N : S ratios achieved by blending ammonium sulfate with urea or adding S to UAN (urea–ammonium nitrate) products such as Flexi N. Blending ammonium sulfate with urea creates a product that absorbs water from the atmosphere, making it difficult to store and handle.

On sandy soils in WA, only 15% of applied S remains in the top 0.5 m one year after application. Gypsum-S applied at 34 kg S/ha to pasture grown on a non-leaching clay loam in WA has achieved a residual benefit to dry matter production for up to 3 years, but this is unlikely to occur on sandy soils.

Iron, aluminium oxides and alkaline soils have the capacity to bind S and reduce leaching; however, the bound S will not be available to plants. [12]

5.5.1 Deficiency in canola

Sulfur is critical for high canola yields, and deficiency is detected at all growth stages. When supply of S is low, there is limited movement of S within the plant, so new leaves, flowers and pods are likely to be more deficient than older leaves and pods. When S and water are adequate, it can translocate within the plant as required. Adequate–high N availability limits the movement of S within plants and deficiency symptoms may be seen on younger leaves.

The maximum response to S is at rates of 10–20 kg/ha on very S-deficient soils. Remember the need to balance N and S levels.

[12] GRDC (2015) Sulfur strategies for western region. GRDC Media Centre, 18 May 2015, http://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

More information

GRDC Update Papers: Review of sulfur strategy

GRDC Update Papers: Sulfur nutrition in canola—gypsum vs sulphate of ammonia and application timing

There is value in tissue testing before stem elongation to ensure the N:S ratio is less than 10:1 which normally means enough S for maximum N utilisation and minimal potential for S deficiency with additional applied N.

Subsoil S concentrations are a more reliable predictor of grain yield response to applied S. In most situations (depending on climate and soil type), the recommended values above which canola crops will not respond to applied S fertiliser are as follows:

- across all rainfall zones: 7.7 S/kg for 0–10 cm and 7.5 mg S/kg for 0–30 cm
- in high rainfall zones 11.0 S/kg for 0–10 cm and 9.5 mg S/kg for 0–30 cm [13]

5.6 Potassium

More information

GRDC Update Papers: Do we need to revisit potassium

GRDC Update Papers: Economics and management of P nutrition and multiple nutrient decline

An adequate supply of potassium (K) is important to provide plants with increased resistance to disease, frost and drought, as well as increased carbohydrate production. Canola crops take up large amounts of K during growth but most of it remains in the stubble, with only a small proportion removed in the grain.

Although soil tests, especially the balance of exchangeable cations, can provide a guide to the K level, tissue tests are the most reliable method to determine whether K fertiliser is needed. Avoid sowing K fertiliser with the seed; it could affect germination. [14]

N.B. The availability of K may be restricted early in the season if conditions are dry. Adequate K will need to be available early in the crop to ensure optimal growth. Be careful with applying K with the seed as it can have a salt effect, which can draw moisture away from the germinating seed.

5.7 Micronutrients

5.7.1 Zinc

Although canola is moderately susceptible to zinc (Zn) deficiency, it is rarely seen in paddocks with pH < 6 CaCl because many fertilisers contain trace levels of Zn, canola appears more effective at using soil Zn, and mild deficiency is difficult to identify.

Soils with pH 7.5 CaCl often express zinc deficiency in cereals and if yield responses to applied zinc are realized with cereals, it is likely that canola will also have a yield response in these same soils.

[13] GRDC (2015) Sulfur strategies for western region. GRDC Media Centre, 18 May 2015, http://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

[14] P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

What to look for

Symptoms listed below are a guide only and should be verified by plant nutrient test.

Paddock

- Plants are stunted and pale with areas of poorer growth alongside healthy, apparently normal plants giving the crop a patchy appearance (Figure 7).
- Worse symptoms are expected on sandy or alkaline grey clay soils (Figure 8), particularly if newly limed, and better on old windrows.
- Plants often improve on windrows.
- Stunted plants with pale green young leaves, particularly between leaf veins. (See Table 6 for conditions with similar symptoms.)
- Leaf blades bend down.
- Internodes are shortened as stems elongate.

Figure 7: Zinc deficiency in canola. (Photos: DAFWA)

Figure 8: Zinc deficiency appears as bronzing on the upper leaf surface and may occur in neutral to alkaline soils. (Photo: B. Holloway, SARDI)

What else could it be?

Table 6: Conditions that result in symptoms in canola similar to zinc deficiency

Condition	Similarities	Differences
Molybdenum deficiency	Smaller plants with pale green leaves; interveinal chlorosis	Molybdenum deficiency also causes scattered dead leaf spots; healthy and deficient plants are often intermixed; and leaves have scorched edges
Copper deficiency	Smaller plants with pale green leaves; interveinal chlorosis	Copper-deficient plants have numerous yellow specks that develop between veins of older leaves, progressing until the whole plant appears pale green

Where does it occur?

- Most sandy-surfaced soils required copper (Cu) and Zn when initially cleared for agriculture.
- Zinc is relatively immobile in soil and becomes unavailable to crops in dry soil.
- Where soil levels are marginal, Zn deficiency can be induced by applications of lime, increased N fertiliser, and Cu fertiliser.
- The use of root-pruning herbicides can induce Zn deficiency.
- Zinc deficiency is more common in high pH and clay soils.

Management strategies

- Use foliar spray (effective only in current season) or drilled soil fertiliser.
- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- Because Zn is immobile in the soil, topdressing is ineffective; it is available to the plant only when the topsoil is wet.
- Mixing Zn throughout the topsoil improves availability through more uniform nutrient distribution.
- Drilling Zn deep increases the chances of roots being able to obtain enough molybdenum (Mo) in dry seasons.
- Seed treatment with Zn is used to promote early growth where root disease is a problem, but the level is lower than a plant needs in the current season.
- Zinc present in compound fertilisers often meets the current requirements of the crop.

How can it be monitored?

- A DTPA Zn soil test provides, at best, a rough guide to soil Zn status.
- Whole-shoot plant test provides a rough guide if paired good and poor samples are taken, but this should be confirmed with a youngest emerged blade (YEB) test.
- Whole shoots of young plants (40 days) below ~23 mg/kg and YEB levels below ~15 mg/kg indicate Zn deficiency. [15]

15 https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-canola DAFWA (2015) Diagnosing zinc deficiency in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-canola

5.7.2 Molybdenum

Role and deficiency symptoms

Molybdenum is important in enabling plants to convert nitrates from the soil into a usable form within the plant. Deficiency is more common in acid soil (pHCa <5.5) but is difficult to diagnose other than by a tissue test. Deficiency can be avoided by applying Mo at a rate of 50 g/ha every 5 years. The most common practice is application of 150 g/ha of the soluble form sodium molybdate (39% Mo) sprayed onto the soil surface. Molybdenum is compatible with pre-emergent herbicides and can be incorporated into the soil with sowing. [16]

Fertiliser requirements

Although fertilisers containing Mo can be used at sowing, the concentration of Mo they contain is less than recommended and they are more expensive than using sodium molybdate.

Molybdenum-treated single superphosphate applied during the pasture phase is cost-effective and it should supply enough Mo for the canola crop. [17]

5.7.3 Magnesium

In recent years, magnesium (Mg) deficiency has been reported in a number of seedling crops. As the crop grows and develops a deeper root system, the deficiency symptoms disappear because most soils have adequate Mg deeper in the profile. Low surface levels of Mg are probably due to low levels of sulfonylurea herbicide residues and the harvesting of subterranean clover hay, where large quantities of Mg are exported from the paddock.

Lime–dolomite blends can be used when liming acid soils if there is a history of deficiency symptoms, and other dry and foliar applied fertilisers are available. [18]

5.7.4 Calcium

Calcium (Ca) is important in plants because it assists in strengthening cell walls, thereby giving strength to plant tissues. Calcium is not readily transferred from older to younger tissue within a plant, so if a deficiency occurs it is first seen in the youngest stems, which wither and die, giving rise to the term 'withertop' or 'Tipple Top'to describe Ca deficiency (Figure 9).

Calcium deficiency is not common but it can occur in acid soils, especially if the level of exchangeable Ca is low. The use of lime (calcium carbonate) on acid soils

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16 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

17 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

18 P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

and gypsum on sodic soils has meant only an intermittent occurrence of withertop in canola. [19]

Calcium is relatively slow moving within the canola plant, this can explain some of the symptoms after a period of rapid growth.

Figure 9: Death of the canola flower head from calcium deficiency. (Photo: D. McCaffery, NSW DPI)

5.8 Toxicity

The most effective treatment for Al and Mn toxicity (Figure 10) is liming to raise the soil pH to >5.0. Lime rates depend on the pH to depth and the cation exchange capacity of the soil. Microfine lime is usually applied at 2.5–4.0 t/ha. Shallow incorporation of lime is sufficient to ameliorate surface soil acidity, but deep ripping is required to incorporate the lime, reduce soil strength and improve drainage where there is the more serious problem of subsoil acidity.

The sensitivity of canola to soil acidity has had beneficial spin-offs, in that it has forced Australian growers to implement liming programs before their soils become too acidic for less sensitive crop and pasture species.

There are breeding programs to improve the Al and Mn tolerance of Australian canola, by using both conventional technology and genetic engineering. The rationale for increasing the tolerance of canola to soil acidity is to broaden management options for growers while they implement liming programs. [20]

Boron deficiency can be confused with the phonological effect of applying herbicides such as Clethodim and Butroxydim.

[19] P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[20] P Hocking, R Norton, A Good (1999) Crop nutrition. 10th International Rapeseed Congress, http://www.regional.org.au/au/gcirc/canola/p-05.htm

Figure 10: *Symptoms of severe manganese toxicity in young canola on an acid soil.*

More information

[Research paper: Risks of boron toxicity in canola and lupin by forms of boron application in acid sands of south-western Australia]

5.9 Nutrition effects on the following crop

Canola has provided the opportunity for more reliable responses to N in subsequent cereals by reducing cereal root diseases. [21] However, low yields and poor growth have been reported in crops following canola.

This is due to the depletion of soil microorganisms called arbuscular mycorrhizal fungi (AMF). They are beneficial soil fungi, assisting the uptake of P and Zn that would otherwise be unavailable to the crop. Canola does not need these fungi to help it take up P and Zn, so under canola the AMF population declines to a low level. To avoid this problem, follow canola with a short-fallow crop such as wheat or another cereal crop rather than pulses that depend on AMF. [22]

[21] R Norton, J Kirkegaard, J Angus, T Potter. Canola in rotations. Australian Oilseed Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0014/2705/Chapter_5_-_Canola_in_Rotations.pdf

[22] P Parker (2009) Nutrition and soil fertility. Ch. 7. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

SECTION 6

FAQ Weed control

6.1 Key points:

- Choose paddocks relatively free of broadleaf weeds, especially charlock, wild turnip, wild radish and other weeds of the Brassica family, because in-crop herbicide options are limited. Grass weeds can be managed in canola by using trifluralin pre sowing. Post-emergent options include Group A grass herbicides; however the level of annual ryegrass resistance to these herbicides has increased dramatically to a point where they are non-effective in many paddocks. The effectiveness of these herbicides in the future is dependent on the use of other non-chemical Integrated Weed Management (IWM) tools to reduce the populations of these resistant weeds. Group A resistant grasses are still of concern.
- Herbicide-resistant varietal systems such as triazine-tolerant (TT), Clearfield® and Roundup Ready® (RR) can be of use in managing weeds in canola, particularly broadleaf weeds. However, careful management is needed to avoid the buildup of resistant weed populations.
- When choosing paddocks for canola be careful with those treated with residual herbicides, especially Group B and triazine herbicides (for conventional varieties); their residues can affect canola. Check labels for re-cropping intervals, some of which are up to 36 months.
- Ensure that all spray equipment is thoroughly decontaminated before using to spray canola. Apply chlorine if the spraying equipment has previously been used to spray sulfonylureas, ammonia for hormone herbicides (salt and amine formulations) such as 2,4-D amine and MCPA, and liquid alkali detergent for Broadstrike™ (flumetsulam) and Eclipse® (metosulam) decontamination. Where possible, use separate spraying equipment for residual herbicides such as the sulfonylureas.
- Imidazolinone-tolerant varieties are marketed as Clearfield® canola. These varieties allow the use of the Group B herbicide Intervix® (imazamox and imazapyr). Clearfield® varieties do not suffer from the yield and oil penalty that the TT varieties exhibit. The use of Clearfield® varieties allows the rotation of herbicide groups and broadens the spectrum of weeds controlled. [1]

More information

NSW DPI: Weed control in winter crops 2015

GRDC: Integrated weed management manual

GRDC: Soil behaviour of pre-emergent herbicides

Monsanto: What is Roundup Ready® canola?

Clearfield stewardship best management practice 2014

GRDC: Herbicide tolerant canola in farming systems: a guide for growers

[1] L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

Weed management is strongly influenced by crop-rotation sequence. Careful planning of a 5-year rotation will enable targeted weed control through both cultural and chemical methods, as well as the ability to plan herbicide rotations. The widespread occurrence of herbicide resistance in Australian weeds puts further emphasis on the need for careful planning and resistance-management strategies such as monitoring, herbicide mode-of-action (MOA) rotation and cultural management techniques.

The area sown to herbicide-tolerant varieties of canola has increased dramatically in recent years; however, widespread use of these varieties without integrated weed-management techniques is likely to accelerate the development of resistance to the herbicides.

More information

Research paper: Incidence of weeds in canola crops across southern Australia

The resistance to several of these herbicides that has already occurred in Australian weeds shows that these herbicide-tolerant varieties are not a panacea for herbicide-resistance management, but they will add significantly to the options available to farmers for resistance management.

6.1.1 Weed spectrum and herbicide resistance

Large numbers of weed species affect canola production; those that feature consistently in Australia are listed in Table 1. Prior to the introduction of herbicide-resistant varieties, control of key broadleaf weeds was the most important constraint to production of canola throughout Australia.

Table 1: Common weeds of Australian canola crops

**Weed species that have been particularly important in restricting canola production prior to the introduction of triazine-tolerant varieties*

Weed (common name)	Scientific name
Wild radish* (Figure 1)	*Raphanus raphanistrum*
Indian hedge mustard*	*Sisymbrium orientale*
Annual ryegrass	*Lolium rigidum*
Shepherds purse*	*Capsella bursa-pastoris*
Wild turnip*	*Brassica tournefortii*
Charlock*	*Sinapsis arvensis*
Paterson's curse*	*Echium plantagineum*
Vulpia*	*Vulpia spp.*
Wireweed	*Polygonum aviculare*
Toad rush	*Juncus bufonius*
Wild oats	*Avena spp.*
Spiny emex	*Emex australis*
Turnip weed*	*Rapistrum rugosum*
Fumitory	*Fumaria spp.*
Buchan weed	*Hirschfeldia incana*
Cape weed	*Arctotheca calendula*
Volunteer cereals	

The degree to which such weeds have restricted the canola area is reflected in the rapid adoption of TT varieties across Australia. [2]

[2] S Sutherland. Canola weed management. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

More information

DAFWA: Weeds

DAFWA: Genetically modified crops and herbicide resistance

UWA AHRI: Weed control systems in herbicide resistant canola – a resistance reprieve?

UWA AHRI: Can we make the canola:wheat rotation work?

UWA AHRI: Burning wet windrows

CropPro: Wheat and canola tools and resources for agronomists

Plant Science Consulting: Weed resistance seed test

GRDC/CropLife: Herbicide resistance mode of action groups

WeedSmart

UWA AHRI: Windrow burning—a good place to start

Nufarm SprayWise decisions

ISHRW: Three herbicide site of action classification systems

Figure 1: Wild radish is a common weed in canola crops.

infocus

6.2 Improving the best practice integrated weed management package: 2013 trial report

A trial funded by the Grains Research and Development Corporation (GRDC) and conducted by the Department of Agriculture and Food Western Australia (DAFWA) examined the positive impact of crop competition, crop-type rotation and mouldboard ploughing on weed management.

6.2.1 Background and aim

Herbicides continue to be the main means of weed control in WA, despite alarming levels of herbicide resistance. Integrated weed management (IWM) describes the means by which growers use a range of weed-management practices at various times of the growing season to achieve acceptable weed control in the face of populations of herbicide-resistant weeds.

The challenge is to determine how much IWM is necessary to reduce the reliance on herbicides to the point where herbicides become the secondary means of weed control. This trial was set up to achieve this aim by first creating a very low weed seedbank through soil inversion with a mouldboard plough, followed by crop competition, weed seedset and harvest-weed management treatments to keep the weed seedbank very low.[3]

6.2.2 Trial details

This is a long-term trial running over four growing seasons.

In the preceding three seasons, the five IWM treatments were:

1. Control (district practice): no-till, wide row-spacing, plus herbicides (knockdown, trifluralin, wild radish spray), conventional harvest
2. Control + harvest weed-seed management with either a Harrington Seed Destructor or windrow burn
3. Control + harvest management + crop competition (a seeding rate of 120 kg/ha, spread 60 kg seed/ha first with combine, followed by sowing with another 60 kg/ha)
4. Control + harvest management+ competition + mouldboard; plots ploughed in 2010 prior to seeding
5. Control + harvest management + competition + mouldboard + low herbicide (knockdown only) weed-seeker pre-harvest

Each of these treatments was dry-sown to canola variety ATR Snapper and TT canola in 2013.

Atrazine (4 L) was applied in two applications, both post-emergent. In 2013, 500ml/ha of Select® (500 mL, active ingredient clethodim) and 100ml/ha Fusilade® (100 mL, active ingredient fluazifop-p-butyl) were part of the herbicide applications.

6.2.3 Results

In 2011 and 2012, brome grass plants were stifling those plots without crop competition or mouldboard tillage (Figure 2).

Numbers of brome grass plants were significantly reduced in 2013 following a controlled burn of all harvest windrows (harvest management) and rotation from wheat to canola, allowing suppression with alternative herbicides. Windrow burning did little to reduce brome grass numbers in previous years because of late harvest and all brome seed being on the ground prior to harvest.

No herbicide for brome grass was applied to mouldboard plots in 2011 or 2012. Therefore, mouldboarding has provided good control, with fewer brome grass plants despite less herbicide.

Crop competition significantly reduced brome numbers.

3 W Parker (2013) Improving the best practice integrated weed management package 2013 trial report. Department of Agriculture and Food Western Australia. https://www.agric.wa.gov.au/canola/improving-best-practice-integrated-weed-management-package-2013-trial-report?page=0%2C3

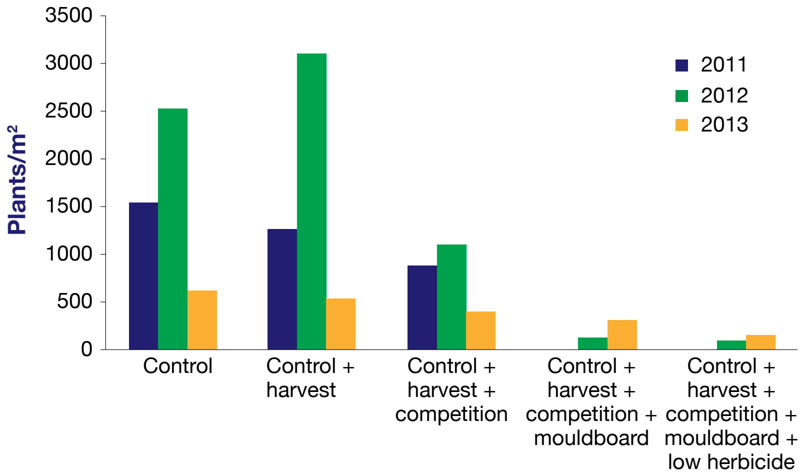

Figure 2: Number of brome grass plants per m² in the five treatments over the last three seasons. Mouldboard ploughing was done in 2010. Canola was sown in 2013.

Wild radish numbers increased due to small escapes in previous seasons (Figure 3). Rotating to canola reduced wild radish numbers.

Plant counts were taken before the application of atrazine; only a few late-germinating wild radish plants may have survived the season (these were not counted).

Mouldboard treatment was successful only if there were no wild radish escapes in the season of mouldboarding.

The low-herbicide treatment received wild-radish desiccation spray only at the end of 2010 or 2011.

This result shows that if a grower uses mouldboard ploughing in a paddock and creates a very low weed seedbank, they must keep it low by continuing to achieve high levels of weed control.

By allowing wild radish to set seed in 2011, this paddock has been put back to where it started in terms of wild radish numbers. [4]

4 W Parker (2013) Improving the best practice integrated weed management package 2013 trial report. Department of Agriculture and Food Western Australia. https://www.agric.wa.gov.au/canola/improving-best-practice-integrated-weed-management-package-2013-trial-report?page=0%2C3

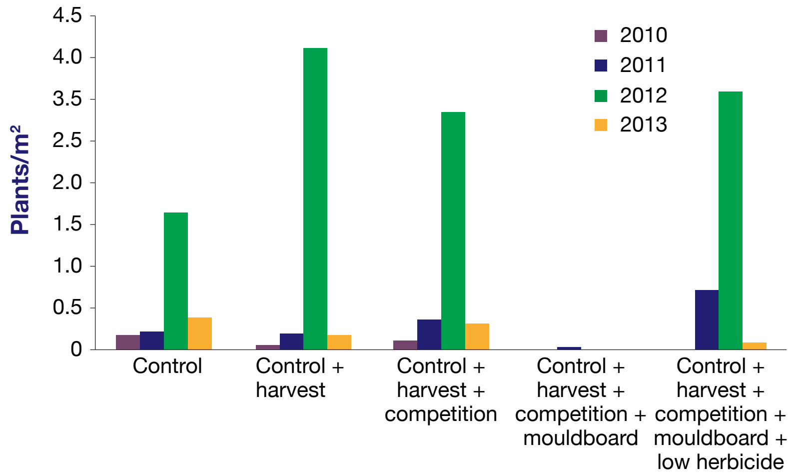

Figure 3: Number of wild radish plants per m² in the five treatments from the last four seasons. Mouldboard ploughing was done in 2010. Canola was sown in 2013.

The large variation in yield across replicates destroys any yield comparison from this trial (Table 2).

Table 2: Yield of canola from treatment plots

IWM treatments	Grain yield (t/ha)	Oil percentage
Control)	0.37	50.2
Control + harvest management	0.39	49.9
Control + harvest management + competition	0.40	48.5
Control + harvest management + competition +mouldboard	0.47	46.1
Control + harvest management + competition + mouldboard + low herbicide	0.33	46
l.s.d. (*P* = 0.05)	n.s.	1.8

Conclusion

Herbicides did not keep brome grass numbers in check under continuous wheat. Wild radish patches missed in the early seasons of the trial led to the buildup of unsustainable numbers. This population remains susceptible to atrazine, and so TT canola is a suitable rotation crop.

It was necessary to rotate to canola to provide alternate herbicides and IWM strategies in order to manage the weeds. Canola crops offer the capacity to windrow-burn safely with high heat and good seed kill.

Crop competition reduced buildup of both brome grass and wild radish, and it should be part of a weed-management strategy. Targeting weed patches with higher rates of crop seed at sowing is one way to integrate crop competition into the program. [5]

5 W Parker (2013) Improving the best practice integrated weed management package 2013 trial report. Department of Agriculture and Food Western Australia. https://www.agric.wa.gov.au/canola/improving-best-practice-integrated-weed-management-package-2013-trial-report?page=0%2C3

6.2.4 Herbicide resistance in Australian weeds

Australian farmers have moved away from aggressive tillage practices because of the extreme risk of soil erosion and improved soil moisture management. Few farmers use inversion tillage as is practiced in Europe, whereas most use reduced-tillage methods. Significant proportions of the crops are seeded using no-till. Therefore, crop sequences and seeding techniques are highly dependent on herbicides.

Repeated use of herbicides has selected for herbicide-resistant weed biotypes. Herbicide resistance now affects many species of Australian weeds, foremost among them annual ryegrass. Where canola production was restricted by weeds such as wild radish prior to the introduction of TT varieties, it is likely that herbicide-resistant weeds will re-impose restrictions if not carefully managed.

This could be the case with multiple- and/or cross-resistance in single species, as well as mixed populations of resistant weed species.

Canola growers in Australia use a range of herbicides on canola crops from many herbicide groups, and the number of groups will increase with the commercial production of additional herbicide-resistant varieties in the next few years (Table 3).

Table 3: Common herbicides in use in canola crops in Australia

Herbicide Groups	Herbicides
A	Fluazifop, Haloxyfop, Diclofop, Diclofop-methyl, Sethoxydim, Quizalofop, Clethodim
B	Intervix*® (Clearfield® varieties)
C	Simazine, Atrazine, Terbuthylazine (TT varieties)
D	Trifluralin, Propyzamide
I	Clopyralid
K	Metolachlor
M	Glyphosate (RR varieties)

www.apvma.gov.au

Many populations of annual ryegrass would now be classified as resistant to diclofop-methyl and clethodim and on some farms ryegrass is cross-resistant to Group A and Group B herbicides. There are confirmed cases where annual ryegrass biotypes are resistant to all selective herbicides currently available. For each paddock, monitoring and resistance testing is imperative to understand the control options open to the grower.

Although the major herbicide-resistance problems in Australian weeds are with Groups A and B herbicides, resistance to Groups C, D, F, I, L and M herbicides have also been increasing.

Wild radish has now developed resistance to Group B, Group C, Group F and group I herbicides. Combined with the resistance in ryegrass, this has serious implications for farmers, particularly those wishing to use the imidazolinone-tolerant (IT) and TT varieties.

Farmers across Australia are being encouraged to adopt IWM in order to address the resistance problem. There are two essential components to IWM: the rotation of herbicide groups to avoid repeated use of the same or similar herbicides, and the avoidance of treating large numbers of weeds with a single herbicide. Weed-seed contamination of canola seed in excess of limits will lead to reduced prices. This is especially the case with weeds from the family Brassicaceae, which cause increased erucic acid and glucosinolates and consequent reduction in canola quality. Weed seed and other debris in the canola seed leads to direct penalties, based on the percentage present. Weed competition can affect nutrient uptake by the canola plants and thus affect yield.[6]

6.2.5 Weed management in different scenarios

Canola following pasture

The pasture ley system of farming was developed in Australia to allow crops to make use of nitrogen provided by legume pastures. A cropping phase of a single year to several years follows a period of pasture production. Growing canola in the first year after pasture has been the preferred practice. The system provides fertile, low-weed-density conditions for the crop. A significant bonus is that cereal root diseases are controlled for the following wheat crop, provided grasses are controlled in the pasture. The ley pasture phase provides farmers one or more growing seasons in which weed numbers can be reduced by using non-selective techniques such as grazing, winter cleaning (pasture manipulation), topping, hay-making and silage production. In the spring prior to sowing, the pasture and weeds are killed with glyphosate. In a well-managed ley system, weed numbers are significantly reduced prior to planting the canola.

Invariably, trifluralin is applied prior to sowing, targeting grassy weeds and susceptible broadleaf species. Following a strong pasture phase, subterranean clover (*Trifolium subterraneum*) can often be dense enough to suppress the seedling canola crop, especially if the 4–6 weeks leading up to planting is dry. Other common weeds are annual thistles and cape weed. In these cases, clopyralid is used.

Producers may need to treat late wild oats and other grass weeds that escaped the trifluralin or emerged late. In this case, a Group A herbicide such as Quizalofop is used.

A common practice is to keep the canola crop as clean as possible of weeds, using the techniques outlined. This often allows the following wheat crop to be produced without selective herbicides.

The ley-pasture cropping system has a great deal of merit in terms of IWM. The system is excellent for reducing pressure on herbicides, as well as managing weeds that are already resistant to herbicides. Crop and pasture phases are usually of similar length (1–5 years). Management of herbicide resistance is straightforward in these

6 S Sutherland. Canola Weed Management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

systems. Unfortunately, the viability of the pasture ley system is closely (although not entirely) linked to livestock product prices.[7]

Canola in a continuous cropping sequence

Weed control in continuous cropping consists of manipulating sowing time, exploiting crop competitive effects and relying heavily on selective herbicides.

Selection pressure for herbicide resistance is often high, especially to the Group A and Group B herbicides, because of the need to use these herbicides in the preceding crops.

Weed numbers tend to be higher because farmers do not have the range of non-selective treatments available in the pasture. This increases the risk of resistant biotypes being present in the crops when the herbicides are applied. Because of herbicide resistance, continuous crop programs may include a forage–fodder or green manure crop so that non-selective weed control can be achieved.

In both the ley system and the continuous cropping system, a significant component of weed management may be achieved through crop competition, although the effectiveness will vary between environments.[8]

Triazine-tolerant canola

In 1999, TT canola accounted for almost 50% of the Australian crop, even though the varieties have a yield penalty relative to non-TT varieties. In most cases, TT canola is chosen because the weeds present cannot be controlled in the conventional varieties. In some situations, TT canola may be chosen as part of a strategy to control annual ryegrass resistant to Group A and Group B herbicides, in order to avoid repetitious use of trifluralin. In addition, the TT varieties were initially grown without an associated best management package, although this has now been rectified. All future herbicide-resistant crops will be introduced with a best management guide.

Some areas have a long history of triazine herbicide use, particularly in lupins. The widespread production of TT canola and use of triazines will certainly lead to an escalation in resistant populations of weeds, particularly annual ryegrass. There is already evidence of triazine resistance in wild radish.[9]

Imidazolinone-tolerant canola

The IT canola varieties offer some significant benefits, but there are important limitations. These varieties are marketed along with an imidazolinone herbicide mix, originally OnDuty®, but this has been replaced with Intervix®. This has a wide

7 S Sutherland. Canola Weed Management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

8 S Sutherland. Canola Weed Management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

9 S Sutherland. Canola weed management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

spectrum of activity and does not suffer from extended plant-back periods on acid soils. Unlike the TT varieties, the IT varieties carry no yield or oil penalties. The introduction of IT varieties has slightly reduced the area of TT canola, which will have herbicide-resistance management and environmental benefits.

Group B herbicides (as used in Intervix®) are 'high risk' in terms of the development of herbicide resistance. Group B herbicides (e.g. chlorsulfuron and triasulfuron) are already used frequently in cropping sequences. Therefore, producers will have to plan carefully how to fit the IT varieties without increasing the frequency of Group B herbicide use. The providers of IT canola are developing best management packages that will help greatly in this regard. The Group B resistance problem is so severe already in some areas (particularly in WA) that the IT varieties may have limited, if any, scope for use. [10]

LibertyLink® canola

LibertyLink® varieties are currently being developed for the Australian market. Presently, there are problems with the efficacy of glufosinate ammonium during the cool growing season, particularly on wild radish and annual ryegrass. This may limit the widespread application of LibertyLink® canola in some areas of southern Australia.

However, when Liberty Link® is combined into hybrids, the additional seedling vigour may enhance competition with weeds. [11]

Roundup Ready® canola

Roundup Ready® canola is available to West Australian producers.

Roundup has a wide spectrum of activity on weeds, has no soil residual problems (in the great majority of situations), and belongs to a low-risk group in terms of herbicide resistance. Given these factors, Roundup Ready® canola was released to offer producers a significant alternative to other varieties, herbicide-resistant or otherwise. The use of Roundup Ready® canola has led to further reductions in the area of TT canola, which may help with management of triazine-resistant weeds and the environment.

A problem that the industry is dealing with is the increasing number of documented cases of glyphosate resistance in annual ryegrass. If glyphosate is the only herbicide used in Roundup Ready® canola, these biotypes will survive unless some other intervention is used, such as cultural methods (weed seed collection and destruction), alternative knockdown and IBS herbicides prior to sowing, cultivation at or prior to planting. There is some level of resistance to all current Group A herbicide options.

[10] S Sutherland. Canola weed management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

[11] S Sutherland. Canola weed management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

Best management packages will need to include recommendations for minimising the risk of increased selection for the glyphosate-resistant biotypes. [12]

6.2.6 Future directions

Canola is set to remain a popular crop in Australia providing grain prices remain satisfactory, blackleg is controlled with varietal tolerance and sclerotinia is managed. However, herbicide resistance in weeds may force producers into less intensive rotations in order to manage seedbanks of resistant weeds.

Weed resistance is likely to restrict the useful life of the IT and TT varieties. This is particularly the case with the IT varieties because the associated herbicides are high-risk for resistance development, and because widespread resistance to these herbicides already exists. [13]

6.3 Herbicide damage

6.3.1 Clethodim

Application of clethodim at the maximum label rate of product as defined for some states (i.e. 500 mL/ha of Select®, which contains 240 g clethodim/L) has been reported to cause the following symptoms in canola:

- delayed flowering
- distorted flower buds
- possible yield suppression

Note that for canola in WA, 250 mL/ha is the maximum label rate for Select®. For Select® Xtra, with 360 g clethodim/L, the maximum label rate for canola in all states is 330 mL/ha.

Recent research in the central west of New South Wales by the Grain Orana Alliance (GOA) had resulted in variable results. Overall damage seemed to be light, and it was difficult to ascertain whether some damage was attributable to frost or to other abnormal conditions. Yield effects were negligible for most sites.

There may be varietal differences in crop damage, although little is known in this regard. However, farmers can control the timing and rate of herbicide application. Spraying earlier may avoid moisture stress issues, particularly in seasons when rainfall is light. Spraying early means late-emerging grass weeds will not be controlled with in-crop sprays but these plants are likely to be suppressed by a rapidly closing canola

12 S Sutherland. Canola weed management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

13 S. Sutherland, Canola Weed Management. Department of Agriculture and Food Western Australia, http://www.australianoilseeds.com/__data/assets/pdf_file/0012/2712/Chapter_12_-_Canola_Weed_Management.pdf

canopy. Seed production from these weeds could still be managed with non-chemical options such as windrow burning. [14]

Clethodim resistance in annual ryegrass is increasing. In the past, this was managed by increasing the rate of clethodim. However, populations of annual ryegrass now exist that are resistant to clethodim at 500 mL/ha, and some will survive when treated with 2 L/ha.

No new post-emergent grass herbicides for canola are in the pipeline, so pre-emergent herbicides will have a greater role in managing ryegrass post-emergence. The ability of some currently registered and potential products for controlling annual ryegrass in canola was assessed in 2012 at Roseworthy, South Australia (Table 4). None of the pre-emergent herbicides was particularly efficacious against clethodim-resistant annual ryegrass and none was better than using clethodim. Currently, the mix of clethodim plus butroxydim (Factor®) applied after a pre-emergent herbicide offers the best control, despite continuing to select for clethodim resistance. [15] N.B. The mix does not consistently offer better grass control, only on selected sites.

More information

GRDC Update Papers: Maintaining the best options with herbicides

GRDC Update Papers: Options for using more residual herbicides in northern no-till systems

GRDC Update Papers: Herbicides and weeds regional issues trials and developments

GRDC Ground Cover: Revisiting canola management can lift returns

Table 4: Control of clethodim-resistant annual ryegrass in canola at Roseworthy, South Australia, 2012

IBS, Incorporated by sowing; POST, post-emergence (applied 8 weeks after sowing); CT, crop-topped. Within a column, means followed by the same letter are not significantly different at P = 0.05

Herbicide program	Annual ryegrass plants 8 weeks after sowing (no. per m^2)	Annual ryegrass spikes at harvest (no. per m^2)	Crop yield (t/ha)
1.5 kg/ha of atrazine IBS + 500 mL/ha of Select® POST	387ab	149cd	1.34a
1.5 kg/ha of atrazine IBS + 250 mL/ha of Select® POST	262b	306c	1.13a
1.5 kg/ha of atrazine IBS + 500 mL/ha of Select® + 80 g/ha of Factor® POST	333b	92d	1.37a
Group K IBS	498a	1105a	0.46d
Group K + 2.0 L/ha of Avadex® Xtra IBS	298b	775b	0.76c
Group K + 2.0 L/ha of Avadex® Xtra IBS	235b	260cd	0.88bc
Group K + 250 mL/ha of Dual Gold® IBS	350ab	802b	0.50cd
Group D IBS	108c	149cd	1.11ab

See the Crop Care Factor technical manual at http://m.cropcare.com.au/assets/2016/1/BRFactor-2015TechnicalManual.pdf for details on how to reduce the risk of butroxydim damage in canola.

For more information on weed management in winter crops, see the *GrowNotes* Wheat (Western Region). Section 6. Weed control.

14 T Cook, G Brooke, M Widderick, M Street (2014) Herbicides and weeds regional issues trials and developments. GRDC Update Papers, 6 March2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Herbicides-and-weeds-regional-issues-trials-and-developments

15 C Preston, P Boutsalis, S Kleeman, RK Saini, G Gill (2013) Maintaining the best options with herbicides. GRDC Update Papers, 28 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/08/Maintaining-the-best-options-with-herbicides

SECTION 7

Insect control

Pests that can pose a problem in canola in Western Australia include blue oat mites (*Penthaleus* spp.), redlegged earth mites (RLEM) (*Halotydeus destructor*), cutworms, diamondback moth, *Helicoverpa*, aphids, Rutherglen bugs, slugs, snails, European earwigs, lucerne flea and wire worms.

7.1 Seed dressings

More information

Canola Diagnostic Tool

Emerging insect pests

'Serial pests' wrap-up—lessons from 2014 and 2015 and some research updates

Insect pests of canola

The seed dressing Gaucho® (imidacloprid) protects emerging seedlings from low numbers of RLEM, blue oat mite and aphids for ~3–4 weeks after sowing. Another seed dressing, Cosmos® (fipronil) protects seedlings from low numbers of RLEM.

Viruses can also occur in canola, carried by aphids that suck sap from leaves, transferring the virus and causing yield loss and sometimes plant death. Protection against early aphid infestation in seedling canola may reduce the incidence of virus in the crop.

Gaucho® (imidacloprid), Poncho Plus® and Cruiser Opti® are seed dressings registered for early season protection from aphids in emerging canola. Sowing canola into standing cereal stubble may help to reduce aphid numbers and hence virus infection. [1]

7.2 Integrated pest management

Pests are best managed using an integrated pest management (IPM) approach. Careful planning prior to sowing, followed by regular monitoring of crops after sowing, will ensure that potential problems are identified and, if necessary, treated early. Monitoring may involve techniques and aids such as sweep nets, a beat sheet or visual assessment.

Integrated pest management uses a range of control tactics to keep pest numbers below the level where they cause economic damage. It is primarily based on biological control of pests, by either encouraging natural enemies or release of biocontrols.

Other methods of control support these biological controls and can include:

- cultural methods such as farm hygiene, weed control, strategic cultivation (pupae busting), physical barriers, quarantine areas, different planting times, crop

[1] L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

rotations, trap crops, use of attractants for beneficials or repellants for pests, and keeping plants healthy so they resist attack

- host-plant resistance such as genetically resistant varieties or physical features that repel pests
- genetic control measures such as release of sterile male insects
- pheromones to confuse mating or aggregation
- use of microbial pesticides such as *Bacillus thuringiensis* (Bt), nuclear polyhedrosis virus (NPV) or *Metarhizium*.
- manipulation of micro-environmental conditions (e.g. planting density, row spacing, row orientation) to make them less suitable for pests or more suitable for beneficials
- use of chemicals as a last resort
- use of 'soft' chemicals or pest-specific chemicals in preference to broad-spectrum pesticides (especially early in the growing season when it is important to preserve beneficials)

Integrated pest management relies on monitoring the crop regularly, having pests and beneficial insects correctly identified and strategic control decisions made according to established damage thresholds. [2]

7.2.1 Area-wide management

Area-wide management (AWM) is IPM that operates over a broad region and attacks the pest when and where it is ecologically weakest, without regard to economic thresholds. It is a system currently used in managing resistance in *Helicoverpa armigera* in cotton. AWM coordinates farmers in implementing management strategies on their own farms to control local populations of *H. armigera* and prevent numbers building up later in the season. AWM strategies involve a detailed understanding of the biology and life cycle of the pest and of how the pest moves around in a region. Strategies can include coordinated timing of operations such as pupae busting, sowing and destroying of trap crops, and spraying of certain chemical types including 'soft' or biological insecticides. [3]

7.2.2 Biological control

Biological control can be defined as the use of natural enemies to control pest outbreaks. The pest is not usually eradicated, but brought down to levels where it does not cause economic damage. Success with biological control has been varied in many situations. Complete success, where the pests do not exceed the economic thresholds, has occurred in only 19% of cases. Many releases of biocontrol agents have had no significant effect. Success has been more common in long-term agro-ecosystems such as orchards and forests, where pest and natural enemy populations

[2] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

[3] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

are more stable. In annual cropping systems, maintaining resources that favour the buildup of natural enemies, for example greater biodiversity of plants, retaining stubble and groundcover and limiting use of broad-spectrum insecticides, will help to keep pests in check. [4]

Types of biological control

- Natural. An existing control agent is encouraged to control pests. This means avoiding the use of chemicals that may destroy these control agents.
- Single release (classical). The control agent is released with the aim of establishing it as a permanent part of the ecosystem. This is usually carried out for introduced pests.
- Multiple release. The control agent is not usually perfectly adapted to the environment (e.g. drought- or frost-intolerant) and so needs to be re-released. This may occur as a 'top-up' after unfavourable conditions, as a regular seasonal release, or as an inundative release where the control agent does not survive well. In this case, the agent is used as a 'living insecticide' that is released in large numbers to reduce pest numbers before it dies.

Biological control agents for insect pests can include:

- Predators. These actively capture their prey. Beetles, lacewings, bugs, flies, spiders and vertebrates are predators.
- Parasitoids. These are host-specific and need only one host to complete their life cycle. They lay eggs in their host and emerge after using the host as a food source. The host is nearly always killed. Parasitoids differ from parasites, which will coexist with the host. Parasitoids include wasps (e.g. the parasitic wasp, which will lay eggs inside lucerne aphids, white cabbage moth caterpillars and scarab larvae) and flies such as the tachinid fly.
- Pathogens. These include bacteria, viruses, fungi, protozoa and nematodes. A few of these organisms can enter and multiply rapidly within the host, e.g. *Metarhizium*, Bt, NPV.

Parasitoid and pathogen control agents are usually more successful than predators because they are more host-specific.

Trichogramma wasps

Trichogramma pretiosum wasps prey on the eggs of *Helicoverpa* spp., loopers, cabbage moths and others, and are suitable for use in minimally sprayed field crops, maize and vegetables, and for *Helicoverpa* in fruit crops. They are <0.5 mm in size and lay their eggs into moth eggs. The wasp larvae develop into a fully formed wasp inside the moth egg, in the process killing the developing caterpillar. *Trichogramma*

[4] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

are supplied as parasitised moth eggs in capsules. These are distributed around the crop and can be applied with water. [5]

Nuclear polyhedrosis virus (NPV)

Insect viruses are naturally occurring, insect-specific pathogens that have been part of the environment for millions of years and play an important role in the natural control of insect populations. Insects consume the virus from the leaves. The virus then moves through the gut wall and invades the body of the insect, causing the insect to stop feeding and die within 5 days because of the breakdown of its internal organs. The body ruptures after death, releasing virus particles that infect other caterpillars. Gemstar® and Vivus Gold® are commercial products that control *Helicoverpa punctigera* and *H. armigera* in cotton and selected crops, with a liquid concentration of virus particles. Typically, they provide 60–90% control of larvae. Both products fit best within an IPM program that uses natural enemies such as ladybeetles and parasites, but can be alternated with synthetic insecticides. As a biological insecticide, efficacy is dependent on environmental conditions for good performance. It needs to be ingested; therefore, coverage of the target area is essential. [6]

Bacillus thuringiensis

The Bt bacteria produce proteins that are characterised by their potency and specificity to certain species, most of which are agronomically important pests. Mixtures of protein crystals and spores have been sprayed in the same way as a chemical pesticide for many years in horticultural industries, but with variable success in broadacre field crops. The caterpillar ingests the protein, which then attacks the gut wall, causing holes, and the insect stops feeding. The bacterial spores contained in the protein then leak through the gut wall and cause bacterial infection. The insect will die, either from this bacterial infection or from starvation. This is the process that makes the Bt protein highly specific and environmentally desirable. Insertion of the Bt gene into cotton plants has taken many years to develop, and breeding is ongoing of plants that express higher levels of the Bt toxin. Resistance to Bt is being carefully monitored and controlled with the development of management programs and new research on multiple insect-resistance genes. Novel strains of Bt are being isolated for a wide range of pest families, including beetles, flies and locusts. [7]

More information

GRDC Fact Sheet— Integrated Pest Management (National)

[5] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

[6] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

[7] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

7.3 Earth mites

Earth mites are the major pests of seedling canola. Damage can be caused by RLEM, *Bryobia* mites, *Baluastium* mites and blue oat mites, which often occur in mixed populations. *Bryobia* and *Balaustium* mites are an increasing problem in some areas. A good mite-control program starts with a population reduction treatment the previous spring (Table 1). Learn to identify these three species of mites to ensure that the correct insecticide and rate is applied to the correct species.

Bare earth treatments. Germinating and establishing crops can be protected by:

- boom spraying the soil surface of previous pasture or high-risk paddocks with a residual insecticide immediately after sowing
- perimeter-spraying bare ground in low-risk paddocks, not forgetting to spray around trees, rocky outcrops and dams, and along water flow-lines

If you are unsure of the level of risk from mites, spray the whole paddock. Three bare-earth sprays are registered that will give several weeks of residual protection. Bifenthrin is registered for RLEM, blue oat mite and *Bryobia* mites, but application rates vary according to the mite species being targeted. Alpha-cypermethrin will control RLEM, whereas methidathion is registered for both RLEM and blue oat mite.

Seed dressings. Imidacloprid (e.g. Gaucho®) and Poncho® Plus (clothianidin + imidacloprid) are registered for use on canola seed for protection against RLEM, blue oat mite and aphids. Poncho® Plus is also registered to control lucerne flea, wireworm and cutworm. A third seed dressing, Cruiser® Opti (thiamethoxam + lambda-cyhalothrin) is registered for suppression of RLEM and lucerne flea. These seed dressings will protect emerging seedlings for 3–5 weeks after sowing. Use treated seed following a pasture phase if a well-timed spring spray of insecticide has been applied. Apply a bare-earth border spray where untreated pastures border the canola crop. Seed companies can supply seed pre-treated with imidacloprid, Poncho® Plus and Cruiser® Opti. Cosmos® Insecticidal Seed Treatment (fipronil) is also registered for control of RLEM in canola.

Even where a seed-dressing or bare-earth treatment has been used, it is advisable to check seedling canola regularly for mite damage as the seed dressings are not enough to deal with medium to high pressure situations. [8]

Redlegged earth mite and blue oat mite (*P. major*) are two soil-dwelling mites that damage crops in autumn, winter and spring. They are primarily pests of seedlings but can also seriously injure older plants. Winter crops at establishment may be severely damaged, particularly if growth during and following emergence is slow. Damaged plants die or remain stunted and weak. Sometimes seedlings are killed before they emerge. Both mite species prefer light, sandy, gravelly sand or loamy, well-drained soils. [9]

More information

Nutrient management may double as pest control

DAFWA: Pests, mites and spiders

[8] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[9] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

Table 1: Recommended control strategies for earth mites [10]

Pre-season (previous spring–summer)
Assess risk High-risk situations: History of high mite pressure Pasture going into crop Susceptible crop being planted (e.g. canola, pasture, lucerne) Seasonal forecast is for dry or cool, wet conditions that slow crop growth Actions if risk is high: Ensure accurate identification of species Use Timerite® (redlegged earth mites only) Heavily graze pastures in early-mid spring
Pre-sowing
Actions if risk is high: Use an insecticide seed dressing on susceptible crops Plan to monitor more frequently until crop established Use higher sowing rate to compensate for seedling loss Consider scheduling a post-emergent insecticide treatment Actions if risk is low: Avoid insecticide seed dressings (esp. cereal and pulse crops) Plan to monitor until crop establishment
Emergence
Monitor susceptible crops through to establishment using direct visual searches Be aware of edge effects; mites move in from weeds around paddock edges Actions if spraying: Ensure accurate identification of species before deciding on chemical Consider border sprays Spray prior to the production of winter eggs to suppress populations and reduce risk in the following season Follow threshold guidelines
Crop establishment
As the crop grows, it becomes less susceptible unless growth is slowed by dry or cool, wet conditions

Feeding

Mites feed by rasping the surface of the cotyledons and leaves and by sucking up the sap. Feeding is normally from late afternoon until early morning, but continues through the day in calm, cloudy weather. Mites are very active and, if disturbed on a plant, will drop or descend to the ground and disperse to find shelter. RLEM usually remain clustered together on the soil or on parts of the leaves during the day. Blue oat mites generally hide by day in the soil beneath damaged plants or under plant debris on the ground. [11]

[10] P Umina (2014) Persistent pests; aphids, mites, millipedes and earwigs. GRDC Update Papers, 5 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Persistent-pests-aphids-mites-millipedes-and-earwigs

[11] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

More information

[Ground Cover: Redlegged earth mites challenge WA growers]

[IPM Guidelines for Grains: Earth mites]

[DAFWA: Diagnosing redlegged earth mite]

[eXtensionaus: Resistant RLEM status update WA]

[Agriculture Victoria: Redlegged earth mite]

[Cesar Australia: Redlegged earth mite]

[Insect pests of canola]

[DAFWA: Prevent redlegged earth mite resistance]

More information

[Persistent pests; aphids, mites, millipedes and earwigs]

More information

[TIMERITE® information package]

7.3.1 Redlegged earth mite

The RLEM is native to southern Africa, and cape weed is its preferred host plant. Other hosts include prickly paddy melon, wild turnip, common sowthistle, Paterson's curse and chickweed (weeds); and canola, lupins, field peas and linseed (field crops). Sometimes mites may move into young winter cereals from a fenceline or adjoining pasture and cause damage along one or more of the crop edges.

Description

Adult mites are eight-legged and ~1 mm long with oval, flattened black bodies and pinkish-orange legs and mouthparts.

Seasonal development

Three overlapping generations usually occur between mid-autumn and spring, and adult populations are normally highest in May–June and September–October. RLEM survive over summer as unlaid, aestivating eggs in the dead bodies of spring-generation adult mites lying on or near the soil surface. The aestivating eggs are highly resistant to desiccation and usually do not begin to develop until late summer–early autumn. They hatch when favourable conditions of soil temperature and moisture occur in the following mid-autumn to early winter.

TIMERITE® for management of redlegged earth mite

TIMERITE® is an information package that provides individual farmers with the optimum spray date for controlling RLEM during spring on their farm. Developed by CSIRO and Australian Wool Innovation, TIMERITE® predicts the optimum date in spring to control RLEM, just after they have ceased laying normal winter eggs on pasture and just before diapause. (Diapause is when adults produce eggs that are retained in the body of the adult female and are therefore protected from the effects of insecticide applications.) The single, strategic spray has a two-fold effect, controlling RLEM in spring and decreasing the summer population that emerges in the following autumn. The package may form part of an integrated management strategy to control this pest.

Close attention should be paid to individual pesticide labels when controlling earth mites. Application rates vary with situations, such as bare earth or post-crop or pasture emergence. Correct identification of earth mite species is essential. Registrations sometimes include RLEM only, not blue oat mites or *Bryobia* mites. Application rates may vary with earth mite species. READ THE LABEL.

This strategic approach has little effect on non-target invertebrates, both pest and beneficial, during the following autumn. Growers need to identify geographically the location to be sprayed. This can be done by a local feature, such as town or mountain, or the longitude and latitude of the area. This information is used to find the optimum date from the package. The spray date for each farm is the same date each year. For information, phone Australian Wool Innovation toll free on 1800 070 099 or visit the website www.wool.com/woolgrower-tools/timerite/. [12]

[12] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

Preventing RLEM resistance to insecticides

Western Australia is the only state to have RLEM that are resistant to the synthetic pyrethroid (SP) insecticides. Resistant RLEM populations are likely to be present in more localities in Western Australia and elsewhere in southern Australia, especially in paddocks that have a history of repeated SP applications (Figure 1).

Figure 1: Redlegged earth mites infest seedlings. (Photo: DAFWA)

How does resistance occur?

Repeated use of SP insecticides within seasons and between seasons selects for RLEM resistance to this chemical group. All SPs have the same molecular mode of action; therefore, once RLEM develop resistance to one insecticide, they are resistant to all insecticides in this chemical group (Group 3A).

The repeated cumulative exposure of RLEM to SPs is the main factor behind resistance developing. If SP insecticide is used against pests such as weevils or aphids, RLEM may also receive a dose of the chemical, even though they are not the direct target.

Chemical control options

Growers with resistant RLEM have been able to control these mites by using insecticides from the organophosphate (OP) group (Group 1B), e.g. dimethoate or omethoate. However, residual populations of SP-resistant RLEM were found on weeds along fencelines and in re-infested paddocks and WA now has a confirmed RLEM population resistant to omethoate.

How long does resistance last?

Insecticide resistance in RLEM is inherited and mechanisms to switch it off have not been found. RLEM at one site have been tested each year for 4 years and are still resistant to SPs, even without further SP application. This indicates that resistance, once established, is likely to persist in RLEM populations over many years. We need to prevent further development of resistance by decreasing overall use of SPs.

Spread of resistance

Locations of resistance within the south of Western Australia are geographically distinct, suggesting that resistance develops in isolated RLEM populations within each property. Resistant RLEM have been found on properties near Esperance, Cranbrook, South Stirlings, Tenterden and Boyup Brook, making it unlikely that resistant RLEM have spread between locations. However, resistant RLEM can move into adjacent paddocks from weeds on fencelines.

Managing resistance

Identify your mites

Redlegged earth mites are often found with other mites, such as blue oat mite, *Bryobia* (clover) mite or *Balaustium* mite; however, resistance has been found only in RLEM. In situations where spray failures have occurred, it is important to identify the mite correctly. Blue oat mites are controlled by all chemicals registered for RLEM control, whereas chemical controls for *Bryobia* mite and *Balaustium* mites differ.

Plan ahead to reduce mite numbers

If you prepare paddocks in the preceding season, there will be lower numbers of pests on your crops. Consider the following strategies to reduce pest numbers:

- Control weeds in the crop and along fencelines. Weeds provide habitat for mites. Controlling weeds with herbicides, cultivation or heavy grazing will decrease mite numbers. A weed-free crop will have few mites and oversummering eggs to carry through to the following season.
- Controlled grazing of pasture paddocks in the year prior to a cropping year will reduce RLEM numbers to levels similar to chemical sprays. Sustained grazing of pastures throughout spring to maintain feed on offer levels below 2 t/ha (dry weight) will restrict mite numbers to low levels. Control RLEM in spring.
- Apply insecticides to some paddocks during spring to prevent RLEM populations producing oversummering eggs. This will decrease the pest population in the following autumn. Only specific paddocks should be selected for spring spraying based on levels of feed on offer, future grazing-management options, seed production requirements and intended paddock use next season. The routine spraying of all pasture paddocks in spring using TIMERITE® dates to prevent a buildup of mites is unlikely to be sustainable.
- Use cropping rotations to decrease reliance on pesticides. Some paddocks will have a higher or lower risk of RLEM damage depending on previous crop rotations. The risk is generally highest if paddocks have been in long-term pasture (with high levels of broadleaf plants) where mite populations have been uncontrolled. Lower risk paddocks that generally do not require mite control are those following a cereal or canola weed-free crop, where conditions are less favourable for mite increase.

What you can do this season

Spray only if you need to

Growers with populations of resistant RLEM have mostly used repeated applications of SP chemicals as 'insurance' sprays to minimise anticipated pest risks. To decrease the likelihood of resistance developing on your property, apply insecticides only on paddocks with damaging numbers of pests.

Where spraying is needed, rotate chemical groups

Rotate between SPs and OPs, within and between seasons; this will help to reduce resistance buildup. If spraying other pests such as aphids, try not to use SPs. Consider other chemical options such as pirimicarb.

Predict hatchings of RLEM on your property to target your control strategy

Knowing the approximate time when the first autumn hatchings of RLEM are occurring on your property will help to determine whether they will coincide with seedling crops. RLEM hatch in autumn from their oversummering egg stage after adequate rainfall and at least 7 days of average temperatures <20°C. Crops sown in seasons with 'early breaks' with maximum temperatures well above 20°C (e.g. canola sown in April) will not be damaged by RLEM.

Use insecticide seed treatments

Use insecticide seed treatments for crops and sown pastures with moderate pest pressure rather than spraying whole paddocks. Seed treatments allow smaller quantities of pesticide to be used that directly target plant-feeding pests, allowing any predatory insects to continue their important beneficial role.

Do you suspect you have resistant RLEM?

If you have RLEM that survive registered rates of insecticide treatments or suspect that you have mites resistant to chemicals, contact the Department of Agriculture and Food, Western Australia's (DAFWA) broadacre entomologists. Arrangements can be made to have mites sampled and tested for their level of resistance. [13]

7.3.2 Blue oat mite

Blue oat mites are often confused with RLEM. There are four recognised species of blue oat mite in Australia: *Penthaleus major*, *P. falcatus*, *P. minor* and *P. tectus*. Accurate identification of the species requires examination by an entomologist. The four species vary in their geographical distribution in Australia.

More information

DAFWA: Diagnosing blue oat mite

Crop mites. Back Pocket Guide

Damage to crops and pastures is incurred in the establishment phase. Host-plant preferences vary with the species, as do their life cycles and tolerances to various pesticides. Host plants include black thistle, chickweed, curled dock, dandelion, deadnettle, prickly lettuce, shepherds purse, variegated thistle and wild oat. Cultivated field-crop hosts include wheat, barley, oats, rye, canola, field peas, lupins and linseed.

Description

Adult mites have eight legs and are ~1 mm long with oval, rounded, dark brown to black bodies, bright red or pinkish red legs and mouthparts, and a red spot or streak towards the hind end of the back.

13 S Micic (2015) Prevent redlegged earth mite resistance. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mites-spiders/prevent-redlegged-earth-mite-resistance?page=0%2C2

Seasonal development

Overlapping generations of the blue oat mite usually occur between mid-autumn and late spring. Blue oat mites oversummer as aestivating eggs laid in mid–late spring by the second-generation adults. These aestivating eggs are highly resistant to desiccation. They do not begin to develop until late summer–early autumn and they do not hatch until favourable conditions of temperature and moisture occur in the following mid-autumn to early winter. [14]

7.4 Lucerne flea

Lucerne flea is an occasional pest of establishing canola crops. The pest is identified by its action of jumping and hopping between plants rather than flying. Early-sown crops are more at risk of attack. Frequent crop inspection from the time of emergence and early control measures are important because of the impact of seedling vigour on crop performance. Ensure that monitoring is sufficient to detect localised patches or 'hot spots'. Seek advice on management and spray strategies. [15]

7.5 Slugs

Slugs kill plants at the seedling and rosette stages and can leave large, bare-soil areas. Slugs are favoured by wet springs and summers, where abundant growth and damp conditions provide an ideal habitat. This allows slugs to breed and survive into autumn and winter, when they attack newly sown crops.

Canola sown into dense stubble or adjacent to grassy fencelines, creek banks or damp areas is at greatest risk because these areas provide an ideal habitat for slugs to survive over summer. Heavy, cracking soils provide additional hiding places for slugs. Closely monitor crops at risk for 6–8 weeks after sowing, so that any infestation can be treated with slug pellets containing metaldehyde, methiocarb or iron chelate. [16]

7.6 Diamondback moth

Diamondback moth (DBM) (Figure 2) has been observed in canola crops for many years in WA,. They have caused significant economic damage in years where late summer/early autumn rain is experienced and host plants such as wild radish and volunteer canola germinate early, allowing DBM larvae to build numbers as the canola crops are sown.

The larvae of DBM do most damage when large numbers are present in seedling crops or when they move from leaves to graze developing pods during crop ripening.

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14 K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

15 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

16 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Diamondback moth has developed resistance to a range of insecticides. Future management will involve regular monitoring and careful selection of control methods. [17]

Figure 2: Management of diamondback moth involves regular monitoring and careful selection of control methods. (Photo: GRDC)

More information

GRDC Fact Sheet: Diamondback Moth in Canola

DAFWA: Diagnosing Diamondback Moth

FAQ 7.7 Aphids

Aphids are common pests of canola in Western Australia. They suck sap from plants and can be found massed on growing points or lower leaves of canola, depending on the aphid species. During growing seasons preceded by above-average rainfall in March and April, aphids can arrive in crops in large numbers early in the season. Cold weather and heavy rainfall during the growing season can help to suppress aphid numbers. [18]

7.7.1 Description

Three aphid species commonly attack canola in Western Australia:

- turnip aphid (Figure 3)

[17] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[18] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

- cabbage aphid (Figure 4)
- green peach aphid (Figure 5)

The three species are described in Table 2.

Figure 3: Turnip aphids on canola flowering spike. (Photo: DAFWA)

Figure 4: Cabbage aphids on canola flowering spike. (Photo: DAFWA)

Figure 5: Green peach aphids on underside of canola leaf. (Photo: DAFWA)

Table 2: Distinguishing features of the three species of aphids found attacking canola in Western Australia [19]

	Turnip aphid	Cabbage aphid	Green peach aphid
Length of adult (mm)	1.4–2.4	1.6–2.8	1.2–2.3
Abdomen colour	Greyish to mid green	Greyish to mid green	Shiny yellow to mid green to pink or red
Other features	Body often has a light waxy covering, dark bars on abdomen	Body covered with a dense white mealy wax	Black patch on abdomen of winged adults. Wingless forms uniform in colour
Colony habit	Dense colonies, usually around growing tips and flowering spikes	Dense colonies usually seen on flowering spikes	Mostly found on the underside of lower leaves. Sparse colonies may occur with turnip or cabbage aphids
Abundance on canola	Usually common and abundant; depending on season	Common and abundant on canola	Common but seldom builds up to large colonies
Alternative hosts	Wild radish, wild turnip and self-sown canola	Wild radish, wild turnip and self-sown canola	Wild radish, wild turnip, and self-sown canola, lupins, cape weed

7.7.2 How crop infestations start

Winged aphids fly into the crop from autumn weeds. Winged aphids that migrate to the crop give rise to colonies consisting mostly of wingless aphids. Aphids that arrive in crops in autumn and persist in low numbers over winter may lead to large, damaging populations that peak in late winter and early spring.

Cold and wet conditions during winter tend to suppress aphid populations. Turnip and cabbage aphids are rarely seen together on the same plant, but both form

[19] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

characteristically dense clusters on the terminal flowering spikes and are generally the most damaging and common species encountered in Western Australian crops.

Careful monitoring for crop pests will often reveal aphids hidden on stems amongst the buds and flowering heads of canola. The green peach aphid is often found in seedling crops; on established crops, it prefers to feed on the undersides of older canola leaves, where it causes little or no damage. [20]

7.7.3 Feeding damage

Large populations of aphids that may develop in late winter and early spring cause damage by feeding on the growing shoot tips, causing wilting, flower abortion and reduced podset.

If aphid populations are very large, the sticky honeydew that they exudate can lead to a black mould growth. This mould rarely occurs in canola crops, but if present, it can reduce the ability of plants to photosynthesise and decrease plant vigour. [21]

7.7.4 Results of feeding-damage trials

Significant yield losses of up to 33% were recorded in Western Australia in a replicated field trial in 2003. Growing canola in low-rainfall areas where drought stress is more likely, coupled with the release of cultivars more susceptible to aphid colonisation, has increased the risk of aphid feeding damage and yield losses to canola in these areas.

Furthermore, aphid populations develop more rapidly on plants suffering from moderate drought stress than on healthy, stress-free plants. The stressed plants being targeted by aphids are less able to compensate for aphid feeding damage than healthy plants. [22]

7.7.5 Yield loss from viruses

Aphids can also transmit virus diseases in canola crops; the most common virus is *Beet western yellows virus* (BWYV). BWYV is persistently transmitted by aphids, and green peach aphids are the most important vector.

Most yield loss occurs when aphids transfer the virus very early in the life of the crop, which can lead to stunting and obvious reddening of plants. Studies by Department of Agriculture and Food WA Plant Virologists on the relationship between virus infection

[20] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[21] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[22] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

and yield losses in canola have shown that a combination of BWYV and green peach aphids can cause yield losses of up to 50% in canola.[23]

7.7.6 Monitoring for aphids

Canola is most sensitive to aphid damage from bud formation through to late flowering. Crops at this stage should be checked regularly for aphids in case numbers escalate to the extent that they cause economic damage to the crop. Start monitoring from late winter and continue through spring.

Aphid distribution can be patchy. Check at least five points of the paddock and look for aphids on at least 20 plants at each point. Check plants and count the number of flowering spikes infested with aphids.[24]

7.7.7 Look for the beneficials

Beneficials include predators such as ladybirds, hoverflies (Figures 6 and 7) and lacewing (Figures 8 and 9), and parasitic wasps. These are a common form of aphid control during the warmer days of spring and when low to moderate numbers of aphids are present, but they have less impact on heavy infestations of aphids.[25]

Figure 6: Hoverfly larva eating an aphid. Hoverfly adults are more likely to be seen in crops. (Photo: DAFWA)

[23] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[24] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[25] S Micic, P Mangano (2015) Aphid management in canola crops, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

Figure 7: Hoverfly adults are more likely to be seen in crops. (Photo: DAFWA)

Figure 8: A lacewing larva feeding on aphids. (Photo: DAFWA)

Figure 9: Brown lacewing adult. (Photo: DAFWA)

7.7.8 What parasitic wasps look like

Parasitic wasp species sting the aphid and lay an egg inside. The larva hatches and slowly consumes the aphid, eventually killing it. The parasite larva creates a 'mummy' by spinning a cocoon inside the aphid, then pupates and soon emerges as an adult wasp. The presence of bloated aphids with a pale gold or bronze sheen indicates parasite activity in the canola crop (Figure 10). [26]

Figure 10: Parasitised aphids are bronze in colour. (Photo: DAFWA)

7.7.9 Threshold for aphids

If >20% of plants are infested with colonies of aphids, control measures should be considered to avoid yield losses. Factors that increase the risk of economic yield losses are poor finishing rains or crops already under some degree of drought stress. [27]

7.7.10 Encourage beneficials

Predators and parasites should be encouraged as a natural way of suppressing aphid numbers. This can be achieved by using 'softer' chemicals (such as pirimicarb), which are aphid-specific and less harmful to other insects. [28]

26 S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

27 S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

28 S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

7.7.11 Cultural controls

Implement early control of weeds such as wild radish and wild turnip on your property to prevent aphid buildup. Sow crops early to enable plants to begin flowering before aphid numbers peak. [29]

7.7.12 Chemical control

Pirimicarb and Sulfoxaflor (Transform®) are currently registered for aphid control in canola crops in this state. Check with your local Department of Agriculture and Food office or the Australian Pesticides and Veterinary Medicines Authority for any off-label permits each growing season. [30]

7.7.13 Green peach aphids and resistance

Green peach aphid has developed resistance to the SP, carbamate and OP groups of insecticides. Transform™ (sulfoxaflor) is a new selective insecticide for control of early-season infestations of green peach aphid. [31]

Aphids can infest crops in the spring, especially in years of moisture stress. Large populations of aphids are more evident and potentially damaging in dry seasons. Monitoring for beneficial insects is important, because control may not be justified in some cases. If control is warranted, careful selection of an insecticide is essential to ensure that damage is not caused to nearby beehives or to beneficial insects within the crop. Ensure that the harvest-withholding period (WHP) of the insecticide is adhered to. Seek advice on thresholds and product registrations or permits before spraying. [32]

Large numbers of green peach aphids occasionally occur on young, vegetative canola. SPs and some OPs have given poor kill results when applied to aphid-infested canola. Often the crop needs to be re-sprayed after SP application, which achieves less-than-optimum kill rates. Avoid using SPs for this reason and because this chemical group selects for insecticide resistance and kills non-target organisms including beneficial insects. [33]

Aphid flights can occur in autumn and winter in some years and can infest young canola crops. Crops may need to be treated with insecticide to prevent transmission

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[29] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[30] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

[31] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[32] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[33] S Micic, P Mangano (2015) Aphid management in canola crops. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/aphid-management-canola-crops?page=0%2C2

More information

[Reducing aphid and virus risk]

[Resistance management strategy for the green peach aphid in Australian grains]

[Unified attack on pests and diseases]

[Insect pests—resistance, virus vectors and lessons from 2014]

[Crop aphids. Back Pocket Guide]

[Insect management in fababeans and canola recent research]

of virus diseases, and to reduce seedling damage and the risk of spring infestations. The green peach aphid is the major vector of *Beet western yellows virus*, which caused major crop damage in area of South Australia in 2014. Seed treated with imidacloprid (e.g. Gaucho®), Poncho® Plus or Cruiser® Opti can protect seedling canola for up to 5 weeks. This is especially important in seasons and at sites where early infestation with aphids occurs. [34]

7.8 Management of bronzed field beetle—a pest of canola in the south of Western Australia

The larvae of the bronzed field beetle (*Adelium brevicorne*) (Figure 11), known as false wireworm, chew stems of young canola plants at ground level, causing plant death and thinning of the crop or the destruction of large areas. Most of the damage occurs to seedlings, but larger plants may be damaged if there are enough large larvae.

Figure 11: Bronzed field beetle (Adelium brevicorne), known as false wireworm. (Photo: DAFWA)

Distribution

Larvae of bronzed field beetle cause economic damage to canola in Western Australia and South Australia, but it is not considered a serious pest in Victoria. In Western Australia, it is most abundant in the South Coast, Great Southern and Lakes areas. It is less prevalent in areas north of Perth and in the eastern wheatbelt.

In South Australia, this pest is most common on Lower Eyre Peninsula and in the Mid North and the South East.

Description

Adults are up to 11 mm long and are a shiny black with a slight bronze appearance in some light (Figure 12). Larvae are dark brown and grow to 12 mm long and 2–3 mm wide, with 12 body segments, the last one having two distinct upturned spines.

34 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Figure 12: Larva, pupa, new adult, and hardened bronzed field beetle adult. (Photo: DAFWA)

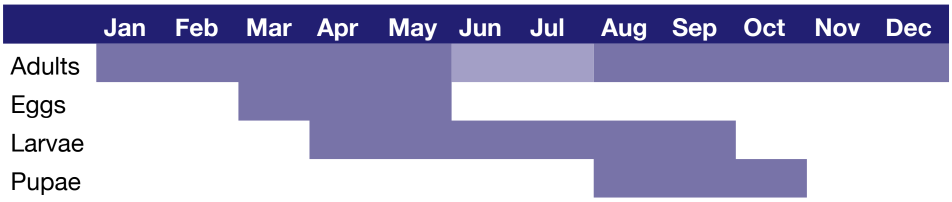
Lifecycle

Over summer and autumn, adults shelter in crop residue, and under wood, rocks or tufts of grass. They do not fly but become very active after autumn rains, when a large proportion of a female's body may be taken up with eggs.

Eggs hatch from late March, depending on soil moisture. When hatching occurs early, these larvae may reach a length of ≥5 mm before the crop is seeded. The larger the larval stage is at seeding, the more damage occurs.

In August, larvae begin changing to the pupal stage and new adults appear soon after. The duration of the life stages is shown in Figure 13.

Figure 13: Duration of lifecycle stages of the bronzed field beetle. (Source: DAFWA)



7.9 *Helicoverpa*

Helicoverpa originate in pastoral regions bordering agricultural areas. Moth flights are monitored from late winter through spring. Ten to 14 days after flights are observed there will be hatchings in susceptible crops. These will need to be monitored to determine if they need to be controlled.

Agronomist's view

Helicoverpa (also known as heliothis or Native Budworm) caterpillars are a regular pest of canola in WA, particularly in the Northern and South East coastal areas, which may require control measures if they are present in large numbers during canola pod fill. Because of the seasonal variation in incidence and timing of infestation relative to crop growth stage, growers should seek advice and check the harvest WHP of the chosen insecticide before deciding to spray.

Seasonal biology

There are generally three or four overlapping generations of caterpillars of the native budworm between September and May. [35]

Scout crops regularly

The amount of damage caused by native budworm and corn earworm varies considerably from year to year. Moth activity alone cannot be taken as a guide for spraying. In some years when moths are common, egg and caterpillar numbers are often limited by adverse cool or cold, wet weather, parasitoids, predators and diseases, and damage may be restricted or insignificant. In other years, a relatively small moth population may produce many caterpillars and cause significant damage. Periodic outbreaks of caterpillars of both species in summer are often associated with heavy rainfall. Check crops at least a week after heavy rainfall. Look for moths, eggs and very small caterpillars, and treat if necessary. Spraying thresholds are unlikely ever to be more than guidelines for timing sprays. Examine crops at least twice a week during the various danger periods.

Before deciding to spray, consider the following:

- likely extent and severity of the infestation
- ability of the crop to tolerate caterpillar damage without any significant loss or to replace leaves or fruiting parts lost to the caterpillars
- value or likely loss if the crop is left untreated
- cost of treatment [36]

7.9.1 Native budworm

Native budworm is widely distributed throughout mainland Australia and during winter breeds in semi-arid parts of Western Australia. The native budworm is indigenous to Australia and can develop large populations over extensive areas on native plants. These populations often migrate into agricultural regions in late winter and spring, causing damage to crops. Migratory flights are unpredictable, and moths may be carried hundreds of kilometres from breeding areas by high-altitude air currents. [37]

[35] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

[36] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

[37] DAFWA (2015) Management and economic thresholds for native budworm. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

7.9.2 Descriptions of eggs and caterpillars

Eggs

Newly laid eggs are white or yellowish white, dome-shaped, flattened at the base, ribbed and 0.5 mm in diameter. Not all eggs are fertile. Fertile and infertile eggs are laid at the same time, and sometimes all eggs laid are infertile. Fertile eggs change to greenish yellow with an irregular brown or reddish brown ring around the middle. Before hatching, the blackish head and grey body of the caterpillar shows through. They hatch in 3–5 days in warm weather and 6–16 days in cooler weather. Infertile eggs appear cylindrical within ~12 h of being laid and then shrivel to a pyramid shape.

Caterpillars

Newly hatched caterpillars are 1–1.5 mm long with dark heads and dark-spotted white bodies. Young caterpillars up to about 15 mm long have dark heads and pale yellow, greenish or brownish bodies with conspicuous upper body hairs in dark bases and, often, narrow dark stripes down the back and along each side. Older caterpillars up to 50 mm long vary greatly in colour from yellow to almost black, often have a broad pale stripe along each side, and their upper body hairs are usually on raised processes.

Egg laying

Egg laying is usually confined to the period from flower bud formation until flowering ends. When moths are exceptionally abundant, infestation can be expected before flowering commences. Eggs are laid, usually singly, on the upper parts of plants—vegetative or floral growing points, young tender leaves, stems and flower buds, flowers and fruits. The moths prefer the more advanced and succulent portions of crops for egg laying and usually avoid poorly grown areas. Eggs may not be obvious to the untrained eye because they are minute. However, moderate to heavy egg lays should be obvious to trained observers. [38]

7.10 Diagnosing weevils in canola

Weevils are beetles with long snouts and can damage or kill young seedlings. Species that damage canola include: the vegetable weevil, more common in high-rainfall areas and often next to trees or bush; *Desiantha* weevil (also known as spotted vegetable weevil), which is widespread; and small lucerne weevil and Fuller's rose weevil, which mainly occur on the south coast of Western Australia (Figure 14).

[38] K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

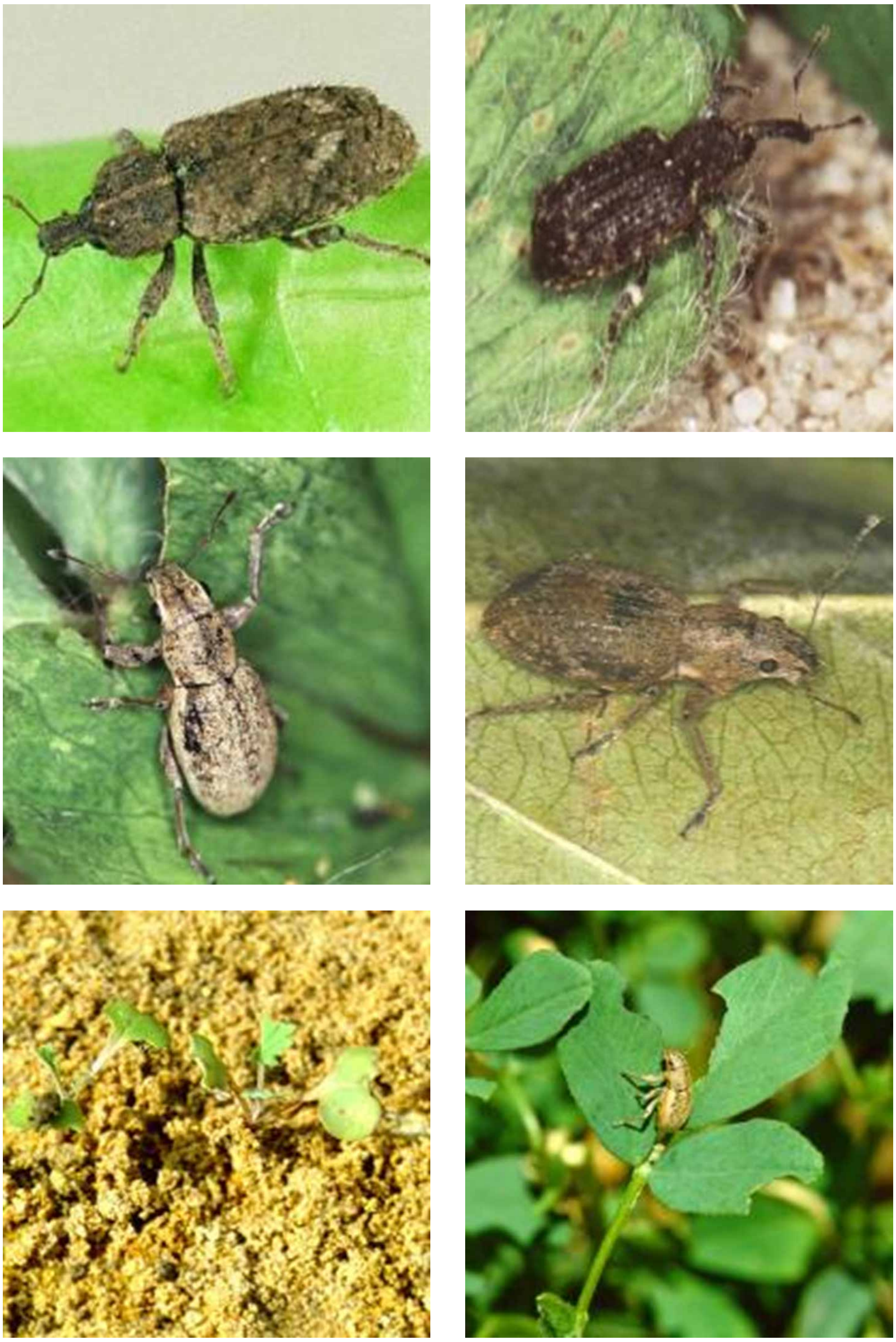


Figure 14: Weevils infesting canola in Western Australia. (Photos: DAFWA)

7.10.1 What to look for

In the paddock:

- Areas of chewed and lopped canola seedlings will be visible.
- Damage from vegetable weevil is usually worst next to paddock edges and bush areas, or in parts of the paddock that had cape weed in the previous year.

On the plant:

- Seedling leaves, petioles and stems will be chewed.
- Stems may be severed, causing rapid death.
- Leaves have crescent-shaped pieces removed, giving them a serrated appearance.

Adult insects:

- Weevils are generally grey and often hard to find.
- Vegetable weevil is about 10 mm long with two short white stripes at an angle on each side of its abdomen.
- *Desiantha* weevil is about 5 mm long, dark-coloured and sometimes has grey flecks on its back.
- Small lucerne weevil is about 5 mm long, light grey in colour, with a white stripe on each side.
- Fuller's rose weevil is about 8–10 mm long but has yellow stripes on its side and back.

7.10.2 What else could it be?

Other pests that might be mistaken for weevils are presented in Table 3.

Table 3: Similarities/differences between other pests and weevils (source: DAFWA)

<table>
<tr><th>Condition</th><th>Similarities</th><th>Differences</th></tr>
<tr><td>Vegetable beetle damage</td><td>Chew stem, petiole, leaves and sever the seedling stem</td><td rowspan="2">Weevils can cause scalloped leaf damage and have characteristic long snouts. They are usually found in the vicinity of the damage</td></tr>
<tr><td>Cutworm in canola and pulses</td><td>Chew stem, petiole, leaves and sever the seedling stem</td></tr>
<tr><td>False wireworm</td><td>Stem ringbarked, sudden plant death</td><td>Weevils also chew leaves and petioles, weevils hidden nearby</td></tr>
</table>

7.10.3 Where did it come from?

With the exception of the vegetable weevil, weevils are flightless and remain in the paddock during their life cycle. Adults eat canola and a range of broadleaf weeds, particularly cape weed. Adults emerge from the soil in spring–early summer and survive by hiding in soil litter, and under stones, plants or clods. Eggs are laid into the surface of the soil and hatch when there is sufficient moisture for plant germination. *Desiantha* larvae feed on grass, and cereal seedlings.

Vegetable weevils rarely fly but adults rest in the soil in bush or paddock edges during summer. They are attracted to any paddock that has cape weed present, and after cape weed germination, they move into the paddock to feed and lay eggs. In early winter, the eggs hatch into green larvae that feed on the plants on which they hatched. The adult weevils also move into the edges of canola paddocks to feed soon after crop emergence.

7.10.4 Management strategies

- An insecticide border spray at crop emergence will help to control vegetable weevil before it moves into the crop. Paddock boundaries should be checked every few days until the crop has four or five true leaves.
- *Desiantha*, small lucerne and Fuller's rose weevil are not controlled by border sprays because they tend not to migrate out of paddocks.
- Paddocks where *Desiantha* weevil larvae damaged cereals in the year before will have *Desiantha* weevil adults present in the current year.
- Weevil numbers in crop can be reduced by controlling plant hosts such as cape weed before canola is sown.
- Spray 'green break' summer weeds.

7.10.5 How can it be monitored?

Check paddock boundaries every few days for vegetable weevil incursion until the crop has four or five true leaves. [39]

7.11 Diagnosing cabbage white butterfly

Larvae of cabbage white butterfly are often found in canola crops (Figure 15). The larvae consume leaves, but numbers are rarely high enough to cause serious damage to the crop.

Figure 15: Life stages of cabbage white butterfly. (Photos: DAFWA)

7.11.1 What to look for

On the plant:

- large irregular holes chewed in leaves
- foliage preferred over floral parts

Insect nymph:

- velvety green caterpillar up to 30 mm long with a pale yellow stripe down the back

Adult insect:

- large moths with 30–40 mm wingspan, predominantly white with black wingspots and markings

[39] S Micic (2015) Diagnosing weevils in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-weevils-canola

7.11.2 What else could it be?

Diamondback moth has a similar green caterpillar that eats holes in leaves. Cabbage white butterfly is smaller, lighter green, and more irritable, often dangling from a silken thread when disturbed.

7.11.3 Management strategies

Cabbage white butterfly is not an economic problem of canola but can be controlled with foliar insecticides. [40]

7.12 Vegetable beetle (*Gonocephalum missellum*)

7.12.1 Description

Adult

- About 9 mm long.
- Matte grey, sometimes encrusted with soil on its back.

Figure 16: Vegetable beetle adult. Photo: DAFWA

Larvae

- about 18 mm long and 2 mm wide when fully grown.
- Three pairs of legs on thorax, shiny, hard skin, worm-like shape ('false wireworm').

[40] S. Micic (2015) Diagnosing cabbage white butterfly. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-cabbage-white-butterfly

Figure 17: Vegetable beetle larva. Photo: DAFWA

7.12.2 Damage

Adult

- Often present in clusters and found under debris or vegetation.
- Feeds on decaying vegetation, but known to attack seedlings.
- More active than African black beetle.

Larvae

- Larvae are soil dwelling and feed on organic matter.
- Can be pests of summer grown crops.
- If present as large larvae when potatoes are near harvest can chew holes in them. [41]

More information

DAFWA: Cockchafer damage in broadacre crops

DAFWA: Diagnosing bryobia mite

DAFWA: MyPestGuide app

DAFWA: Identifying soil beetle pests

7.13 Other soil pests

As with slugs, there are increasing reports of European earwigs causing significant damage to emerging crops. Stubble retention, in combination with wet springs and summers and an early autumn break, appear to favour the buildup of these insects. The damage caused by earwigs can be difficult to identify, and because control can also be difficult, growers should seek advice if they suspect or see earwigs. Several soil-dwelling insect pests such as cutworms, wireworms, bronzed field beetle, cockchafers and false wireworms have caused damage to emerging canola seedlings in recent years. In severe cases, plant stands can be thinned to such an extent that the paddock requires re-sowing. Occurrence of these pests is difficult to predict, so advice on their control should be sought prior to sowing if any problems are foreseen. The most severe damage tends to occur in crops following pasture, or if stubble has been retained. [42]

41 S. Micic (2015) Vegetable beetle. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/pest-insects/identifying-soil-beetle-pests?page=0%2C1#smartpaging_toc_p1_s6_h2

42 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

SECTION 8

Nematode management

8.1 Root-lesion nematodes

Root-lesion nematodes (RLN) can have an impact on canola growth (Figure 1). However, following harvest, levels of the RLN *Pratylenchus neglectus* have been found to decline rapidly, due to the release of isothiocyanates from decomposing root tissue. Sulfur-deficient or stressed crops are more likely to host increasing nematode numbers during the season and have less effect on their decline at the end of the season. [1]

Testing soil is the only reliable way to determine whether RLN are present in a paddock. Before planting, soil tests can be carried out by PreDicta B (SARDI Diagnostic Services) through accredited agronomists to establish whether crops are at risk and whether alternative crop types or varieties should be grown. Growing-season tests can be carried out on affected plants and associated soil; contact the Department of Agriculture and Food Western Australia (DAFWA) or PreDicta B.

Canola is considered moderately susceptible to *P. neglectus*, *P. quasitereoides* and *P. penetrans*. [2]

More information

Managing root lesion nematodes: how important are crop and variety choice?

Root lesion and burrowing nematodes: diagnosis and management

Plant parasitic nematodes Fact Sheet (Southern & Western Region)

eXtensionAUS: Root-lesion nematode

Root lesion nematode has a picnic in 2013

1 L Serafin, J Holland, R Bambach, D McCaffery (2005) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

2 GRDC (2015) Root-lesion nematodes. GRDC Tips and Tactics, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

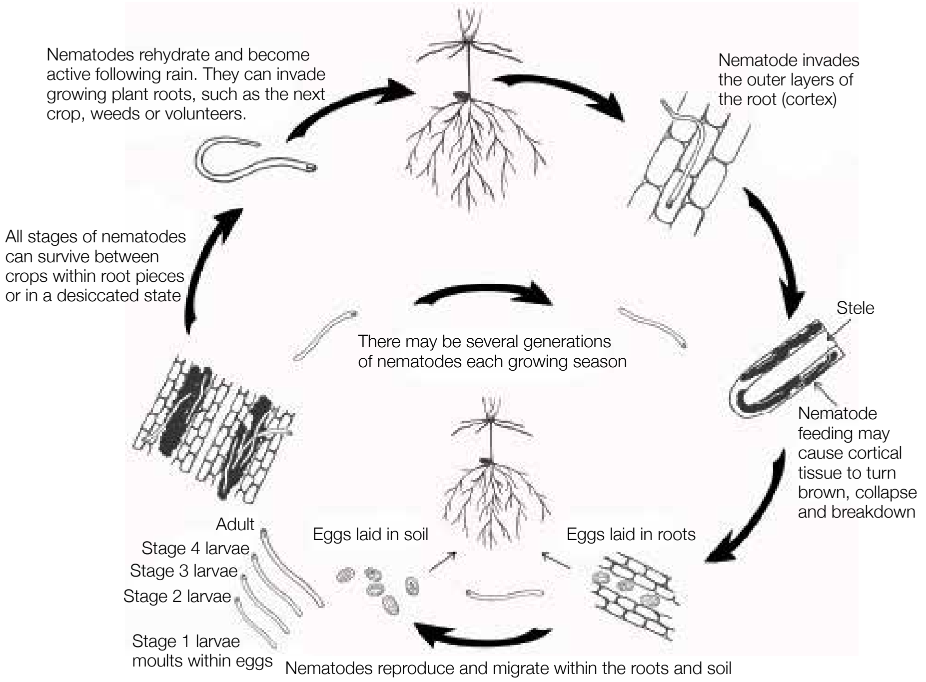


Figure 1: Disease cycle of root-lesion nematode. Adapted from: GN Agrios (1997) Plant pathology, 5th edn. (Illustration by Kylie Fowler) [3]

More information

[Root-lesion nematodes](#)

[RLN in WA](#)

[*Pratylenchus quasitereoides*—WA's home grown root lesion nematode](#)

8.2 RLN in Western Australia

- RLN are found over 5.74 million ha (or ~65%) of the cropping area of Western Australia (WA).
- Populations potentially limit yield in at least 40% of these infested paddocks.
- The main species found in broadacre cropping in WA are *P. neglectus*, *P. quasitereoides* (previously known as *P. teres*), *P. thornei* and *P. penetrans*.
- The host range of RLN is broad, and it includes cereals, oilseeds, grain legumes and pastures, as well as many broadleaf and grass weeds.

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8.2.1 *Pratylenchus quasitereoides*—WA's home-grown RLN and its unique impacts on broadacre crops

Key messages

- *Pratylenchus quasitereoides* is unique to WA, has a wide host range and is capable of causing significant yield damage.
- Crop rotation and selection of resistant cultivars are the keys to management of RLN. Growers need to know which species of RLN are present because cultivars resistant to one species may be susceptible to another, so suitable rotations will vary.

3 GRDC (2015) Root-lesion nematodes. GRDC Tips and Tactics, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

- Ongoing DAFWA research is developing rotational recommendations through the characterisation of wheat cultivar resistance and tolerance levels.
- Become familiar with root and crop symptoms associated with nematode damage.
- Make use of available testing services to determine nematode species and levels, but be aware that PreDicta B cannot currently detect the presence of *P. quasitereoides* in crops.
- AGWEST Plant Laboratories can conduct in-season nematode diagnosis.
- Consider the influence of soil nematode levels not only on the current crop, but also on subsequent crops in the rotation.

Aims

Root-lesion nematodes are microscopic, migratory endoparasites. This means that RLN enter roots, feed on cell contents, and then either remain to continue feeding within the same root or exit and move to nearby root systems. This process damages the root system, making water and nutrient uptake less efficient. Plants are therefore less able to tolerate other stresses. RLN damage is estimated to cause crop losses of ~$190 million/year in southern and Western Australia. [4]

It is estimated that one or more species of RLN occur in at least 60% of WA cropping paddocks, that is, over at least 5.3 million ha of the WA cropping zone. Surveys also found that RLN is at yield-limiting levels in at least 40% of paddocks. Several types of RLN are responsible: *P*. *neglectus* is the most frequently identified in WA, occurring in at least 40% of paddocks; *P*. thornei occurs rarely (~8% of paddocks); and *P. quasitereoides* is found in ~15% of cropping paddocks in WA. Cereal yield losses due to RLN are ~10–30% but can be higher (25–75%) for individual crops, particularly where *P. quasitereoides* occurs.

Pratylenchus quasitereoides is unique to WA, can reach high population levels, and can cause more significant and widespread damage within a crop than *P. neglectus*. Information is required to enable growers to manage *P. quasitereoides* within their cropping rotations by using species that are poor hosts or non-hosts, or resistant cultivars of wheat and barley to limit the multiplication of this pest in the soil. Crops resistant to *P. neglectus* can be highly susceptible to *P. quasitereoides*, which means that a different suite of rotational crops and cultivars is needed for effective management. It is therefore imperative that the species of RLN is correctly identified in field diagnoses.

Nematodes cannot be controlled in broadacre Australian agriculture by chemical means; therefore, genetic and other solutions should be deployed to facilitate effective management in dryland cropping systems. This involves not only the development and use of cereals with resistance and/or tolerance, but also the appropriate use of non-cereal crops in rotational sequences to maintain low nematode populations. By screening and field-testing the resistance and tolerance of wheat and barley cultivars,

[4] V Vanstone, G Holloway, G Stirling (2008) Managing nematode pests in the southern and western regions of the Australian cereal industry: continuing progress in a challenging environment. *Australasian Plant Pathology* 37, 220–234.

relevant information can be supplied to allow growers to incorporate cultivars into rotations that limit the populations of, and damage caused by, nematodes.

Methods

Field assessments

Trials conducted in 2009 at Katanning assessed resistance of a wide range of crops to *P. quasitereoides*, including 22 wheat, 21 barley and 12 canola cultivars. Resistance refers to the effect of the plant on the nematode; resistant plants inhibit nematode reproduction, resulting in declining nematode numbers. To determine resistance, nematode numbers were compared at planting and anthesis, with the level of multiplication of the nematodes over the growing season providing an estimate of the relative susceptibility or resistance of the cultivars assessed (multiplication by >1 indicates a susceptible cultivar). These assessments provided valuable information for development of current field and glasshouse trials.

Current trials are conducted over 2 years. In the first year, *P. quasitereoides*-resistant and -susceptible crops are bulk-sown to manipulate nematode levels to produce 'high' and 'low' populations at which to compare yields of 24–26 wheat cultivars in the following year. In this way, relative cultivar tolerances are determined based on the yield differences that occur between paddocks with the 'high' and 'low' nematode populations. Tolerance is a measure of the effect of the nematode on plant growth, so the larger the yield difference, the more intolerant the cultivar. For tolerant cultivars, there will be little difference in yield between the paddocks with 'high' and 'low' nematode populations. Resistance information was also collected for each variety.

Glasshouse trials

Crop-cultivar resistance data are required to recommend management and rotations. Glasshouse trials allow assessment of multiple cultivars in highly replicated trials. Cultivar testing of wheat, barley, canola, field peas and lupins was conducted. Because of the inherent variability in nematode experimentation, trials will be repeated up to five times to validate.

Results and discussion

Susceptibility to *P. quasitereoides* varies between cultivars and crops. For example, at the Katanning field trial, nematodes multiplied 3–16 times for wheat, 3.5–14 times for barley, and 3–11 times for canola cultivars. At Toodyay in 2012 and in glasshouse trials, although the average multiplication was lower (range 1–4.5 times), results also indicate that cultivar susceptibility ranges from very susceptible (VS) to moderately resistant–moderately susceptible (MR–MS) (Tables 1 and 2). Data collected from field and glasshouse trials between 2009 and 2012 are being used to build reliable information for *P. quasitereoides*.

Significant yield effects occurred for wheat varieties at Toodyay in 2012 when assessing yield against nematode numbers at anthesis (Table 2). Very high yield impacts were recorded for cvv. Carnamah and Emu Rock (24%), Machete (16%), and Arrino and Westonia (12%). Significant yield loss was also evident for Brookton and EGA Eagle Rock (15%) and Ruby (7%). Coupled with resistance data, these results indicate that Emu Rock may be only moderately susceptible but very intolerant to

P. quasitereoides, whereas the other varieties are intolerant but range in levels of susceptibility to the pest. Yield effects were negligible for most of the remaining varieties tested; of note, Yitpi and Yenda appeared tolerant of *P. quasitereoides*.

Table 1: Most resistant and most susceptible cultivars of various crops as determined in studies of resistance/susceptibility to P. quasitereoides

Results are provisional; number of trials indicated in parentheses

Crop	Most resistant cultivars tested	Most susceptible cultivars tested
Lupin	Tanjil (1)	Coromup (1)
Field pea	Kaspa (1)	PBA Gunyah (1)
Barley	Yagan (1), Wimmera (1), Mundah (2)	Stirling (2), Hamelin (2), Vlamingh (2), Bass (1)
Canola	Stubby (1), Tanami (2)	Rottnest (1), Thunder (2)
Wheat	Mace (≥3), Yitpi (≥3), Stiletto (≥3)	Calingiri (≥3), Carnamah (≥3), Catalina (≥3)

Table 2: Yield impacts for wheat cultivars in the field trial at Toodyay, 2012

Provisional resistance ratings developed from results for P. quasitereoides glasshouse and field trials, with comparison to P. neglectus resistance ratings. S, susceptible; R, resistant; V, very; M, moderately

Cultivar	Yield loss (%)	Provisional resistance rating for *P. quasitereoides*	Resistance rating for *P. neglectus*
Arrino	12	S	S
Carnamah	24	VS	S
Emu Rock	24	MS–S	S
Mace	0	MS	MS
Magenta	0	MS	MS–S
Westonia	12	S	S
Wyalkatchem	0	MS–S	MR–MS
Yitpi	0	MS–S	MS–S

Data collected to date indicate that *P. quasitereoides* has a broad host range (Table 3). Wheat, canola, lupins, barley and field pea cultivars assessed between 2009 and 2012 appear susceptible to this pest (Table 1 and 2). Importantly, levels of susceptibility varied for both host species and cultivar. Smaller increases in nematode numbers when growing a more resistant cultivar or crop may produce smaller impacts on both the current crop and in subsequent seasons. This impact could be mitigated by appropriate cultivar and crop selection.

Table 3: Reaction of major crop and pasture species to Pratylenchus neglectus, P. quasitereoide and P. penetrans. [5]

Hosting ability	*P. neglectus*	*P. quasitereoide*	*P. penetrans*
Susceptible	Wheat Barley Chickpea	Wheat Canola Barley Oat	Field peas Lupins Chickpeas Oats Durum wheat Wheat Triticale Faba beans Wild oats Wild radish
Moderately susceptible	Canola Durum wheat Oat	Narrow-leafed lupin	Barley Canola
Resistant	Field pea Narrow-leafed lupin Faba bean Triticale Lentil Safflower Narbon beans		

Nematodes are characterised by patchy infestations and variable impacts on plants, depending on environmental conditions. RLN lifecycle and impact in a crop is influenced by seasonal variations, soil type and management practices for any given year. For example, seasonal influence of rainfall may have affected the multiplication of RLN in the field trials assessed in 2009 and 2012. Katanning in 2009 experienced rainfall of 356 mm between May and October, and *P. quasitereoides* multiplication ranged from 3 to 16 times across the wheat, barley and canola cultivars tested. Toodyay in 2012 had 260 mm, and *P. quasitereoides* multiplication of 1–4 times was measured.

Across trials, some cultivars have shown inconsistent results to date that may be related to environmental influences. For example, cv. Endure behaved as a highly susceptible crop at Katanning in 2009, with *P. quasitereoides* multiplication of 16 times, but in the subsequent glasshouse and 2012 field trial, it has been much more moderately susceptible. Wyalkatchem and Arrino have also ranged from susceptible to moderately resistant between trials. These inconsistencies highlight the importance of repeated trials in a range of circumstances.

Conclusions

The most commonly found RLN, *P. neglectus*, affects broadacre cropping across Australia. The volume and reliability of information available for this pest reflects local and national research initiatives over >20 years. *Pratylenchus quasitereoides,* on the other hand, is unique to WA and research into this nematode has been much more

5 GRDC (2015) Root-lesion nematodes. GRDC Tips and Tactics, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

limited. Current DAFWA research initiatives will continue to develop tolerance and resistance information for selection of rotations and suitable cultivars. More data are required for this RLN species; however, both glasshouse and field trial assessments to date indicate that crop reaction may vary from that for other *Pratylenchus* species. It is therefore important to ascertain the species of nematode affecting the crop to determine the appropriate management. This is particularly important with respect to *P. quasitereoides*, because it appears that crops may be more affected by this species than by the more common *P. neglectus*.

Research in WA focuses on management, principally through rotational recommendations for cereal cultivars and other host crops. Results for *P. quasitereoides* are preliminary, and although some provisional recommendations are appropriate, development of rotational advice requires further field and glasshouse assessment of the commercial cultivars grown within the farming system against this RLN species encountered in the WA broadacre growing areas. This information will be widely extended to growers and consultants to facilitate the management of RLN and minimise losses incurred by grain growers. [6]

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8.3 Impact of crop varieties on RLN multiplication

8.3.1 Take-home messages

- Know your enemy—test soil to determine whether RLN are a problem, and which species are present.
- Select wheat varieties with high tolerance ratings to minimise yield losses in RLN infected paddocks.
- To manage RLN populations, it is important to increase the frequency of RLN-resistant crops in the rotation.
- Multiple resistant crops in a rotation will be necessary for long-term management of RLN populations.
- Avoid crops or varieties that allow the build-up of large populations of RLN in infected paddocks.
- Monitor the impact of your rotation. [7]

Figure 2 is a simplified chart highlighting that the critical first step in the management of RLN is to test the soil and determine whether there is a problem to manage. Where

6 S Collins, S Kelly, H Hunter *et al.* (2013) *Pratylenchus quasitereoides*—WA's home grown Root Lesion Nematode (RLN) and its unique impacts on broadacre crops. GRDC Update Papers, 12 March 2013, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Pratylenchus-quasitereoides-WAs-home-grown-Root-Lesion-Nematode

7 B Burton (2105) Impact of crop varieties on RLN multiplication. GRDC Update Papers, 1 March 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

RLN are present, growers should focus on planting tolerant wheat varieties and on increasing the number of resistant crops or varieties in the rotation. [8]

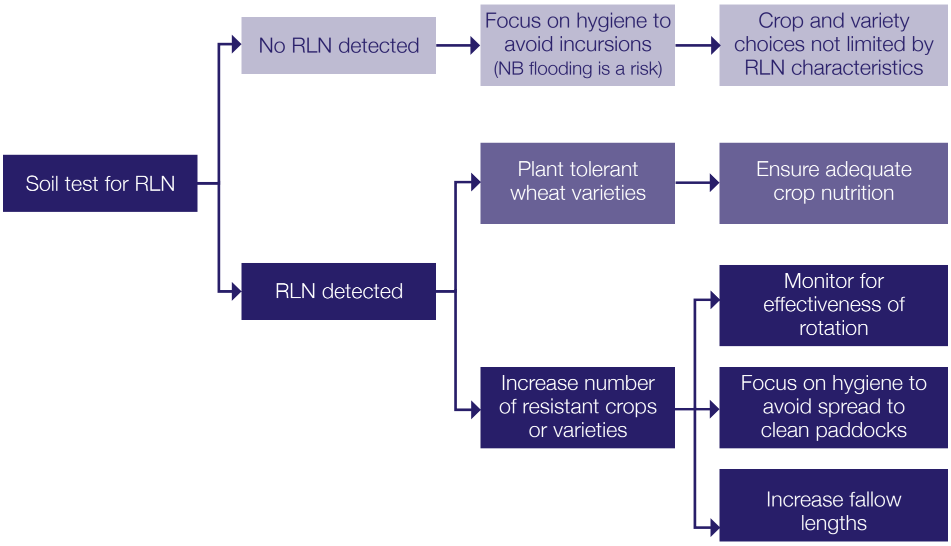

Figure 2: Management flow chart for root-lesion nematode.

More information

[Variety choice and crop rotation key to managing root lesion nematodes]

[Impact of crop varieties on RLN multiplication]

8.3.2 Soil testing

The first step in the management of RLN is to test the soil and determine whether the problem is present. Testing of soil samples is most commonly conducted via DNA analysis (commercially available as the PreDicta B test from SARDI) with sampling to depths of 0–15 or 0–30 cm.

To organise testing and sending of soil samples, visit the PreDicta B website.

8.3.3 Management of RLN

- Nematicides. There are no registered nematicides for RLN in broadacre cropping in Australia. Screening of candidates continues, but RLN are a very difficult target with populations frequently deep in the soil profile.
- Nutrition. Damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture and can induce nutrient deficiencies. Under-fertilising is likely to exacerbate RLN yield impacts; however, over-fertilising is unlikely to compensate for a poor variety choice.
- Variety choice and crop rotation. These are currently the most effective management tools for RLN. Note that the focus is on two different characteristics: *tolerance*, which is the ability of the variety to yield under RLN pressure; and *resistance*, which is the impact of the variety on the buildup of RLN populations. Varieties and crops often have different tolerance and resistance levels to different RLN species.
- Fallow. RLN populations will generally decrease during a 'clean' fallow, but the process is slow and expensive in lost 'potential' income. Additionally, long fallows

8 B Burton (2105) Impact of crop varieties on RLN multiplication. GRDC Update Papers, 1 March 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

may decrease levels of arbuscular mycorrhizal fungi (AMF) and create more cropping problems than they solve. [9]

Resistance differences between winter crops

The primary method of managing RLN populations is to increase the number of resistant crops in the rotation. Knowledge of the species of RLN present is critical, because resistance to different species of RLN varies between crops. For example, canola is generally considered resistant or moderately resistant to *P. thornei*, along with sorghum, sunflowers, maize, canary seed, cotton and linseed. Wheat, barley, chickpeas, faba beans, mungbeans and soybeans are generally susceptible, although the level of susceptibility may vary between varieties. Field peas have been considered resistant; however, many newer varieties appear more susceptible. Figure 3 shows the mean *P. thornei* population remaining after a range of winter crops were grown near Weemelah, New South Wales, in 2011. Crops were sown in individual trials to enable weed and pest control, and so data cannot be directly compared; however, the data broadly indicate the magnitude of differences in *P. thornei* resistance between these crops. Assessment of the risk of buildup of *P. thornei* in different crops (i.e. susceptibility) and of whether variety differences exist shows that canola has low to moderate risk of buildup, but no varietal differences have yet been detected (Table 4). [10]

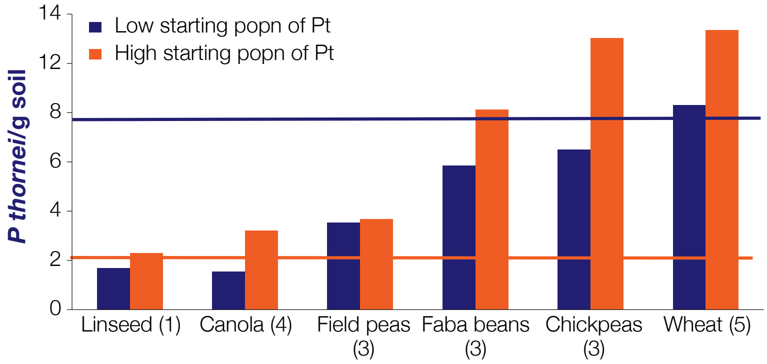

Figure 3: Comparison of P. thornei populations remaining in March–April 2012 following different winter crop species near Weemelah, NSW, 2011. Numbers of varieties within crops are in parentheses. The two horizontal lines indicate the respective 'low' and 'high' starting levels of P. thornei in March 2011. Soil sampling depth was 0–30 cm.

9 B Burton (2105) Impact of crop varieties on RLN multiplication. GRDC Update Papers, 1 March 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

10 B Burton (2105) Impact of crop varieties on RLN multiplication. GRDC Update Papers, 1 March 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

Table 4: Comparison of crops for risk of P. thornei buildup and the frequency of significant variety differences [11]

Crop	*Pt* buildup risk	Variety differences
Sorghum	Low	None observed
Cotton	Low	None observed
Sunflowers[A]	Low	None observed
Linseed[A]	Low	–
Canola[A]	Low to medium	None observed
Field peas[A]	Low to medium	Low
Durum wheat	Low to medium	Moderate
Barley	Low to medium	Moderate
Bread wheat	Low, medium to high	Large
Chickpeas	Medium to high	Moderate to large
Faba beans	Medium to high	Low
Mungbeans[A]	Medium to high?	Moderate to large?

[A]Data from only one or two field trial locations for these crops.

[11] B Burton (2105) Impact of crop varieties on RLN multiplication. GRDC Update Papers, 1 March 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

SECTION 9

Diseases

Blackleg and Sclerotinia stem rot are the most economically important diseases (Table 1) in Western Australia (WA). Other foliar diseases are present but sporadic. Seasonal conditions play a major role in the occurrence of these diseases.

Club root has significance in the Northern Agricultural Region and requires constant vigilance.

Table 1: Incidence of canola diseases in Western Australia

Disease	Occurrence
Blackleg	Very widespread
Sclerotinia stem rot	Common in Northern Agricultural Region and South Coast Region
Downy mildew	Isolated incidence in high-rainfall areas
White leaf spot	Common but low impact
Section Club roxiiot	Perceived risk to Northern Agricultural Region
Charcoal rot	Identified in Central Agricultural Region
Beet western yellows virus	Common and damaging
Root-lesion nematodes	Common and damaging?

More information

Research paper: Dynamics of fungal diseases of canola in Western Australia

GRDC Ground Cover: Foliar fungal diseases of pulses and oilseeds

GRDC Update Papers: Viral diseases in canola and winter pulses

Canola diseases. The Back Pocket Guide

GRDC Update Papers: Blackleg pod infection, resistance group monitoring and sclerotinia

GRDC Update Papers: Canola and pulse management; maintaining the vigilance

9.1 Blackleg

Blackleg is the most important disease of canola, and management of the disease need not be complex. The most effective strategies to reduce the severity of blackleg include growing varieties with an adequate level of resistance for the district, separating the present year's crop from last year's canola stubble by at least 500 m, and using a fungicide seed dressing or fungicide-amended fertiliser.

Typically, ~90% of spores that infect new-season crops originate from the previous year's stubble. However, significant numbers of spores from 2-year-old stubble may be produced if seasonal conditions have been dry or the stubble is still largely intact. Spores can travel 1–2 km on the wind, but most originate more locally. A buffer distance of at least 500 m and up to 1 km is recommended. Use of fungicide seed dressings containing fluquinconazole or fertiliser treated with flutriafol will also assist in minimising the effects of blackleg and protect seedlings from early infection, which later causes stem canker development. Although raking and burning can reduce canola stubble by up to 60%, it is the least effective strategy in managing blackleg and is therefore not generally recommended. [1]

[1] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Canola growers are urged to consult the latest Blackleg Sporacle model from the Department of Agriculture and Food Western Australia (DAFWA) to determine what action they may need to take to protect their crop from this potentially devastating disease.[2]

The Blackleg Sporacle model was developed by the department with the support of GRDC, and is based on 4 years of epidemiology research on the timing of maturity of fruiting bodies and the spore release pattern throughout the wheatbelt.

According to a GRDC report, blackleg has the potential to cost the WA canola industry >$175 million per annum if not controlled. Presently, the estimated annual cost of blackleg is nearly $60 million.[3]

All current canola varieties are now assessed for the presence of resistance genes and classified into resistance groups. If the same variety has been grown for two or more seasons, consider changing varieties for this season. Consult the Blackleg management guide, autumn 2015 Fact Sheet to determine the resistance group for your current canola varieties and select future varieties that belong to a different group.[4]

Summary:

- Monitor your crops to determine yield losses in the current crop.
- Choose a cultivar with adequate blackleg resistance for your region.
- Never sow a canola crop into last year's canola stubble.
- Reliance solely on fungicides to control blackleg poses a high risk of fungicide resistance.
- If your monitoring has identified yield loss and you have grown the same cultivar for ≥3 years, choose a cultivar from a different resistance group.

More information

DAFWA Crop Disease Forecast

Research paper: Chemical control of blackleg disease of canola in Western Australia

[2] DAFWA (2015) Blackleg Sporacle gazes into disease risk. Department of Agriculture and food Western Australia, https://www.agric.wa.gov.au/news/media-releases/blackleg-sporacle-gazes-disease-risk

[3] DAFWA (2015) Blackleg Sporacle gazes into disease risk. Department of Agriculture and food Western Australia, https://www.agric.wa.gov.au/news/media-releases/blackleg-sporacle-gazes-disease-risk

[4] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

9.1.1 Four steps to beating blackleg

Step 1. Determine your farm's risk

Use Table 2 to determine your farm's blackleg risk. Combined high canola intensity and adequate rainfall increase the probability of severe blackleg infection.

Table 2: Regional environmental factors that determine risk of severe blackleg infection

Environmental factors	Blackleg severity risk factor								
	High risk			Medium risk			Low risk		
Regional canola intensity (% area sown to canola	>20	16–20	15	11–14	11–14	10	6–9	5	<5
Annual rainfall (mm)	>600	551–600	501–550	451–500	401–450	351–400	301–350	251–300	<250
Total rainfall March–May prior to sowing (mm)	>100	>100	>100	>100	91–100	81–90	71–80	61–70	<60

More information

GRDC: Blackleg management guide, autumn 2015 Fact Sheet

GRDC Media: GRDC funding canola stubble screening for fungicide-tolerant blackleg

GRDC: Revised spring blackleg management guide Fact Sheet

Managing blackleg and sclerotinia in canola. The Back Pocket Guide

GRDC Ground Cover Supplement: Optimising canola profitability

Oilseeds WA: Assessment of fungicide efficacy against blackleg disease

MFMG: Investigating Fungicide Best Practice Management

Step 2. Determine each crop's blackleg severity in spring

- Assess the level of disease in your current crop. Sample the crop any time from the end of flowering to windrowing (swathing). Pull 60 randomly chosen stalks out of the ground, cut off the roots with a pair of secateurs and, using the reference photos in Figure 1 below, estimate the amount of disease in the stem cross-section. Yield loss occurs when more than half of the cross-section is discoloured.
- A dark-coloured stem is a symptom of blackleg (Figure 1). Stem cankers are clearly visible at the crown of the plant. Severe cankers may cause the plant to fall over as the roots become separated from the stem.

If you have identified that you are in a high-risk situation (steps 1 and 2), use steps 3 and 4 below to reduce your risk of blackleg for future seasons.

If you are in a low-risk situation and you have not identified yield loss due to blackleg infection when you assessed your crop, continue with your current management practices.

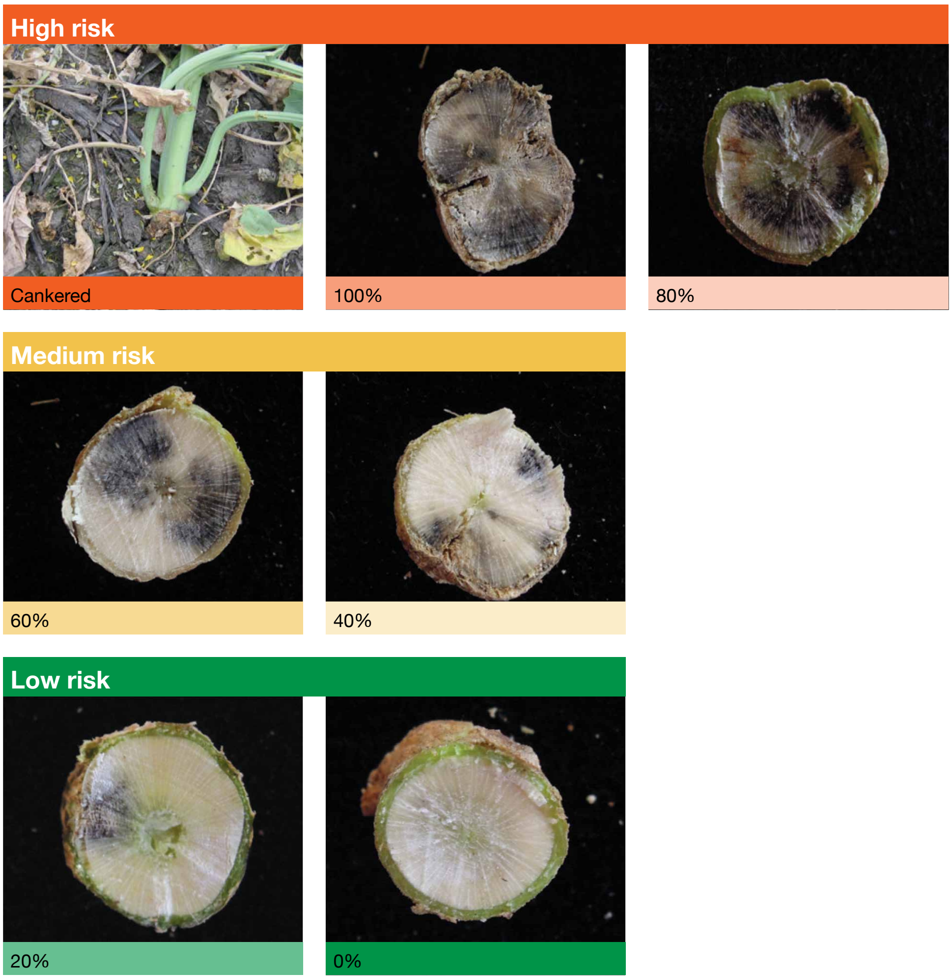

Figure 1: Crop blackleg severity.

Step 3. Management practices can reduce the risk of blackleg infection

If your crop monitoring (see step 2) showed yield loss in the previous year, the following practices can be used to reduce blackleg severity. Complete the following process for each canola paddock to be sown.

- For each of the management factors listed in Table 3 below (and in the Blackleg risk management worksheet accompanying the Blackleg management guide, autumn 2015 Fact Sheet), circle where each canola paddock fits to determine the risk of blackleg. For example, for 'blackleg rating', if your cultivar is ATR-Stingray, circle 'MR', indicating a low risk of blackleg; or for 'distance from last year's canola stubble', if your proposed canola crop is 200 m away, high risk is indicated.
- Complete all management factors to determine which practices are causing increased risk and how they can be reduced. For example, for 'distance from last year's canola stubble', choose a different paddock, at least 500 m away from last year's stubble, reducing the risk from high to low.

Table 3: Management factors used to determine which practices are increasing the risk of blackleg infection

For blackleg rating of cultivar: VS, very susceptible; S, susceptible; MS, moderately susceptible; MR, moderately resistant; R, resistant; see text below (Blackleg rating) for further details

Blackleg rating of cultivar	VS	S–VS	S	MS–S	MS	MR–MS	MR	MR–R	R
Distance from last year's canola stubble	0 m	100 m	200 m	300 m	400 m	500 m	>500 m	>500 m	>500 m
Fungicide use	No fungicide		Foliar applied fungicide		Seed dressing fungicide	Fertiliser applied fungicide	Seed dressing + fertiliser applied fungicide	Seed dressing or fertiliser applied + foliar fungicide	Seed dressing or fertiliser applied + foliar fungicide
Years of same cultivar grown	Same cv. or resistance group for >3 years			Same cv. or resistance group for 3 years			Same cv. or resistance group for 2 years	Same cv. or resistance group for 2 years	Same cv. or resistance group for 2 years
Distance from 2-year-old canola stubble					0 m	100 m	250 m	250 m	250 m
Canola stubble conservation				Inter-row sowing	Disc tillage	Knife-point tillage	Burning or burying tillage	Burning or burying tillage	Burning or burying tillage
Month sown				June–Aug.	15–31 May	1–14 May	15–30 April	15–30 April	15–30 April
Dual purpose grazing canola					Grazing canola				

Step 4. Blackleg resistance groups

Canola cultivars have different combinations of blackleg resistance genes. Over time, growing cultivars with the same blackleg resistance genes has led to changes in the virulence of the blackleg pathogen, which has enabled it to overcome cultivar resistance. By rotating between cultivars with different resistance genes, you can reduce the probability of resistance breakdown and reduce disease severity.

Based on steps 1–3, are you in a high-risk region or have you observed increasing blackleg severity and grown the same cultivar in close proximity for ≥3 years?

- No. Your current management practices should be sufficient to manage blackleg resistance adequately.
- Yes. You may be at risk of the blackleg fungus overcoming the blackleg resistance of your cultivar. It is recommended that you grow a cultivar with a different combination of blackleg-resistance genes (see table 3 in Blackleg management guide, autumn 2015 Fact Sheet). You do not need to change resistance groups (cultivars) every year. [5]

5 GRDC (2015) Blackleg management guide, autumn 2015. GRDC Fact Sheet, 29 April 2015, http://www.grdc.com.au/GRDC-FS-BlacklegManagementGuide

9.1.2 Blackleg rating

Practices to deal with the breakdown of blackleg resistance in intensive canola districts are based on large screening trials. Industry understanding of the blackleg pathogen of canola has progressed substantially over the past few years. An important practical development from this work is that all current commercial cultivars and advanced breeding lines have been screened to determine their complement of blackleg resistance genes. This has enabled researchers to allocate cultivars into one of seven resistance groups.

Growers are familiar with the rating of crop varieties for susceptibility (S) through to resistance (R) to a specific pathogen. However, the sexually reproducing pathogen blackleg is adept at overcoming cultivar resistance, and this compromises a cultivar's blackleg rating. Field observations have found that blackleg resistance is often overcome when the same variety is regularly grown across large areas in a region for >3 years.

Seven resistance rotation groups have been established (named A–G). If there is a risk of high blackleg severity in a location where the same cultivar has been grown for ≥3 years, then a cultivar from a different resistance group needs to be sown (see Blackleg management guide Fact Sheet).

One canola cultivar from each of the seven resistance groups has been sown adjacent to National Variety Trials (NVT) sites to monitor how blackleg populations evolve to overcome cultivar resistance. In 2011, this blackleg monitoring identified regional differences in infection levels between resistance groups. This information was used as the basis of a pre-sowing, early-warning system to alert growers in a region to the potentially high level of blackleg inoculum able to attack cultivars in a specific resistance group.

There are 32 blackleg-monitoring sites across Australia in WA, New South Wales, South Australia and Victoria. [6]

All varieties are rated according to the independent Australian National Blackleg Resistance rating system, in which all canola-breeding companies are participants. The ratings, based on relative differences between varieties, are as follows:

- resistant: R
- resistant to moderately resistant: R–MR
- moderately resistant: MR
- moderately resistant to moderately susceptible: MR–MS
- moderately susceptible: MS
- moderately susceptible to susceptible: MS–S
- susceptible: S
- susceptible to very susceptible: S–VS
- very susceptible: VS

6 GRDC (2014) 2014—Revised blackleg spring management guide. GRDC Ground Cover Issue 101, http://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS101/Advances-in-blackleg-management

More information

eXtensionAUS: Blackleg monitoring sites

GRDC Update papers: eXtensionAUS (Southern region)

Varieties with a rating of 'resistant' (R) in areas of high blackleg risk and at least 'moderately resistant' (MR) in areas of lower blackleg risk will normally give sufficient disease protection. [7] The blackleg-resistance ratings for all varieties for 2015 are available in the Blackleg management guide, autumn 2015 Fact Sheet (see table 3 therein). [8]

9.2 Sclerotinia stem rot

Sclerotinia stem rot is a fungal disease that can infect a wide range of broadleaf plants, including canola. Disease development is favoured by prolonged wet conditions in late winter followed by periods of prolonged leaf wetness during flowering.

Yield losses range from nil to 20% in some years, but losses have been as high as 35%. Districts with reliable spring rainfall and long flowering periods for canola appear to develop the disease more frequently. Continual wheat–canola rotations are also very effective at building up levels of soil-borne sclerotia.

Burning canola stubble will not control the disease effectively, because *Sclerotinia* survives mainly on or in the soil. Crop rotation with cereals, following recommended sowing times and ensuring that crops do not develop heavy vegetative growth, which is likely to reduce air circulation, are the best means of reducing the impact of the disease.

The inconsistent relationship between the level of stem infection and yield loss makes it difficult to predict an economic response from using foliar fungicides in any one year. The specific environmental conditions for development of Sclerotinia stem rot will not occur every year. For example, in dry conditions, even if the fungus is present, the disease may fail to develop.

The fungicide Prosaro® (active ingredients prothioconazole + tebuconazole), and iprodione and some procymidone products, are registered for the management of Sclerotinia stem rot.

Consult your farm adviser and refer to the Sclerotinia stem rot in canola Fact Sheet. [9]

Key points for managing Sclerotinia stem rot:

- An outbreak of Sclerotinia stem rot is highly dependent on the season.
- Prolonged wet or humid conditions during flowering favour the disease.
- Consider past outbreaks of the disease as a guide to potential yield loss.

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7 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

8 GRDC (2015) Blackleg management guide, autumn 2015. GRDC Fact Sheet, 29 April 2015, http://www.grdc.com.au/GRDC-FS-BlacklegManagementGuide

9 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

More information

GRDC: Sclerotinia stem rot in canola Fact Sheet

Canola diseases. The Back Pocket Guide

GRDC Update Papers: Canola disease update 2015 (NSW)

AOF: Economics and timing of fungicide application to control Sclerotinia stem rot in canola

GRDC Media: Tips and tools for managing Sclerotinia in 2015

- Avoid growing canola in paddocks with a history of Sclerotinia stem rot over the past 4 years, or in adjacent paddocks.
- Well-timed fungicide treatments, when canola crops are at 20–30% flowering stage, can be highly effective in reducing the level of infection.
- No Australian canola varieties have known resistance to the disease. [10]

infocus

9.2.1 Managing Sclerotinia stem rot in canola in Western Australia

Sclerotinia stem rot is one of the most variable and unpredictable diseases of canola, and incidence of infection can vary greatly between paddocks and between years. Yield losses can be severe in years of higher moisture, with losses exceeding 20% under conducive conditions. Cool temperatures and prolonged precipitation are ideal conditions for its development.

Rotation, tillage and fungicides are currently the best strategies for managing Sclerotinia stem rot, including:

- long rotation
- rotate with non-host crops
- avoiding sowing close to last year's infected crop
- use of clean seed
- use of foliar fungicide [11]

Rotation

Crop rotation can help in reducing disease severity. Leave canola out of the rotation for as long as possible (at least 3 years) to allow Sclerotia to decompose, thus reducing the risk of subsequent infections. Include in rotations species that are unaffected by *Sclerotinia*, such as cereals. Leave out species such as lupins, chickpeas and lentils, which are very susceptible. Windborne spores may be blown a great distance into susceptible crops. Separate canola crops by ≥100 m from paddocks that had conspicuous levels of Sclerotinia stem rot in the previous year. [12]

Symptoms

Sclerotinia can infect any part of the plant (Figure 2). Symptoms appear as bleached greyish white or brownish white fungal growth covering portions of the canola stem, sometimes just above soil level but also at any height in the canopy (Figure 3). After

[10] GRDC (2014) Canola disease management in the northern region. GRDC Ground Cover, 21 March 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Canola-disease-management-in-the-northern-region

[11] R Khangura, C Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

[12] R.Khangura ,C. Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

infection is well established, the disease causes plants to wilt and ripen prematurely (Figure 4), resulting in lodging and reduced seed production (Figures 5 and 6).

Figure 2: Sclerotinia leaf lesions can appear as watermarks on canola leaves. (Photo: DAFWA)

Figure 3: Early stem lesion appearing as a bleached oval area, indicating Sclerotinia stem rot in canola. (Photo: DAFWA)

Figure 4: Bleached canola stem indicative of Sclerotinia. Infected canola stems stand out as looking bleached and maturing early amidst healthy plants. (Photo: DAFWA)

Figure 5: Stem bleaching, rotting and lodging due to Sclerotinia stem rot in canola. (Photo: DAFWA)

Figure 6: Infected stems are weak and can lodge. (Photo: DAFWA)

Advanced infection will have hard, black, generally irregular-shaped to rounded bodies (sclerotia) on the inside of the affected and bleached parts of the stem. Stems can be carefully split to observe the black sclerotia within (Figure 7). The sclerotia, which are >2 mm in diameter, are the survival structure of the fungus. They appear like rat droppings. In moist weather, they can also form on the outside of the infected stem or roots (Figure 8). If the weather is favourable, canola pods also may become infected. Infected pods appear creamish white in colour and usually contain white, mouldy seeds (Figure 9). In some instances, these seeds are replaced by sclerotia, which contaminate harvested seed samples. Further information on diagnosis is available at MyCrop—Diagnosing Sclerotinia stem rot in canola. Samples can be submitted for definitive diagnosis to AGWEST Plant laboratories (this is a chargeable service).[13]

Figure 7: Canola crop inspection includes breaking open the bleached stem. This may reveal black sclerotia, the resting phase of the fungus. (Photo: DAFWA)

[13] R.Khangura ,C. Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

Figure 8: Severe infection on stem showing fluffy white fungal growth and sclerotia. (Photo: DAFWA)

Figure 9: Sclerotinia infection causes creamish white pods that usually contain white mouldy seeds. (Photo: DAFWA)

Assessment of Sclerotinia risk

Risk factors for Sclerotinia stem rot infection include:

- paddock history
- rotation with susceptible crops
- disease incidence in the last affected crop
- distance from last affected crop
- rain events during flowering

For disease to occur, sclerotia or spores must be present to initiate infection. However, the sclerotia can survive for ≥6 years in the soil, so risk persists for several years.

A canola crop is considered at risk of developing Sclerotinia stem rot if:

- Sclerotinia has been present within the past 3 years in the paddock or an adjacent paddock.
- An intensive rotation with other broadleaf crop species has been followed. For example, if a canola or susceptible crop has been grown in the past 2 years, then the risk is high compared with a paddock where only cereals have been grown for the past 5 years.

The over-riding determinant of the severity of Sclerotinia stem rot that develops in a crop is the weather during flowering on the primary stem. Moisture in the crop canopy is required for infection to occur and develop into stem rot. This usually results from frequent rain events of ≥5 mm. Infrequent rain or light showers are unlikely to result in sufficient canopy wetness for yield-limiting infections to occur. [14]

Cause and disease cycle

Sclerotinia stem rot is caused by the fungus *Sclerotinia sclerotiorum*. It survives as sclerotia in the soil for many years. The fungus may also survive by colonising other host plants, such as wild radish and cape weed. During cool, moist weather, sclerotia in the soil germinate and produce small, cream-coloured, mushroom-like bodies (apothecia). These grow to ~5 mm in diameter and become darker coloured as they age (Figure 10).

14 R.Khangura ,C. Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

Figure 10: Healthy, young apothecia of Sclerotinia look like tiny white mushrooms (top); over time they age and dehydrate and turn brown (bottom). (Photos: DAFWA)

These apothecia contain large numbers of ascospores, which become airborne and blow to nearby crop plants. Although the spores rarely infect healthy stems and leaves directly, they readily infect canola petals (Figure 11). The fungus infects stems and leaves when infected petals fall and stick to leaf axils, and the fungus invades healthy plant tissue using the infected petal as a food source. Cool, wet weather favours the disease, and mist, dew and fog provide enough moisture for infection.

Sclerotia resting in the soil can also germinate to produce hyphae or mycelia, which can penetrate the stem base of a nearby canola plant and cause basal stem infection. However, direct germination of sclerotia is not a common cause of infection in canola. [15]

[15] R.Khangura ,C. Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

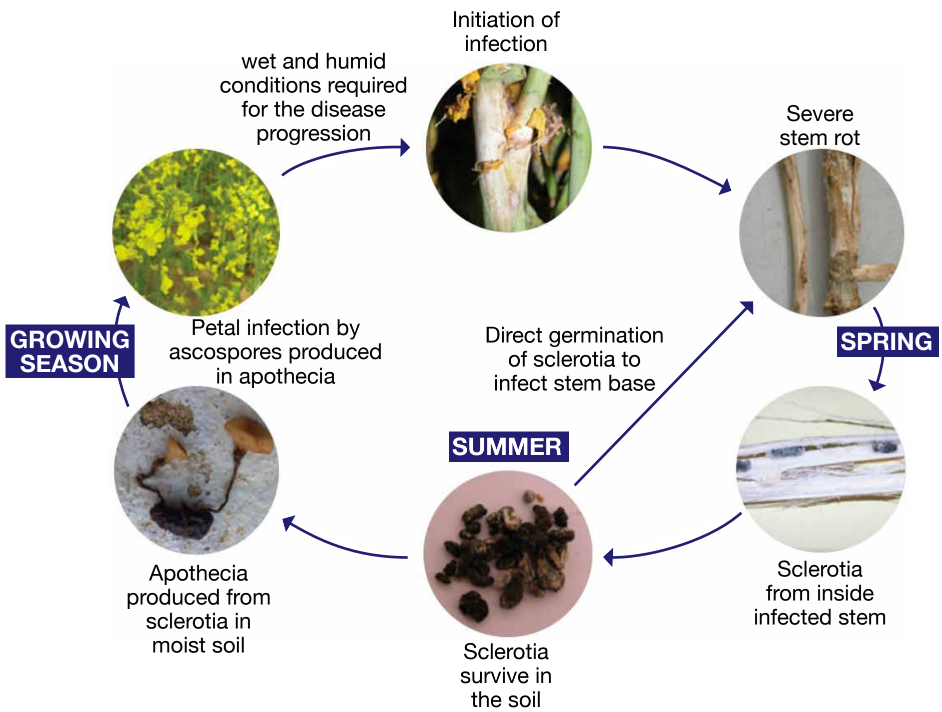

Figure 11: Lifecycle of Sclerotinia in canola.

Hosts

Sclerotinia sclerotiorum has a wide host range including >400 different plant species. It infects most of the broadleaf crops. Among these, lupins and chickpeas are commonly infected, whereas faba beans and field peas appear to be less susceptible. Broadleaf weeds such as wild radish and cape weed are also hosts and play a role in carryover of the fungus. [16]

Tillage

Mouldboard ploughing of infected stubble may reduce carryover to subsequent crops, because deep burial (below 15 cm) limits germination of sclerotia and development of apothecia. Most sclerotia germinate if they are close to the soil surface (within 2–3 cm) but may survive for ≥5 years when buried at greater depths. However, deep burial is only effective if deep tillage is not used in the following years, to ensure that sclerotia are not brought back to the soil surface later. Hence, management with tillage is uncertain. [17]

Fungicides

The decision to spray should be based on:

- presence of inoculum (previous Sclerotinia infections in paddock or nearby, sightings of apothecia in area)
- favourable conditions for the development of fungus

16 R.Khangura ,C. Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

17 R Khangura, C Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

- crop growth stage (see below, *Assessment of flowering stages in canola*)
- frequent showers during flowering
- yield potential

Always use fungicides according to the product label.

Timing of fungicide application:

The timing of fungicide application is extremely important for the effective control of this disease. Trial data from WA suggest that in the case of early onset of disease, early applications at 15–30% bloom may give excellent control of the disease, whereas late applications (40–50% bloom) may be too late. However, an economic response from late applications may be achieved if disease epidemics start late in the season (as occurred in many areas in 2013 with a wet spring). On average in most seasons, application at 20–30% bloom may be a good strategy if only one fungicide spray is to be applied, but research is ongoing on this timing.

If there has been an early application (10–20% bloom) and the forecast is for a wet spring, which will favour the disease, then a second application may be required at ~40–50% bloom. However, the decision on whether to spray is determined by the disease risk, the current price of canola and the yield potential of the crop. Application before 10% flowering (10 flowers open on main stem) is not recommended. *Sclerotinia* infection and spread requires moist conditions, so if it is dry, disease progression in the crop will slow. Hence, being flexible and monitoring future rainfall patterns is important in the timing of fungicide application. Application close to the next rainfall event is a good strategy.

See *Current research* below for discussion of the economics of fungicide application. [18]

Registered fungicides

Table 4 provides information on the foliar fungicides currently registered in WA for controlling Sclerotinia stem rot in canola.

Table 4: Chemicals currently registered for use as foliar fungicides in Western Australia, their application rates and trade names

Active chemical	Rate	Trade name
Iprodione	2 L/ha	Rovral® Liquid, Chief® 250, Iprodione Liquid 250, Corvette® Liquid, Civet® Liquid, Deathcap 250, Ipral 250, Iprodex 250, Flex GT 250, Shelby 250
Procymidone	1 L/ha	Fortress®, Procymidone 500, Sumisclex® 500, Sumisclex® Broadacre
Prothioconazole + tebuconazole	375–450 mL/ha	Prosaro® 420 SC

The Registered foliar fungicides for canola in WA shows current registrations for both *Sclerotinia* and blackleg.

[18] R Khangura, C Beard (2015) Managing sclerotinia stem rot in canola, Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

Varieties

All current commercial canola varieties are considered to have low resistance to *Sclerotinia*. However, some varieties may be less susceptible than others. Late-flowering varieties may escape infection provided their flowering window does not coincide with spore release or extended humid weather conditions. Sow only good-quality seed that is free of sclerotia.

Assessment of flowering stages in canola

Flowering (bloom) stages in canola can be difficult to determine, so a standard method of assessing them is provided here. Correct determination of flowering stages will enable fungicides to be applied at the right time.

Flowering stage should be assessed on the main stem:

- 10% bloom, 10 flowers open on main stem
- 20% bloom, 14–16 flowers open on main stem
- 30% bloom, ≥20 flowers open on main stem
- 40% bloom, ≥30 flowers open on main stem
- 50% bloom, all flowers are open or have opened, crop is at its most intense yellow (full flower)
- 60% bloom, flowering intensity is beginning to decline

Current research

Currently, DAFWA is undertaking research in the following areas in relation to Sclerotinia stem rot:

- *Sclerotinia* surveys
- epidemiology (petal testing, spore trapping and research with sclerotia to understand the disease lifecycle)
- timing of fungicide application, and investigating non-chemical measures for control
- effect of flowering time on *Sclerotinia* development
- screening for resistance under controlled environment
- development of a *Sclerotinia* risk-forecasting tool based on WA conditions

See the GIWA 2013 Crop Updates paper: Why Sclerotinia was so bad in 2013—Understanding the disease and management options.

Incidence in Western Australia

Survey results have shown high incidence of Sclerotinia stem rot across canola crops in WA in 2008, 2009, 2011 and 2013, with significantly higher incidence in the Northern Agricultural Region in all years except 2013 (Figure 12). This does not mean that the disease cannot be a problem in southern areas of the state. Survey results of 71 crops in the Southern Agricultural Region in 2009 showed >20% exhibiting symptoms of Sclerotinia stem rot, and in four worst affected crops, the incidence ranged between 69% and 80% (Figure 13). In addition, in 2013, incidence was relatively high in the Southern Agricultural Region.

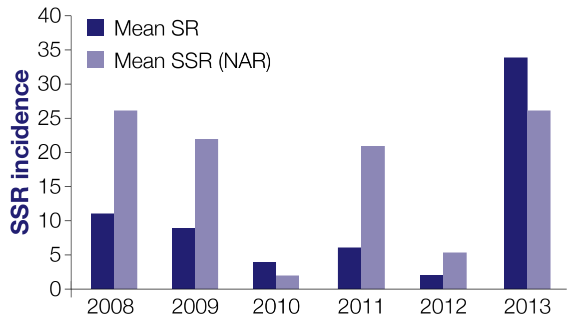

Figure 12: Sclerotinia stem rot (SSR) incidence in Western Australia (2008–13), including the Northern Agricultural Region (NAR).

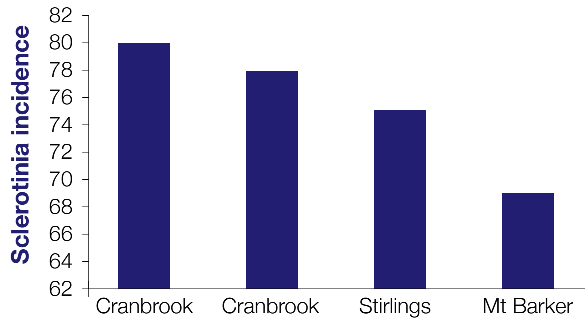

Figure 13: Survey results assessing the prevalence of Sclerotinia stem rot in four crops in the Southern Agriculture Region of Western Australia.

Variety resistance

Why is it so difficult to breed canola varieties with resistance to Sclerotinia stem rot?

- lack of reliable screening techniques
- challenges in screening lines under field conditions
- pathogen variability

Efficacy and economics of fungicide applications

Research has shown that treatment with fungicides improved the percentage disease index by a significant level, and grain yields have shown significant improvements compared with untreated controls. The economics of these treatments, however, is largely dependent on the cost of fungicide applied; the more expensive fungicides do not improve yields enough to recoup application costs. Tables 5 and 6 provide an indication of the economics of fungicide applications. [19] [20]

[19] https://www.agric.wa.gov.au/canola/managing-sclerotinia-stem-rot-canola?page=0%2C1

[20] R Khangura, B MacLeod. **Managing the risk of Sclerotinia stem rot in canola.** WA Farmnote 546, Department of Agriculture and Food Western Australia.

Cost return tables

Table 5: Return on fungicide application ($/ha) for a range of crop yield potentials and expected yield response when a single application of fungicide is made by plane ($15/ha) for a total cost of $41/ha, with canola price $500/t

Yield response	Crop yield (t/ha)							
	0.7	1.0	1.2	1.5	1.8	2.0	2.2	2.5
0	–41	–41	–41	–41	–41	–41	–41	–41
+5	–24	–16	–11	–3	4	9	14	22
+10	-6	9	19	34	49	59	69	84
+15	11	34	49	71	94	109	124	147
+20	29	59	79	109	139	159	179	209
+25	47	84	109	147	184	209	234	272
+30	64	109	139	184	229	259	289	334
+35	82	134	169	222	274	309	344	397
+40	99	159	199	259	319	359	399	459

Table 6: Return on fungicide application ($/ha) for a range of crop yield potentials and expected yield response when a single application of fungicide is made by self-propelled boomspray ($5/ha) for a total cost of $31/ha, with canola price $500/t

Yield response (%)	Crop yield (t/ha)							
	0.7	1.0	1.2	1.5	1.8	2.0	2.2	2.5
0	–31	–31	–31	–31	–31	–31	–31	–31
+5	–14	–6	–1	7	14	19	24	32
+10	4	19	29	44	59	69	79	94
+15	21	44	59	81	104	119	134	157
+20	39	69	89	119	149	169	189	219
+25	57	94	119	157	194	219	244	282
+30	74	119	149	194	239	269	299	344
+35	92	144	179	232	284	319	354	407
+40	109	169	209	269	329	369	409	469

9.3 Clubroot in canola

Clubroot is caused by the soilborne fungus *Plasmodiophora brassicae* and is not considered common or a serious risk. It has generally been found in the northern canola-growing regions of WA. DAFWA surveys in 2008–10 found that the average incidence of this disease in northern areas ranged from 7% to 25%. Conditions in southern areas were dry in that period and no incidence was recorded.

A 2013 survey of canola by DAFWA found mild levels of clubroot in one sample from the southern region; however, the Stirling to Coast grower group found no incidence in that region in the latest season.

Good machinery hygiene practices between paddocks and properties and longer canola rotations of up to 5 years can prevent spread where present.

9.4 *Rhizoctonia*, damping-off

Damping-off in canola is caused by a complex of *Rhizoctonia*, *Fusarium* and *Pythium* species. *Rhizoctonia* affects a wide range of crops, including canola. It and has become more prevalent, particularly in cereals, across WA in recent years in the wake of minimum-tillage practices that provide a habitat for the fungus during summer.

Damping-off and hypocotyl rot of oilseeds and legumes are all caused by different strains of *Rhizoctonia solani*. Affected seedlings fail to emerge, or collapse at ground level in patches. These diseases occur when conditions are unfavourable for germination and early seedling growth.

However, yield loss is unusual unless plant numbers are severely reduced or there is patchy establishment. Dry-sown crops are more at risk, but if crops are re-sown, soil tillage will generally control the fungi.

Seed fungicide treatments such as Maxim® XL or Apron® at sowing can also reduce damage caused by *Rhizoctonia* and/or *Pythium*. See your agronomist and/or www.apvma.gov.au.

9.5 Downy mildew, powdery mildew

Surveys by DAFWA in 2008–10 found high levels of powdery mildew in canola in 2008. The impact of this disease on the state's oilseed crops is not known, and it is not considered a high risk.

Downy mildew is very common in canola crops across Australia, but it is rarely found after the vegetative stage and it tends to have little effect on crop performance.

9.6 White leaf spot

White leaf spot is more common in wetter years. The disease is generally present on leaves of young canola plants; however, with prolonged wet weather, it continues to progress up in the canopy and can affect stems and pods during flowering.

White leaf spot is not generally considered serious unless pods are affected. Some yield loss can be expected if leaf lesions join and cause premature defoliation.

White leaf spot can be managed through rotations and cultural practices. Currently, no fungicides are registered for the control of white leaf spot.

9.7 Alternaria leaf and pod spot

Leaf and pod infection by *Alternaria* was generally considered to occur sporadically in WA, until 2013, when many crops across the state were found to have infection on the pods. Pod infection can result in heavy seed infection, and sowing *Alternaria*-infected seed can cause seedling blight.

Moderate temperatures and frequent rainfall during spring favour this disease. Disease is both seed- and stubble-borne and can be managed by sowing clean seed and avoiding sowing close to infected residues. No fungicides are registered for the control of *Alternaria* in canola.

9.8 Managing viruses

Management of viruses centres on implementing best agronomic practice:

- Retain standing stubble to deter migrant aphids from landing.
- Sow at the optimal seeding rate and sowing time, because earlier sown crops are more prone to aphid attack.
- Control in-crop and fallow weeds to remove the in-crop and nearby sources of virus infection. [21]

Beet western yellows virus (BWYV) is a persistently transmitted virus that infects a wide range of crops and weeds. Its main vector is the green peach aphid (*Myzus persicae*).

Virus-control strategies should be based on preventing infection, because infected plants cannot be cured. Preventive measures to avoid BWYV infection in canola include seed treatment with systemic insecticides that are effective for green peach aphid control and sowing in standing wheat stubble. [22]

What to look for

Paddock

Discoloured, sometimes stunted plants occur in patches, in thinner crop areas or the edge of the paddock, and gradually spread.

Plant

- First signs are red, yellow or purple colours at the ends or edges of older leaves, then yellowing in the middle of the leaf.
- Colours are more intense between leaf veins and on the upper side of the leaf.
- Petioles and leaf veins are green or pale.
- Discoloured leaves become thickened and may cup inwards.
- Infected plants are often stunted and pale, and produce few flowers or seeds.
- Late-infected plants show leaf symptoms but are not stunted and have lower yield loss. [23]

Growers are advised to check canola crops early in the season for aphid presence. If aphids are found, an effective insecticide should be applied.

There is no indication that the occurrence of BWYV in canola poses a threat to neighbouring pulse crops.[24]

More information

GRDC Update Papers: *Beet western yellows virus* (synonym: *Turnip yellows virus*) and green peach aphid in canola

Canola diseases. The Back Pocket Guide

GRDC Media Centre: Watch for chickpea viruses near canola

[21] GRDC (2014) Canola disease management in the northern region—details. GRDC Gound Cover, 21 March 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Canola-disease-management-in-the-northern-region/Details

[22] eXtensionAUS. Latest on canola disease—2015 GRDC Update Papers. eXtension, http://www.extensionaus.com.au/2015-grdc-update-canola-papers/

[23] B. Coutts (2015) Diagnosing beet western yellow virus in canola. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-beet-western-yellow-virus-canola

[24] eXtensionAUS. Latest on canola disease—2015 GRDC Update Papers. eXtension, http://www.extensionaus.com.au/2015-grdc-update-canola-papers/

More information

[NSW DPI: Virus diseases in canola and mustard]

[GRDC Resources: Reducing aphid and virus risk]

[GRDC Update Papers: Virus development in canola crops during 2014 in New South Wales and implications for the oilseed and pulse industry]

Of the three virus species recorded in canola in Australia, BWYV is the most common and has potential to cause yield losses in canola. Commercial canola varieties appear resistant to *Turnip mosaic virus* (TuMV). However, some lines of condiment mustard and juncea canola (both *Brassica juncea*) have been severely affected by TuMV in trials in northern New South Wales. The importance of *Cauliflower mosaic virus* (CaMV) in canola and *B. juncea* is not known.

All three viruses are spread by aphids from weeds, which act as hosts. BWYV can come from a range of weed, pasture and crop species. Turnip weed, wild radish and other *Brassica* weeds are important hosts of TuMV. Substantial yield losses from viruses, particularly BWYV, can occur even when there are no obvious symptoms.

Seed treated with an imidacloprid product or Poncho® Plus (imidacloprid + clothiandin) is recommended to protect crops from early infestation with aphids. [25]

[25] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

SECTION 10

Plant growth regulators and canopy management

Not applicable for this crop.

SECTION 11

Crop desiccation/spray out

More information

Check current registered chemical labels at: Australian Pesticides and Veterinary Medicines Authority

Farm Weekly: New canola weed control option

Direct harvesting canola with desiccation or swathing to reduce ryegrass seed set

(For information on swathing, see Section 12. Harvest.)

Chemical desiccation is an alternative to swathing and very effective where crops have lodged or where weeds have emerged in maturing crops. The most commonly used desiccant is diquat (Reglone®), which is registered for ground and aerial application on canola crops (refer to product label for application rates).

Desiccation can be a useful strategy on variable soil types; for example, where heavier soil types or drainage lines keep the crop greener for longer, a desiccant can hasten harvest of these areas and reduce the risk of problems arising from high moisture. It can also be used where swathing contractors are not available.

Diquat (Reglone®) has no detrimental effects on the seed or its oil quality if applied at the correct time. It works through contact action and requires almost complete coverage of the plant to work effectively. An experienced aerial operator can apply it to ensure uniform coverage with minimal spray drift.

The correct time for desiccation is when 70–80% of seeds have changed colour in middle pods, which is when the crop has passed its optimal swathing stage. The crop will be ready to harvest within 4–7 days (minimum 4 day Harvest Witholding Period) after the desiccant is applied, depending on the size and density of the crop.

More information

Pre-harvest herbicide use. Fact Sheet.

Harvest options for canola—windrowing timing, direct heading, desiccation with Reglone and treatment with Pod-Ceal. Effects on yield and oil percentages

Using paraquat in canola, wheat or barley warning: crops will cause residue violations

Desiccate only an area of crop that can be harvested over a period of 1–2 days. The harvester must be ready within 4 days of a desiccant being applied to minimise the potential of losses from shattering. Withholding periods should be adhered to.

Other products not registered for use in canola should not be used as desiccants because issues with chemical residues can affect markets and quality of the canola.

Desiccation is generally considered a special-purpose management aid to be used when problems with windrowing, weeds or harvesting are anticipated. Specialist agronomic advice should be sought. [1]

Glyphosate (specifically Weedmaster DST®) is registered for pre-harvest application. It should be noted that the intention is to control weeds present in the crop at the approved timing, that is, *apply to mature standing crop from early senescence (minimum 20% of canola seeds as a random sample from various heights in the crop*

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[1] P Carmody (2009) Windrowing and harvesting. Ch. 14. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

canopy from the main stem, have changed to a dark brown/black colour) prior to swathing or direct harvest (minimum 5 day Harvest Witholding Period).

It is not intended to be used to manage canola maturity (i.e. bringing grain moisture down for harvest). Speed of crop desiccation is dependent on crop stage, growing conditions and weather conditions during and after application.

Table 1: Product registrations for pre-harvest weed control and desiccation VARY by crop type. Always check product labels (NOTE: Paraquat/diquat products, for example Spray.Seed®, are not registered for pre-harvest weed control or desiccation). [2]

Crop	Paraquat	Diquat	Glyphosate
Canola	Paraquat is not registered for: • in-crop spray topping; • pre-harvest crop desiccation; • under-the-cutter-bar spraying during swathing or windrowing activities; • pre-harvest weed control; • spraying over the top of swaths or windrows **DO NOT USE PARAQUAT PRODUCTS FOR THESE USE PATTERNS** These use patterns are unregistered.	Pre-harvest crop desiccation (all states): Spray when 70% of the pods are yellow and the seeds are browny or bluish and pliable. Canola ripens unevenly and is prone to pod shatter and seed loss. Direct harvest four to seven days after spraying. **WHP: DO NOT harvest for at least 4 days after application.**	**Only weedmaster®DST® is registered for pre-harvest use in canola.** Apply to mature standing crop from early senescence (minimum of 20% seed colour change to a dark brown/black colour from within the crop) prior to windrowing or direct harvest. Use the higher when crops or weeds are dense and/or where faster desiccation is required. DO NOT use on crops intended for seed DO NOT harvest for 5 days after application to standing crops DO NOT overspray windrows DO NOT apply to standing crops and again at the time of windrowing Refer to the complete weedmaster®DST® label and critical comments section.

[2] GRDC (2014), Pre-harvest Herbicide Use fact sheet. http://www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

SECTION 12

Harvest

Canola crops can be either windrowed (Figure 1) or direct-harvested. The method chosen depends on the availability and cost of contract windrowing, the type of harvesters available and the relative risk of adverse weather in a particular locality. Some of the advantages of windrowing are: uniform ripening, earlier harvesting (7–10 days), less exposure to spring storms and rain, reduced shattering losses during harvest, and less hail and wind loss. Harvesting can usually continue 'around the clock'. [1] Some advantages of direct heading include cost, availability of headers on farm and a higher harvest index on low-yielding crops.

Figure 1: Windrowing prior to harvest is the more common practice. (Photo: Rebecca Jennings)

More information

[Direct heading canola. Fact Sheet]

[Harvest management. Module 7. Better canola]

[DAFWA trial: Retained canola seed options at Grass Patch, 2013]

12.1 Windrowing

Key points:

- Physiological maturity occurs when the seed moisture content reaches 35–45%.
- Check the crop regularly from 14 days after the end of flowering (10% of plants with flowers).

[1] L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

- Look for colour change across the whole plant, particularly in crops with lower plant populations.
- Sample from representative areas of the paddock, and check all varieties for change in seed colour; it will vary within a district.
- Book a contractor early in the season and contact again when the crop has reached the end of flowering.
- Optimal windrowing stage lasts for 4–6 days in most areas.
- When seed losses are obvious on the windrower, stop and consider direct harvesting. Planning is critical for a smooth harvest operation. Less experienced growers are advised to organise a contractor or an experienced neighbour to carry out the windrowing.

Canola is an indeterminate plant, which means it flowers until limited by temperature, water stress or nutrient availability. As a result, pod development can last over 3–5 weeks, with lower pods maturing before higher ones. Consequently, canola is often windrowed to ensure that all pods are mature at harvest.

Older canola varieties had a lengthy flowering period, but growers now have access to a greater range of varieties with differing maturities and more tolerance to pod-shattering.

Some early-maturing varieties have been developed with shorter flowering and pod maturity periods. Direct harvesting (instead of windrowing) is more of an option for these shorter statured and earlier maturing varieties in some regions.

Whether the crop is windrowed or direct-harvested will depend on the varieties grown, soil types, seasonal conditions, availability of windrowers, and the size and variability of the crop. Canola crops that are variable in their maturity or show significant differences in the maturity of the top and bottom pods are ideally windrowed to minimise shattering losses. The plant should be windrowed before the lower pods approach shattering stage.

Like hay cutting, windrowing of canola hastens the maturity of the crop, allowing the top pods to be harvested at the same time as the lower pods. By cutting the crop and placing it in a windrow on the stubble, the pods and seeds can dry faster than a standing crop (by as much as 8–10 days). Windrowed canola is much less susceptible than a standing crop to wind, rain and hail damage. In the windrow, seeds will reach a uniform harvest moisture content of 8% within 6–10 days of being cut.

Several harvester-front options are available for canola. A belt front, for example, can be used to windrow or direct-head a crop, but with minor modifications, it can also be used to harvest a windrowed crop. Various pick-up attachments or crop lifters can be used on existing open-front headers to harvest canola windrows.

For most canola-production areas, windrowing has the following advantages:

- allowing earlier harvest (8–10 days) because seed matures more evenly
- hastening maturity (in higher rainfall areas)
- evening maturity where soil types are variable in individual paddocks
- reducing losses from hail and excessive winds
- providing flexibility for the grower with large areas, because the timing of harvest is not as critical
- reducing shattering losses during harvest
- around-the-clock operation to cover large areas
- helping to control escaped or herbicide-resistant weeds in some cases [2]

12.1.1 When to windrow

Windrowing should start when 50–70% of seeds have changed colour to red, brown or black (Figure 2). The crop is usually ready for windrowing 20–30 days after the end of flowering, and should be regularly checked for changes in seed colour. The end of flowering is considered to be when only ~10% of plants have any flowers left on them.

Windrowed crops should be ready to harvest 5–14 days after windrowing, depending on the weather. The moisture content of the grain should be ≤8%. [3]

[2] P Carmody (2009) Windrowing and harvesting. Ch. 14. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[3] L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

In warmer, drier areas, windrowing is better done when seed reaches 50–60% seed-colour change. Under higher temperatures, the windrowed plant dries too rapidly to allow seeds to mature fully in the pods and oil content can be lower.

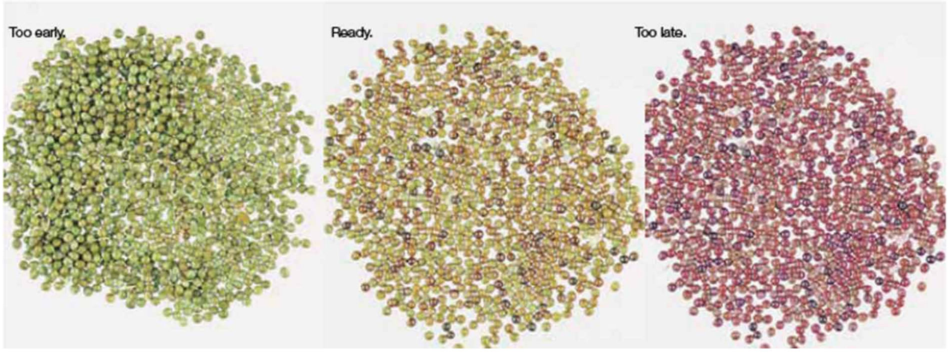

Figure 2: *Seed-colour changes determine the optimum time for windrow timing. (Photo: DAFWA)*

In summary, windrowing too early can result in lower yields and oil contents, and too late will lead to shattering losses.

The optimum time for windrowing is when the top third of the plant has mostly green seeds. These should be firm but pliable when rolled between the thumb and forefinger. The middle section of the plant will have 80% of seed green or green-red and be very firm but pliable; the other 20% may be red-brown to light brown. The bottom third of the plant will have dark brown to black seeds.

The time from the end of flowering to windrowing will vary with season, paddock and variety. Check each crop every year to determine the best windrowing time.

If using a contractor, ensure that they are booked well in advance. Noting the end of flowering will help the grower and the contractor to determine approximately when the crop will be ready to windrow. It is most important that a decision to windrow is made based on assessment in a representative area of the paddock.

The optimal windrowing stage for canola lasts ~4–6 days, depending on temperature and humidity. Each day that windrowing is delayed past the optimum time will make the crop more susceptible to shattering losses. These can be minimised by operating at night or when humidity is high after dew or rain. However, where shattering losses during windowing are obvious, growers are advised to change strategy to direct harvesting or to desiccation followed by direct harvesting.

More information

[Revisiting canola management can lift returns]

Windrowing too early, for example, by 4–5 days, can lead to yield losses of up to 10% and reduced oil content. A canola crop should never be windrowed before seed colour has changed, because it will result in significant yield loss. Rollers can be attached to the back of windrowers to help push the windrow down into the stubble and minimise wind damage. Note: withholding periods of pesticides relate to windrowing, not to harvest, if windrowing operations occur. [4]

[4] P Carmody (2009) Windrowing and harvesting. Ch. 14. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

12.2 Direct harvest

Direct harvesting is cheaper than windrowing and it can be done with an open front with an extended platform or with a belt-front attachment. Canola is ready to harvest when almost all pods are dry and rattle when shaken, pods are pale brown, and the seeds are dark brown to black and have <8% moisture content. [5]

Direct heading of canola can often be carried out sooner than assumed, because although the crop stalks may still be green, crop delivery is based on grain moisture, not plant moisture.

Most headers are capable of direct heading canola; many machines come out of Europe where crops are regularly direct-headed. It is critically important to set up the header front correctly, according to the manufacturer's instructions.

Common draper fronts can be used to direct-harvest canola but can be problematic when there is an uneven flow of the crop into the machine. When canola is cut and fed onto the mat, it tends to bounce and fluff up and feed through in lumps. To counter this, a top cross-auger can be fitted that sits across the back of the header front, above the belt. When the canola fluffs up, it hits the auger, which then flicks it towards the centre to even the feed into the header.

Conventional 'tin-front' headers that have an auger at the bottom of the table are also capable of direct heading canola.

The crop takes virtually no threshing to get the grain out of the pods, so machines can be set wide-open to handle a significant amount of crop residue.

Incorrect setting-up of the reel can cause significant losses when direct heading canola. The reel on the header comes into play only when the crop is not feeding easily into the machine, so it should be set high, well forward and only slightly faster than the machine's groundspeed. The reel is not there to rake the crop into the header front because this will create losses from seed shatter. Rather, it should be a backstop for when the crop does not feed into the machine.

Harvesters should have sharp cutter bars so that they cleanly cut the crop rather than 'gnaw' it off.

TO ACCESS THE GRAIN ORANA ALLIANCE HARVEST LOSS CALCULATOR, VISIT: http://www.grainorana.com.au/documents

More information

Direct heading canola. Fact-Sheet.

Direct heading canola delivers at Devenish.

The benefits of disc seeders direct heading canola and on-farm storage.

Harvest options for canola—windrowing timing, direct heading, desiccation with Reglone and treatment with Pod Ceal. Effects on yield and oil percentages.

Harvesting canola in 2013—to windrow or direct head?

Canola harvest: is direct heading a serious option?

Early planning the key to canola direct harvesting.

[5] L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

infocus

12.2.1 Comparison of canola varieties with delayed direct harvest, Gibson, Western Australia

In this trial at Esperance Downs Research Station, Gibson, most canola had acceptable losses prior to harvest, even with delayed harvest (Figure 3). The greatest proportion of losses occurred at harvest. The PodGuard™ variety IH51RR had significantly smaller losses than other varieties both before and at harvest.

Figure 3: Esperance Downs Research Station delayed harvest 2014. (Photo: DAFWA)

Background and aim

Farmers are shifting from swathing (windrowing) to direct harvesting of canola. This allows them to speed up their operations. It is unclear whether all cultivars chosen by growers are suitable for direct harvesting. Although cultivars are marketed as suitable for direct harvesting, there appears to be no systematic testing of cultivars to determine whether these claims are correct. In particular, it is not known whether some cultivars shed more seed than others prior to harvest. If farmers move to direct harvesting, this could become an issue.

Bayer CropScience have released for the Australian market a canola variety (IH51RR) with the PodGuard™ trait. This non-genetically modified (GM) trait is reputed to virtually eliminate shedding of seed out of the pods of canola. This trial includes IH51RR, and it will provide a source of independent testing of the trait in Western Australia.

The aim was therefore to determine whether canola cultivars vary in rates of shedding.

Trial and treatment details

Site information and fertiliser rates are presented in Table 1. There were 12 treatments comprising four cultivars (IH51RR, IH30RR, Hyola 404RR, ATR Stingray) and three harvest times (on time, and 2 weeks and 4 weeks later).

The experimental design was a split-plot with four replicates. Main plots were times of harvest and subplots were varieties.

Table 1: Details for canola delayed direct harvest trial, Gibson, Western Australia

Property	Esperance Downs Research Station (EDRS), Gibson, Paddock N14
Agzone 6	Growing season rainfall (GSR, Aug.–Oct.) 314 mm; GSR + stored water (estimate) 324 mm. Thunderstorm caused 44 mm rain in one day with associated strong winds on 14 Nov., 3 days prior to second harvest
Soil type	Fleming sand, duplex (1.4% organic carbon)
Paddock rotation	Wheat 2013, subterranean clover-based pasture 2012 and 2011
Sowing date	14 May
Fertiliser	Gypsum (17% Ca, 14% S) at 400 kg/ha topdressed over whole site before seeding; Agras No.1 (16%N, 9.1%P, 14.3%S, 0.06% Zn) at 102 kg/ha at seeding; muriate of potash at 120 kg/ha topdressed over whole site 4 weeks after seeding; urea (46% N) at 103 kg/ha topdressed over whole site on 10 July; Twin Zinc (70% Zn) at 1 L/ha on 4 July; Mantrac (50% Mn) at 1 L/ha on 9 July; UAN (32%N) at 70 L/ha on 4 Aug.

Results and conclusions

The Bayer PodGuard™ variety IH51RR had smaller losses at harvest than other varieties, averaging 3% losses at the latest harvest date compared with 10-14% for the other varieties (Figure 4).

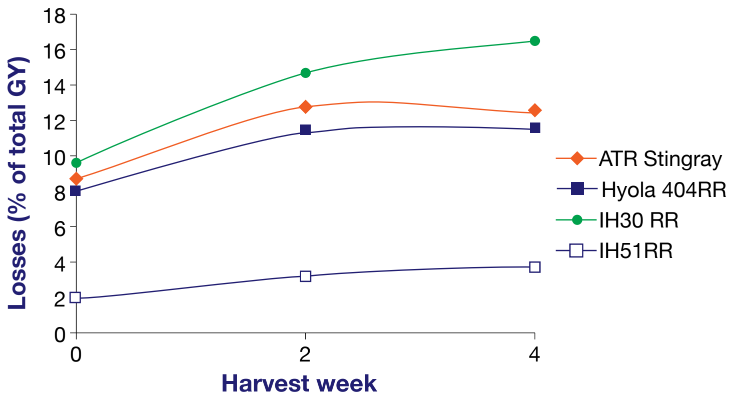

Figure 4: Losses (% of total grain yield, GY) over time for four canola varieties at Gibson in 2014.

Most of the losses of all varieties occurred at harvest. Despite strong winds and rain prior to the second harvest, shedding before harvest was lower than expected, ~15–70 kg/ha (17–29% of total losses), with most loss at harvest (~70–400 kg/ha). Interestingly, the PodGuard™ variety IH51RR did not shed seed out of the pod, but any losses prior to harvest were due to the occasional pod dropping off the plant.

The losses at harvest when using the Department of Agriculture and Food Western Australia (DAFWA) small-plot harvester were likely to be larger than when using wider commercial machines (usually <150 kg/ha). The harvester was moving slowly (3 km/h) to enable stopping at the end of the plots; this resulted in the crop building up at the knife, and consequently, the reel was spending considerable time beating the crop before it moved into the broad elevator. When the DAFWA harvester is moving more quickly, this buildup is reduced. Nevertheless, the trial demonstrated that the PodGuard™ trait does result in lower total losses.

More information

[Harvesting canola in 2013-to-windrow or direct head?]

[Harvest options for canola—windrowing timing, direct heading, desiccation with Reglone and treatment with Pod Ceal—effects on yield and oil percentages]

However, the variety IH51RR appears inherently lower yielding and of lower oil production than most other canola varieties. Consequently, even with greater losses in other RR cultivars, IH30RR and Hyola 404RR produced similar yields (~2.8 t/ha) and more oil (46% compared with 43% for IH51RR). It would therefore be interesting to see the performance of this non-GM trait in a better genetic background. [6]

12.3 Comparing windrowing and direct heading

12.3.1 Windrowing

This technique is likely to be the most widely used. The majority of canola is currently windrowed (Figure 5). The objective of windrowing is to lay the cut material on top of the lower stem material to allow air movement under the windrow to assist in the drying process.

Advantages of cutting the crop and placing it in a windrow on the stubble:

- The pods and seeds will ripen faster than a standing crop (by as much as 8–10 days).
- Windrowed canola is much less susceptible to wind and hail damage than is a thin, standing crop, especially if it has been desiccated with diquat (Reglone®).
- Seeds will reach a uniform harvest moisture content of 8% earlier than with desiccation or direct heading.
- It can help in the management of uncontrolled or herbicide-resistant weeds.
- Even, well-made windrows will speed up the harvest operation.

Disadvantages:

- There are additional costs.
- In very wet seasons, the crop can deteriorate in a windrow.
- The optimum timing lasts only 4–6 days depending on the temperature and humidity.
- The use of contractors may compromise timing.
- Timing of windrowing is determined by percentage change in seed colour, which is a compromise to allow for variability in the weather post-windrowing.
- Windrowing too early can lead to yield losses of up to 30% and reduced oil content, whereas too late makes the crop far more susceptible to shattering losses.
- Poorly made windrows that are uneven result in 'lumps' or 'haystacks', which will slow the harvesting process; any blockages that occur can be time-consuming and costly to clear, especially where contractors charge on a machine-hour basis.
- If the cut plants are 'pushed' down onto the ground during the windrowing operation, the dry-down time may be increased, especially if moderate to heavy rain is received before harvesting.

6 M Seymour (2015) Comparison of canola varieties with delayed direct harvest, Gibson (14ED11). Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/comparison-canola-varieties-delayed-direct-harvest-gibson-14ed11?page=0%2C0

Figure 5: The majority of canola crops are windrowed prior to harvest.

Timing

Collect pods from the main stem of a number of plants and from different positions in the canopy to determine the optimum timing for windrowing. The top third of the plant will have mostly green seeds that are firm but pliable; the middle third, ~80% of seeds green or green-red and very firm but pliable, and 20% red-brown to light brown; and the bottom third, dark brown to black seeds. [7]

Check withholding periods when using Reglone® (see www.apvma.gov.au).

12.3.2 Direct heading

Recent research into direct cutting of canola has shown it to be a viable harvest alternative to windrowing in some circumstances. Favourable conditions for direct heading include having a crop canopy that is slightly lodged and knitted together, even maturity across the paddock, and few green weeds (or when sprayed with a desiccant).

Advantages of direct heading:

- There are no windrowing or desiccation costs.
- Crops dry out faster after wet weather than windrowed crops.
- Crops are allowed to maximise yield potential and oil contents.
- It suits rocky areas, which can be a problem when windrowing, and reduces the risk of harvester blockage that can occur with windrows.

[7] J Midwood (2013) Canola harvest: is direct heading a serious option. GRDC Update Papers, 6 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Canola-harvest-Is-direct-heading-a-serious-option

Disadvantage:

- In crops that are variable, the wait for ripening can expose the crop to wind damage, and thicker crops can take a considerable time to ripen evenly.

Timing

The general colour of the crop is a poor guide of when to harvest; use seed moisture content. The addition of pod sealants is an extra management aid when direct harvesting; it helps by reducing pod shattering and by allowing crops to achieve their full yield potential but is an added cost. When sprayed onto the crop, it provides a unique elastic, semi-permeable membrane over the filling pods. Timing is earlier than the optimum time for windrowing. [8]

12.3.3 Desiccation followed by direct heading

The most common desiccant is diquat (Reglone®), which is registered for aerial application.

Advantages:

- The technique is useful on variable soil types because it allows more even crop ripening.
- It is ideal for weedy crops.
- Crops dry out faster after wet weather than a windrowed crop.

Disadvantages:

- There are shedding losses if a ground-rig has to be used.
- Shattering losses can be very high in windy conditions.
- It is expensive, especially if the desiccant is applied by air.

Timing

The correct time for desiccation is when 70–80% of seeds have changed colour in the middle pods; this is when the crop has passed its optimal windrowing stage. The crop will be ready to harvest within 4–7 days after the desiccant is applied, depending on the size and density of the crop.

Other desiccants such as glyphosate are regularly used pre-harvest on canola in Canada and Europe. This provides far slower senescence of the plants, considerably reducing pod shattering and providing superior end-of-season grass-weed control. [9]

[8] J Midwood (2013) Canola harvest: is direct heading a serious option. GRDC Update Papers, 6 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Canola-harvest-Is-direct-heading-a-serious-option

[9] J Midwood (2013) Canola harvest: is direct heading a serious option. GRDC Update Papers, 6 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Canola-harvest-Is-direct-heading-a-serious-option

12.4 Swathed canola on raised beds

FAQ

Harvesting crops on raised beds differs from harvesting on normal seedbeds only in terms of the constraints imposed by tracking the harvesting equipment in furrows, if so desired (Figure 6). Ideally, harvesting machinery should have wheel tracks that fit the furrows, but normally the beds are harvested with standard-sized tyres and equipment driving on top of the beds.

Swathing crops on raised beds is possible, but special care should be taken to line up the swath width with a multiple of the raised beds.

Effective swathing on raised beds requires a swather that places the swath on the top of a bed. This can be arranged by adapting the swather's opening to match the top of a bed. If a swath is not located squarely on top of a bed, some of it will fall into the furrows.

A swath that overhangs the furrows is unlikely to be a problem to lift and harvest, provided it is harvested when seed moisture content is at, or slightly above, the limit and the straw is still a little pliable, as with field peas. If the swath placement is not wholly on top of a bed and the straw is too wet or too dry, its pick-up and threshing will be inefficient and harvest loss will occur.

Other options can be implemented where farmers have a large enough crop to make it worthwhile to invest extra time and capital. For example, one farmer in the Esperance district has configured his bed-former to build a 2.5-m-wide bed amongst beds that are 2.0 m wide, specifically to carry a swath and facilitate the harvest of the swaths. [10]

[10] D Bakker (2014) Swathing and harvesting on raised beds. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/waterlogging/swathing-and-harvesting-raised-beds

Figure 6: Harvesting on raised beds. (Photo: DAFWA)

12.5 Wet harvest issues and management

Canola generally withstands extended wet harvest periods better than other crops such as wheat. Severe windstorms can cause seed shatter more readily in canola; however, newer varieties have been selected to improve this characteristic. [11]

12.6 Receival standards

Canola receival standards are presented in Table 2. [12]

Table 2: Commodity standards—canola (from AOF 2014)

Parameter	Specification
Oil (%)	42.0 base level; 1.5% premium or deduction for each 1% above or below 42
Free fatty acid (%)	1.0 base level; 2% deduction for each 1% over the base level, rejectable over 2.5
Moisture max. (%)	8.0; 2% deduction for each 1% over maximum
Test weight min. (kg/hL)	62.0; rejectable under this limit
Protein	Unlimited
Seed retention	Unlimited
Germination	Unlimited

[11] L Serafin, J Holland, R Bambach, D McCaffery (2009) Canola: northern NSW planting guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/148300/canola-northern-NSW-planting-guide.pdf

[12] AOF (2014) Quality standards, technical information and typical analysis. 2014/15. Australian Oilseeds Federation, http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/AOF_Standards_201415_Final.pdf

The Western Australian canola receival standards are:

- CAN: non-GM canola. This segregation is for non-GM canola varieties only. The adventitious presence of up to 0.9% of GM events approved by the Australian Government Office of the Gene Technology Regulator is permitted.
- CAG: canola. This segregation is for all approved GM canola as well as any non-GM variety.

More information

[Quality standards, technical information and typical analysis, 2014/15]

[GRDC's Integrated Weed Management Hub]

Effective separation of canola varieties on-farm is key to delivering canola grain to the correct segregation. Lateral flow strip-test kits are available from Foss Pacific to test for the presence of approved GM material in canola.

Certified seed

As part of the segregation process, growers must check the identity and purity of the seed to be sown. Seed to be planted for CAN canola crops must be at least 99.5% pure, or in other words, contain <0.5% GM seed. Check the seed label for information on variety and purity.

12.7 On-farm segregation of canola varieties

Growers planning to deliver to the non-GM canola segregation (CAN) must separate glyphosate-tolerant and non-glyphosate-tolerant canola crops by at least 5 m.

Figure 7: Crop of canola in flower next to a leafy wheat crop. (Photo: DAFWA)

12.7.1 Processes to segregate canola varieties

All canola growers need to know how to segregate different canola varieties to meet CBH Group (Co-operative Bulk Handling Ltd) delivery standards and international trading standards. Growers also need to discuss their planting intentions for boundary paddocks with their neighbour before planting (Figure 7).

The processes required to segregate canola varieties are similar to the processes used to segregate other grains such as feed barley from malt barley.

In accordance with best practice, growers should ensure that:

- all bags of seed are labelled;

- seed of different varieties are stored separately;
- seed is stored in vermin-free areas;
- lot numbers of all seed sown are retained; and
- record is kept of where each seed-lot was sown.

12.7.2 Farmer-saved canola seed

Some seed companies allow growers to retain open-pollinated varieties for sowing in subsequent years. Farmer-saved seed should be tested by a commercial laboratory for the presence of approved GM varieties before sowing. This will provide confidence that the seed will produce CAN grain. Growers intending to retain seed must ensure that a 400-m buffer is maintained between the seed crop and glyphosate-tolerant canola crops, including those on neighbouring properties.

12.7.3 Machinery hygiene

Good machinery hygiene is essential for the delivery of segregated canola. Thoroughly clean all grain-handling and storage equipment between handling of different varieties of seed or grain. The Australian Oilseeds Federation has published a useful guide: 'Harvesting equipment clean down guidelines—canola'.

It is important to ensure that farm staff and contractors know the variety and status of canola being grown on your property and the processes required to ensure effective segregation. Seed bags, silos and trucks should be clearly labelled to minimise the risk of accidental mixing of different grades or varieties of canola.

12.7.4 Crop management

The Licence and Stewardship Agreement for glyphosate-tolerant canola requires growers to maintain a 5-m buffer between glyphosate-tolerant canola crops and any non-glyphosate-tolerant canola crops. If canola is planted within the 5-m buffer zone, this canola crop must be harvested and delivered as CAG canola.

Swathed canola crops are at risk of being moved into adjacent paddocks (including neighbouring properties) via strong winds or floodwaters. Avoid swathing boundary paddocks if possible; if you must swath, leave a buffer of standing crop about one header-width wide along the boundary fence.

If you are aware that heavy rainfall could carry plant material from your property onto neighbouring properties, consider installing diversion banks to prevent movement of plant material. Develop a plan to manage any resultant herbicide-tolerant volunteer plants. Discuss your management plans with your neighbours before planning canola in your boundary paddocks.

Growers need to be aware that staff of utilities such as Western Power, Water Corporation and telephone companies may gain access to the wayleaves on their properties without notification or permission. This could lead to the accidental transfer of pollen and seed between paddocks, but the percentage should be extremely low and is unlikely to affect the delivery standards of grain.

12.7.5 Volunteers

The control of all herbicide-tolerant volunteers must be part of your weed-management plan. Good paddock records are required to ensure that volunteer canola plants are controlled in succeeding crops with the appropriate chemical. Prevention is better than cure, so every effort should be made to minimise the spread of canola seed outside the sown paddocks. Always clean down seeders, swathers and headers within the paddock before moving the equipment to other areas.

Numerous herbicide options are available to manage herbicide-tolerant canola volunteers. Select a chemical that is compatible with the current crop in the paddock.

Livestock grazing canola stubble can excrete viable canola seeds for up to 7 days. To minimise the spread of herbicide-tolerant volunteers, it is advisable to contain livestock in an area of the paddock and provide supplementary feed for a week before moving them to a canola-free paddock.

12.7.6 Record keeping

Be aware of and comply with any requirements for record keeping for your canola plantings. It is anticipated that the grains industry will continue to move towards adoption of quality assurance systems by all growers. [13]

12.8 Weed management at harvest

Weed seed removal can be achieved in two ways:

1. Harvesting provides an excellent opportunity to remove weed seeds from the system and prevent them from being spread across the paddock or farm. Collecting seed at harvest has the potential to be a useful component of an integrated weed management program.
2. Grazing weed-contaminated crop residue can be a cost-effective way of controlling weed growth. Animal digestion of weed seeds prevents a large proportion of seeds from entering the seedbank.

Weed-seed collection at harvest will not increase grain yield, because the weeds have already caused damage to the crop. The tactic can only prevent increases to the seedbank, and it may give a yield advantage to the next season's crop through reduced weed numbers during the season. [14]

More information

Crop Weeds: Weed management at harvest

For more information, see Section 6. Weed management.

[13] DAFWA (2014) On-farm segregation of canola varieties. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/canola/farm-segregation-canola-varieties

[14] S Peltzer, A Douglas (2015) Crop Weeds: Weed management at harvest. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/grains-research-development/crop-weeds-weed-management-harvest?page=0%2C0

SECTION 13

Storage

13.1 Canola storage at a glance

- For safe storage and optimum quality, canola should be stored ‘cool and dry’.
- Aim to store canola seed with 42% oil content at <7.0% moisture content. Samples with high oil content (50%) can be stored safely at <6.0% moisture content.
- Clean out storage facilities, grain-handling equipment and headers to reduce carryover of storage pests from one season to the next. This minimises early infestation pressure.
- Aeration to promote uniform, cool storage conditions is a key strategy for maintaining oil and seed quality. During summer, aim for stored canola temperatures in the range 18°–23°C.
- For oilseeds, monitor storages fortnightly and keep records. Sieve grain and use probe traps to detect insect pests. Make visual inspections and smell the canola. Check canola temperature at a number of locations in the storage. [1]

More information

Storing oilseeds—Grain Storage Fact Sheet

Cool and dry conditions maintain canola quality—Farming Ahead

[1] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

13.2 Storing oilseeds

Storage of oilseeds on-farm requires attention to detail, because limited tools are available compared with cereal grain storage. Oilseeds are also more susceptible to quality deterioration and have fewer insect-control options. To retain the canola's market value, care must be taken to maintain oil quality, visual appearance, and freedom from moulds, insect pests and unregistered chemicals. [2]

The decision to store oilseeds requires planning, careful management and a suitable storage system. [3]

Points to consider when storing oilseeds such as canola:

- Limited chemical control options for insect pests in stored oilseeds increase the importance of careful management and planning.
- Aeration cooling is required when storing oilseeds to maintain seed and oil quality, limit insect reproduction and reduce risk of mould development.
- Seek advice about the appropriate fan size to use to aerate canola. Canola's small seed size will reduce fan output by 40–50% or more. In some situations, the fan may fail to produce any airflow.
- Moisture content in oilseeds must be much lower than in cereal grains. The high oil content increases the risk of moulds and quality damage.
- Successful phosphine fumigation requires a gas-tight, sealable silo.
- To prevent residues on canola, do not use the standard chemical insecticide structural treatments. Use diatomaceous earth (DE) products such as Dryacide®. [4]

13.3 Seed quality and moisture content at storage

Windrowing canola may have advantages over direct harvesting of the standing crop. It hastens and evens out the drying rate of ripe canola. If direct harvesting, harvest at <7% moisture content to allow for paddock variability with respect to crop maturity.

Timing of harvest and header settings—drum speed, concave gap and fan speed—have a significant impact on minimising trash and impurities and seed damage. If admixture in the seed sample is high, fines can concentrate directly below the storage fill-point, leading to heating and fire risk. Larger pieces of crop trash may also concentrate along silo walls, leading to mould development.

The presence of damaged seeds is more attractive to storage pests such as the rust-red flour beetle (*Tribolium castaneum*).

[2] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

[3] GRDC (2014) Storing oilseeds. GRDC Stored Grain Information Hub, http://storedgrain.com.au/storing-oilseeds/

[4] GRDC (2014) Storing oilseeds. GRDC Grain Storage Fact Sheet, July 2014, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-9_Oil-Seed-July14.pdf

Safe moisture content for storage depends on temperature and oil content. The higher the oil content and storage temperature, the lower the moisture content must be for safe storage. At 25°C, canola with an oil content of 45% is safe to store at <7.0% moisture content. Canola with 50% oil content is safe at <6.0% moisture content (see Figure 1).

The aim is to store the canola in conditions that achieve an equilibrium relative humidity of <60% in the storage (see Figure 1). This reduces the risk of mould development, canola self-heating and oil quality deterioration.

Use of aeration to cool seed temperatures to ≤20°C is a key aid to reliable canola storage. [5]

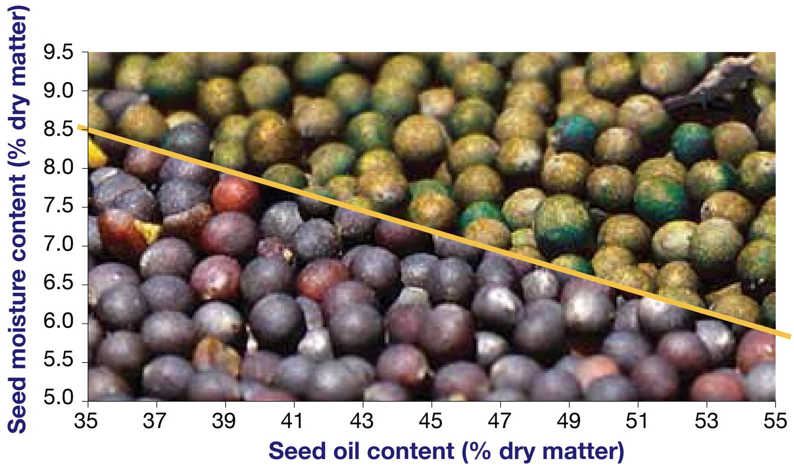

Figure 1: Safe storage conditions for canola at 60% equilibrium relative humidity. The relationship between seed moisture content and oil content is shown at 25°C (yellow line). Canola stored at conditions above the line is at potential risk of seed and oil quality loss. (Source: CSIRO Stored Grain Research Laboratory)

13.4 Types of storage

Ideal storage for canola is a well-designed, cone-based, sealable silo fitted with aeration (Figure 2). The storage should be designed for minimum damage to seed, ease of cleaning and hygiene for empty storages, and suitability for effective use of aeration cooling.

If seed requires insect pest control, the silo is then sealed (gas-tight) for the required period as stated on the product label (usually 7–10 days) to enable effective phosphine fumigation. For all storage types, extra caution should be taken to prevent rain/water ingress into storages. [6]

5 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

6 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

Figure 2: Aerated, sealable silos.

13.5 Hygiene—structural treatment

Most common insecticide treatments for storage surfaces are not to be used on storages for holding canola. **Warning**: if unregistered chemical residues are detected by grain buyers, it can have serious long-term consequences for domestic and export markets.

Diatomaceous earth (amorphous silica) or inert dust is a naturally occurring, mined product with insecticidal properties. Products such as Dryacide® can be applied as a dust or slurry spray onto internal surfaces of storage areas and equipment. Once old grain residues have been physically removed or washed out of storages and equipment, Dryacide® can be applied as a non-chemical treatment to reduce insect pest carryover.

Insect pests survive in any sheltered place with grain residues—in grain hoppers, augers, field bins and inside headers. All of these attractive locations require attention.

Some products based on pyrethrin + piperonyl butoxide (e.g. Rentokil's Pyrethrum Insecticide Spray Mill Special® or Webcot SPY® natural pyrethrum Insecticide) are registered for moth control in oilseed storage areas or storage sheds. They can be used as a structural-surface spray or fogging–misting treatment. They are not to be applied as a grain treatment. Use only as labels direct and only use products registered for use in the state or territory as stipulated on the label. Discussion with grain buyers and traders prior to use of any products is also important. [7]

[7] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

13.6 Aeration

Aeration should be considered an essential storage tool for canola. Correctly managed, it creates uniform, cool conditions in the seed bulk and slows most quality-deterioration processes.

Aeration:

- helps maintain oil quality— low free fatty acid content / rancidity, good colour and odour;
- reduces the risk of 'hot spots', moisture migration and mould development;
- slows or stops breeding cycles of storage insect pests (e.g. rust-red flour beetle) by maintaining grain temperatures at <20°C; and
- maintains germination and seed vigour for longer when kept cool and dry. [8]

Canola, being a much smaller seed than cereal grains, adds significantly more back-pressure to the aeration fan. This means that an aeration cooling system set up to produce airflows of 2–4 litres per second per tonne (L/s.t) in cereal grain will typically produce only 40–60% of that when used in canola.

When setting up storages to cater for cereals and canola, seek advice about the fan sizes and number required to achieve the 2–4 L/s.t.

Other factors that affect the amount of airflow through the grain:

- depth of the grain in storage
- amount of fine admixture and foreign plant material in the grain
- design and size of fan ducting and venting on top of the silo

The area and type of ducting must be adequate to disperse the air through the storage and not to be blocked by the small canola seeds. Avoid splitting airflow from one fan into multiple silos, because the back-pressure in each silo will vary and incorrectly apportion the amount of airflow to each. This will be exacerbated if different grains are stored in each silo, such as canola in one and a cereal in the other. [9]

13.6.1 Aeration cooling

Fans providing low airflow rates of ~2–4 L/s.t can both cool seed and provide uniform seed temperature and moisture conditions in the storage. Always check that the fan's design and capacity is suitable for the small canola seed. In some cases, an aeration fan may not be able to create any airflow through canola.

Well-managed cooling aeration typically makes seed temperature fall safely to ~≤20°C within days. Regular checking of canola in storage is essential. Make visual

8 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

9 GRDC (2014) Storing oilseeds. GRDC Stored Grain Information Hub, http://storedgrain.com.au/storing-oilseeds/

inspections, check seed moisture, use a temperature probe to monitor bulk seed temperature, and sieve for insects. [10]

13.6.2 Automatic controllers

Often, 'aeration cooling' fans are simply turned on and off manually or a timer clock is used. However, much can be gained by investing $5000–7000 in an automatic controller that selects the optimum run-times and ambient air conditions under which to turn on the fans. The controller continually monitors air temperatures and relative humidity and may select air from only 2 or 3 days in a week or fortnight. One unit has the capacity to control fans on multiple silos. [11]

13.6.3 Operation of aeration fans

- Run fans constantly during the first 4–5 days when grain is first put into the silo. This removes the 'harvest heat'. Smell the air coming from the silo top-hatch. It should change from a warm, humid smell to a fresh, cool smell after 3–5 days. The first cooling front has moved through.
- For the next 5–7 days, set the controller to the 'rapid' setting. This turns fans on for the coolest 12 h of each day to reduce the seed temperature further.
- Finally, set the controller to the 'normal' mode. The fans are now turned on for ~100 hours per month, selecting the coolest air temperatures and avoiding high-humidity air. [12]

13.6.4 Aeration drying

Well-designed, purpose-built, high-flow-rate aeration-drying systems with airflow rates of 15–20 L/s.t can dry seed reliably. During aeration drying, fans should force large volumes of air through the grain bulk for many hours each day. This ensures that drying fronts are pushed quickly through so that seed at the top of the silo is not left sitting at excessively high moisture contents (Figure 3).

Seeds from oilseed crops are generally well suited to this form of drying when correctly managed. Utilise all ambient air available with relative humidity <70% to provide a low average relative humidity for each run time. This can reduce moisture content without the risk of heat damage to seed oil quality. Monitor regularly and take care that seed in the bottom of the silo is not over-dried. Seek advice when undertaking aeration drying for the first time.

Do not use aeration fans with low airflow rates when attempting to dry high-moisture seed.

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10 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

11 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

12 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

Automatic controllers for aeration drying are also available to run fans at optimum ambient air conditions. Some controller models provide the option to switch to either cooling or drying function. Ensure that the controller is fitted with a good-quality relative humidity sensor. [13]

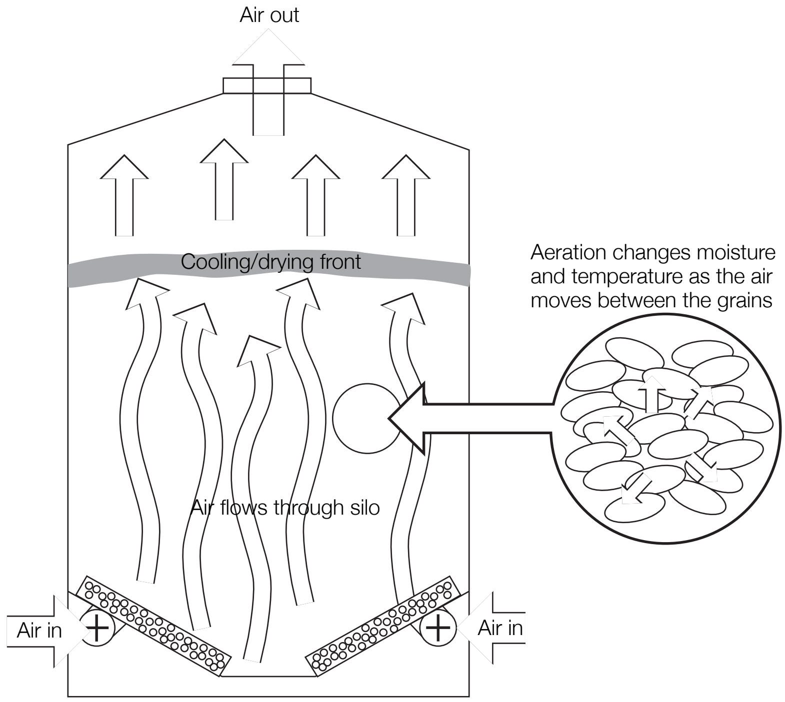

Figure 3: Cooling–drying fronts in the aeration process. (Source: C. Newman, DAFWA)

13.6.5 Heated air drying

For hot-air drying of canola seed, fixed-batch, recirculating-batch or continuous-flow dryers are all suitable for reducing moisture content. Always consider the blending option first if low-moisture canola seed is available. Canola seed dries very rapidly compared with cereal grains, so close attention must be given to temperature control and duration to ensure that seed is not over-dried. It is wise to use the minimum amount of additional heat:

- Use air temperatures in the 40–45°C range.
- Stay nearby and monitor moisture content every 15 min. Over-drying of canola seeds can occur rapidly. Seek advice if drying canola for first time.
- For batch-dryers when moisture content readings reach 8.5%, turn off the heat source and move to the seed-cooling phase with fan only. Retest once cooled.
- Use belt conveyors or run the auger full when moving seed to reduce seed damage.
- Aim to make good use of storage aeration fans, before and after the drying process. [14]

[13] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

[14] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

13.6.6 Fire risk

The dust and admixture associated with oilseeds presents a serious fire risk. Harvesting and drying are high-risk operations where constant vigilance is required. Good housekeeping in and around equipment and close observation of problem sites will reduce the threat.

In case of fire, ensure that appropriate equipment is at hand and a plan of action understood by operators. Without careful management, canola seeds in storage with high moisture content and/or high levels of admixture pose a risk of mould formation, heating and fire through spontaneous combustion. [15]

13.7 Insect pest control

Several insect pests will infest stored oilseeds, usually favouring the grain surface. These are the rust-red flour beetle (Figure 4), Indian meal moth (*Plodia interpunctella*) (Figure 5), warehouse moths (*Ephestia* spp.) and psocids (*Liposcelis* spp.)

Figure 4: Rust-red flour beetle (Tribolium castaneum).

15 P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

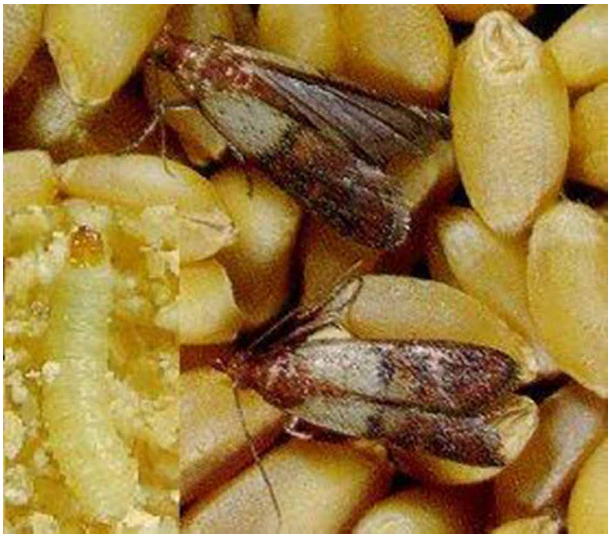

Figure 5: Indian meal moth (Plodia interpunctella).

These pests multiply rapidly given food, shelter, and warm, moist conditions. They can complete their full life cycle in about 4 weeks under optimum breeding temperatures of ~30°C.

Only a few treatments are registered for insect control in oilseeds. Always check labels prior to use and abide by use restrictions for different states and territories in Australia. For most states, treatments include phosphine, pyrethrins, DE, and ethyl formate as Vapormate®. Use of pyrethrins and DE should be limited to storage-area treatments, and Vapormate® is restricted for use by licensed fumigators only. This leaves phosphine as the key farm storage treatment for oilseed storage pests.

Phosphine fumigation must take place in a gas-tight, well-sealed silo. If the silo passes the standard pressure test, it shows that there are no serious leakage points. Given this, phosphine gas can be held in the silo at high enough concentrations for sufficient time to kill all life stages of the pest (eggs, larvae, pupae, adults).

Several silo manufacturers make aeratable, sealable silos that pass the Australian Standard Pressure Test—AS 2628. Like most oilseeds, canola seed has the ability to adsorb phosphine gas, and so it is important to use the full, correct label dose rate.

By using phosphine bag-chains, belts or blankets, placement and removal of the treatment is simplified. If using the standard phosphine tablets, ensure that tablets are kept separate from the canola seed by using trays so the spent tablet dust can be removed following fumigation.

If aeration cooling has been in use and the seed temperature is <25°C, ensure that the fumigation exposure period is ≥10 days. See product label for details.

Once the fumigation is completed, release the seal, vent the gas, and return the stored canola to aeration cooling. [16]

[16] P Burrill (2012) Safe storage. Module 8. In Better canola—canola technology update for growers and advisors. Australian Oilseeds Federation, http://www.australianoilseeds.com/__data/assets/pdf_file/0019/9082/MODULE_8_-_Safe_Storage_of_Canola_Philip_Burrill_-_V2_Sep_2012.pdf

13.8 Further reading

Stored Grain Information Hub for Grain Storage, Quality Control, Insect & Pest Management. GRDC, www.storedgrain.com.au

Storing oilseeds. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/storing-oilseeds/

Vigilant monitoring protects grain assets. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/monitoring-protects-grain/

Northern and Southern Regions. Stored grain pests—identification. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/stored-grain-pests-id-ns/

Hygiene & structural treatments for grain storage. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/hygiene-structural-treatments/

Aerating stored grain, cooling or drying for quality control. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/aerating-stored-grain/

Performance testing aeration systems. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/testing-aeration/

Fumigating with phosphine, other fumigants and controlled atmospheres. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/fumigating-with-phosphine-and-ca/

Pressure testing sealable silos. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/pressure-testing/

Grain storage facilities: planning for efficiency and quality. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/grain-storage-facilities/

Phone enquiries: grain storage specialists: 1800 weevil (1800 933 845)

SECTION 14

Environmental issues

More information

GRDC Ground Cover: Study seeks new insights into heatwave effects

Frost, moisture stress and heat stress can all have an impact on grain yield, oil content and oil quality. Frost can occur at any time during the growth of the canola plant, but the most damaging frosts occur when pods are small. Pods affected at this time have a green to yellowish discoloration, then shrivel and eventually drop off. Pods affected later may appear blistered on the outside of the pod and usually have missing seeds.

Moisture stress and heat stress are linked; the plant will suffer heat stress at a lower temperature if it is also under moisture stress. Flower abortion, shorter flowering period, fewer pods, fewer seeds per pod and lower seed weight are the main effects, occurring either independently or in combination. [1]

GRDC's new approach to frost

Frost has been estimated to cost Australian growers ~$360 million in yield losses both directly and indirectly every year. The Grains Research and Development Corporation (GRDC) has long acknowledged the severe impacts of frost on crop production, and since 1999 has invested ~$13.5 million in more than 60 frost-related projects. [2]

With every second year, on average, delivering frosts significant enough to wipe out tens of millions of dollars of Western Australian crops, it is no surprise that the state's grain growers place frost management at the top of their research, development and extension priority list. [3]

By 2014, GRDC increased investment in frost research to establish the National Frost Initiative (NFI). This 5-year, national initiative is tackling frost from several angles and aims to deliver growers a combination of genetic and management solutions to be combined with tools and information to improve prediction of frost events.

The three-pronged initiative addresses:

1. Genetics. The aim is to rank current wheat and barley varieties for frost susceptibility and identify more frost-tolerant wheat and barley germplasm;

[1] T Potter (2009) The canola plant and how it grows. Ch. 3. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

[2] T March, S Knights, B Biddulph, F Ogbonnaya, R Maccallum, R Belford (2015) The GRDC National Frost Initiative. GRDC Update Papers, 10 February 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

[3] DAFWA. Frost. Climate & weather. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/climate-land-water/climate-weather/frost

2. Management. Are there management practices or preventive products that growers could use to reduce the impact of frost?
3. Environmental prediction. Focus is on predicting the impact of frost events on crop yields and mapping frost events at the farm scale to enable better risk management. [4]

The Department of Agriculture and Food, Western Australia (DAFWA) plays a major role in addressing the impact of frost on the state's growers through a combination of on-farm and genetics research and development activities. [5]

Listen to GRDC Driving Agronomy podcasts:

- New GRDC-funded research will seek to find out whether applying additional potassium to a crop will help it resist the stress of drought and frost.
- 2015 will see the introduction of frost-tolerance ratings in cereal crops. On this program GRDC Managing Director, John Harvey, explains how it came about and talks about some other research and development highlights.

More information on GRDC Driving Agronomy:

GRDC DRIVING AGRONOMY

http://grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts/2014/02/Potassium-Frost-and-Drought

http://grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts/2013/12/Frost-Tolerance-Ratings-on-the-Way

GRDC Media Centre: Pre-seeding planning to manage frost risk in WA

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4 T March, S Knights, B Biddulph, F Ogbonnaya, R Maccallum, R Belford (2015) The GRDC National Frost Initiative. GRDC Update Papers, 10 February 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

5 DAFWA. Frost. Climate & weather. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/climate-land-water/climate-weather/frost

GRDC Ground Cover: Retained stubble: friend or foe?

14.1 Frost

Canola is least tolerant to frost damage from flowering to the clear watery stage (~60% moisture).

Symptoms include:

- yellow-green discoloration of pods (Figure 1)
- scarring of external pod surfaces
- abortion of flowers (Figure 2)
- shrivelling of pods
- pods eventually dropping off (Figure 3)
- shrivelling and absence of seeds (Figure 4)

Plants in frost-prone areas lose flowers and young pods, or they have scarred pods with damaged seed. Plants develop more flowers and set pods if there is sufficient time and soil moisture.

Low-lying areas, light-coloured soil types and dry soil and areas with more retained stubble are likely to show more damage. To assess the canola properly, the pods need to be opened to check grain development.

More severe frost causes developing buds to turn yellow, die and fall off, leaving gaps in the flowering spike between more developed pods and new flowers that form afterwards.

Severe frosts can kill developing seed, which turns into a mushy brown mass that dries to a small black or brown speck. The pod surface can turn yellow-green or develop a paler, scarred surface. Partial seed death leads to unevenly filled pods.

More information

[GRDC Update Papers: Frost-damaged crops—where to from here?]

[DAFWA: Frost and cropping]

[GRDC Update Papers: What's going on with frost?]

[GRDC Update Papers: The GRDC National Frost Initiative]

[GRDC Media Centre: Pre-seeding planning to manage frost risk in WA]

Late frost, when the seed is at the filling stage, causes significant losses, with shrivelled seed that may retain its green colour and affect oil quality. [6]

Figure 1: Yellow-green discoloration of pods, compared with healthy green pods.

Figure 2: Canola plant showing various stages of pod loss and flower abortion.

[6] DAFWA (2015) Diagnosing frost damage in canola. MyCrop. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-frost-damage-canola

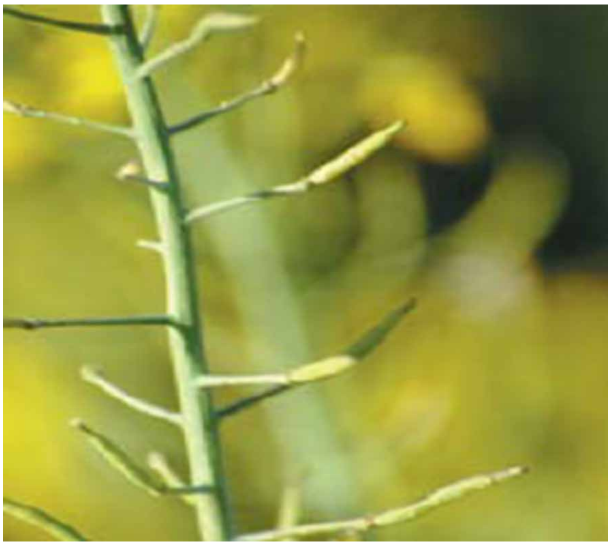


Figure 3: Stunted pods that have dropped off.

Figure 4: Missing and shrivelled seeds.

Canola flowers for a 30–40-day period, allowing podset to continue after a frost. Open flowers are most susceptible to frost damage, whereas pods and unopened buds usually escape. If seed moisture content is <40% when frost occurs, oil quality will not be affected. [7]

Once established, canola is relatively frost-tolerant, but damage can occur during the cotyledon stage and the seedlings can die if frosted. Plants become more frost-tolerant as they develop.

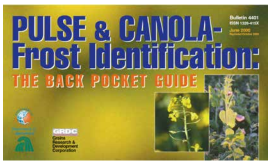
Seedling growth and vigour are reduced at temperatures <7°C, and occasionally seedlings will die.

[7] C White (2000) Pulse and canola—frost identification. The Back Pocket Guide. Reprinted 2003. Department of Agriculture, Western Australia/GRDC, https://www.grdc.com.au/Resources/Bookshop/2012/01/Pulse-Canola-Frost-Identification-The-Back-Pocket-Guide-GRDC046

More information

DAFWA: Diagnosing frost damage in canola

Pulse and canola frost identification. The Back Pocket Guide



GRDC Ground Cover: Cautious optimism for frost-tolerance advance

GRDC Media Centre: Smoking out frost effects

More information

GRDC Ground Cover: Frost pre-empted by research and experience

GRDC Resources: Managing frost risk—a guide for southern Australian growers

Soluble carbohydrates accumulate when there is a rapid reduction in leaf temperature. This accumulation suppresses photosynthesis, and therefore seedling growth rates, during the cooler winter months. [8]

14.1.1 Frost damage in crops—where to from here?

- Frost is a relatively rare occurrence but some areas are more prone to it.
- Frost frequency has increased in many areas in the last 20 years.
- Minor agronomic tweaks might be necessary in some frost-prone areas but for most growers it should be 'steady as she goes'.
- In the event of severe frost, monitoring needs to occur up to 2 weeks afterwards to detect all of the damage.

A small survey conducted by the Department of Environment and Primary Industries, Victoria (DEPI) in October–November 2013 showed that 68% of 111 respondents in south-eastern Australia were very or moderately concerned about frost damage in cereals. For frost damage in canola, the percentage was less, at 40%, and in pulses 57%. [9]

What causes frost?

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the southern ocean but settled, cloudless weather. When the loss of heat from the earth during the night decreases the temperature at ground level to 0°C, a frost occurs (Figure 5). Wind and cloud reduce the likelihood of frost by reducing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature reaches 0°C, the length of time it stays below 0°C, and how far it drops below 0°C. [10]

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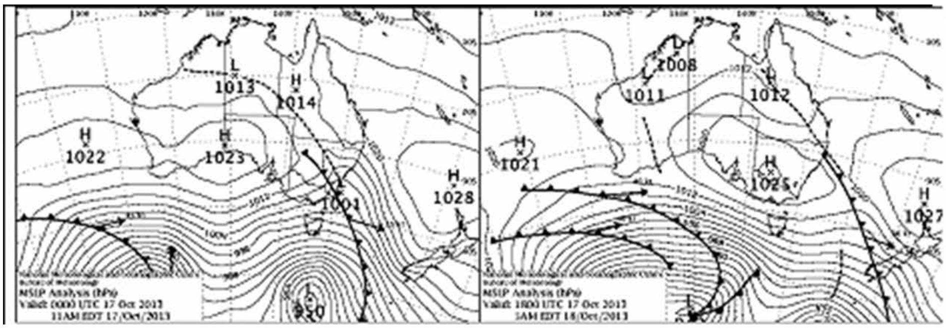
8 J Edwards, K Hertel (2011) Canola growth and development. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

9 D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

10 D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here



A cold front passes through, injecting cold air in from the Southern Ocean the day before the frost.

Overnight the high stabilises over SE Australia meaning clear skies and no wind. Frost happens.

Figure 5: Common weather patterns experienced prior to frost occurrence.

Frost effect on the plant

Two types of frost are experienced, 'white' and 'black'. White frost occurs when the air around the plant is moist and the temperature around the plant is ≤0°C. Ice crystals form on the surface of the plant (hence 'white'). The water between plant cells freezes and draws water out of surrounding cells to form more ice. When frost melts slowly (e.g. in winter), damage is minor and the plants repair themselves. Often, the least damage is in the shadows of trees where the thaw is slower, or on the side of the grain head away from the sun. The visual effect is similar to drought stress because plants can temporarily appear wilted. In spring, the thawing can be rapid and damage can be severe.

Black frost occurs when the temperature drops below 0°C but the surrounding air is dry (e.g. in drought conditions). Ice cannot form on the plant surface and the water between cells freezes quickly and forms large crystals. These large crystals 'pop' holes in the cells, causing permanent damage. Once thawed, the plant parts affected immediately look floppy, spongy and discoloured. If that plant part is a flower or a developing ovary, the result can be detrimental to yield.

Frost damage occurs to canola pods, flowers and seeds. Podding canola is very sensitive to frost. [11]

Are frosts becoming more frequent?

- In southern regions of Australia, despite global warming, the number of spring frosts has increased and the period of frost occurrence has changed (i.e. broadened over southern New South Wales (NSW), Victoria and part of South Australia and become later over Western Australia and western parts of South Australia).
- Frost occurrence is linked to a long-term southerly shift in position and intensification of the band of high pressure typically located over Central Australia in spring.
- Over many parts of NSW, the length of the frost season has increased by as much as 40 days.

[11] D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

- Field and simulation studies of wheat have shown flowering and maturity occurring 7 days earlier per 1°C of warming. This quicker phenology combined with changes to the underlying likelihood of frost will contribute to a significant increase in risk of frost damage.
- Subsequent studies have shown that this current level of risk is expected to continue over the next 20 years despite continued increases in mean temperatures. [12]

In the DEPI survey, 66% of respondents thought that frosts occurred 1–3 years in 10, but the spread of responses between 'never' and 'every year' was large. Geographic viewing of the data might help to elucidate this better for the different regions.

It is ironic that as temperatures (particularly those in winter and spring) are increasing, frost remains a major issue. CSIRO researchers have discovered that in some areas of Australia, the frost number is rising (greatest in August) (Figure 6). Eyre Peninsula, Esperance, northern Victorian Mallee and Central West NSW were the only major crop-growing areas to be less affected by frost in the period 1961–2010 (Crimp *et al.* 2014). Contributing factors are thought to be that the latitude of the subtropical ridge of high pressure is drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period. [13]

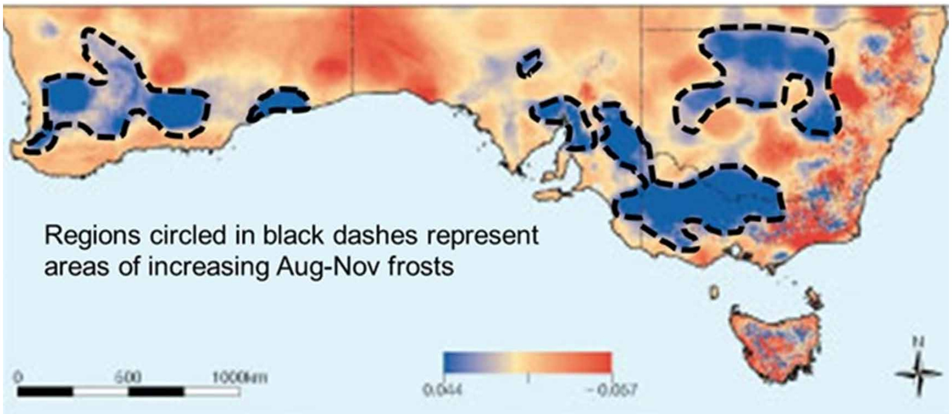


Figure 6: Regions of increasing frosts in August–November. (Source: Steven Crimp)

Key management strategies

Paddock selection is critical for canola. Avoid sowing canola on high frost-risk paddocks; frost damage is irreversible.

Risk may be reduced by:

- later sowing or choosing varieties to spread flowering time of crops
- avoiding potassium deficiency
- early grazing

[12] S Crimp, D Gobbet, D Thomas, S Bakar, U Nidumolu, P Hayman, G Hopwood (2015) 'Jack' of frosts—recent trends and drivers of change. GRDC Update Papers, 17 February 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Jack-of-frosts-recent-trends-and-drivers-of-change

[13] D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

- sowing more tolerant crops in frost-prone paddocks
- inspecting canola crops between grainfill and prior to swathing if night air temperature (recorded 1.2 m above ground) falls below –1°C
- check low-lying, light-coloured soil types and known frost-prone areas first, followed by other areas

More information

[DAFWA: Frost and cropping. Managing frost affected crops]

To identify frost damage open up pods and check for mushy or shriveled grain. Often, these pods will have a scarred or blistered surface when inspected closely. [14]

The importance of sowing time and flowering dates

To maximise frost-risk resilience, you need a mix of sowing dates and maturity types to avoid damage from the late frosts. In years of severe frost, it may be impossible to prevent damage. [15]

A simulation study at locations in southern NSW in 2014 showed that slower developing spring varieties had their highest yield from early sowing (early–mid April), whereas faster developing spring varieties were at flowering/early podfill before and during the harsh frost period of early August if sown early, which reduced grain yield at frosty sites.

More information

[GRDC Update Papers: Early sowing of canola in southern NSW]

[DAFWA: Canola variety guide for Western Australia]

[DAFWA: Canola seeding rate calculator]

This is because pod development is the stage at which canola is most sensitive to frost damage. The youngest water-filled pods (>60% water) are the most sensitive to frost damage; however, they have also demanded less energy at this stage, so the loss of these pods may not significantly limit yield if time and favourable seasonal conditions are sufficient for compensation. The older and more developed the seed within the pod, the lower the water content and the more frost-tolerant it becomes, but also the greater energy it has used to develop. When temperatures are cold enough to damage these pods, there is generally a much greater yield loss to the plant due to less ability to compensate, especially in low rainfall environments. [16]

The DEPI survey asked growers and advisors what they currently do to mitigate frost damage (Table 1). Most respondents use crop types and maturity length regularly, but few will mix up their sowing times to manipulate frost-risk exposure. Even fewer choose to sow later. Some do treat frost-prone areas differently or grow smaller areas of the susceptible crops. [17]

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14 DAFWA (2015) Diagnosing frost damage in canola. MyCrop. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-frost-damage-canola

15 D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

16 R Brill, J Kirkegaard, J Lilley, I Menz, D McCaffery, C McMaster (2015) Early sowing of canola in southern NSW. GRDC Update Papers, 17 February 2015, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Early-sowing-of-canola-in-southern-NSW

17 D Grey (2014) Frost damage in crops—where to from here? GRDC Update Papers, 12 March 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

Table 1: Results of the DEPI survey regarding growers' methods of mitigation of frost damage (n = 111)

	All the time	Most of the time	Some of the time	Never	Other
Sowing a mix of crop types	26%	36%	28%	10%	
Sowing a mix of crop maturities	20%	33%	37%	10%	
Sowing at a mix of times	5%	16%	46%	32%	
Delaying sowing	3%	2%	37%	59%	
Treating frost-prone areas differently	9%	10%	32%	49%	
Growing less of the most susceptible crops	7%	13%	48%	32%	
Other					3%

14.1.2 Issues that can be confused with frost damage

Many other problems can be confused with frost damage. The main ones are those causing distortion of the plant, absence of the seeds or unusual colour (see examples in Figures 7–9). Management and recent environmental conditions should be taken into account when identifying any crop disorder.

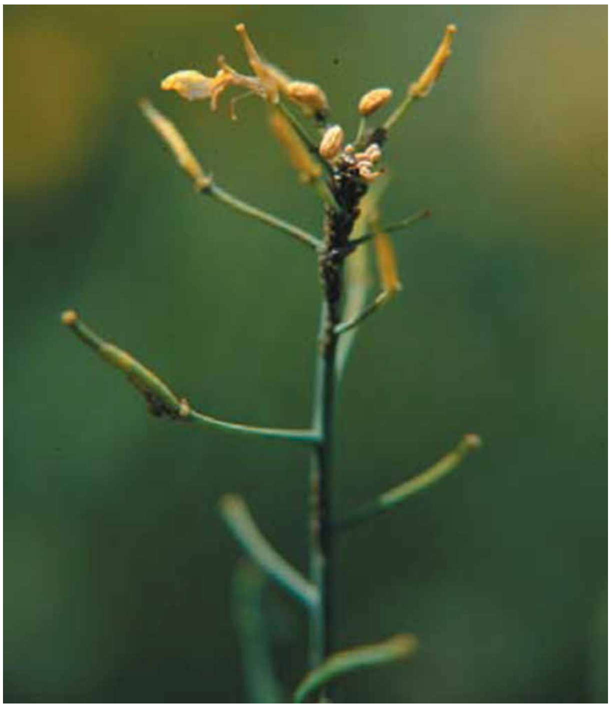


Figure 7: Aphids on canola flower stem.

More information

GRDC Driving Agronomy podcasts. New frost ratings

GRDC Media Centre: What to do with a frosted crop

GRDC Ground Cover: Cold problem in the hot seat

GRDC Ground Cover: Frost: no room for complacency

GRDC Driving Agronomy podcasts. Frost to stay

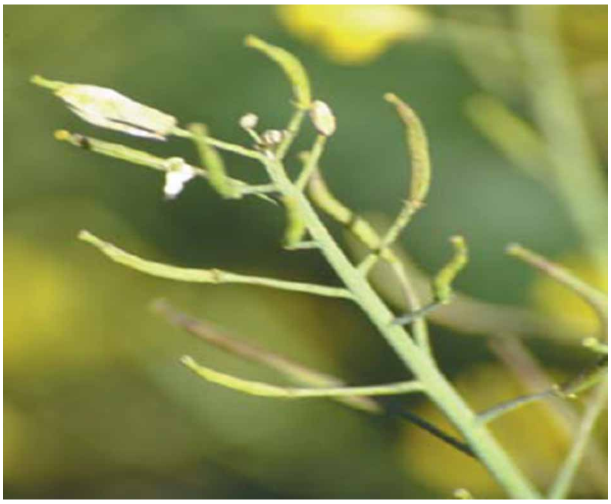


Figure 8: Sulfur deficiency and aphids. Flower petals retained; pods stunted with yellowing–reddening.

Figure 9: Herbicide damage in lupins.

It is important to remember that frost damage is random and sporadic, and not all plants (or parts of plants) will be affected, whereas most disease, nutrient and moisture-related symptoms will follow soil type. [18]

The optimum temperature range for leaf development of canola is 13°–22°C. At higher temperatures, growth is faster, and the period of leaf development is therefore shorter. Lower temperatures do not reduce yield in early growth, except when heavy frosts

18 C White (2000) Pulse and canola—frost identification. The Back Pocket Guide. Reprinted 2003. Department of Agriculture, Western Australia/GRDC, https://www.grdc.com.au/Resources/Bookshop/2012/01/Pulse-Canola-Frost-Identification-The-Back-Pocket-Guide-GRDC046

occur, but they do slow the rate of development. As temperatures increase to >20°C in July and August, yields are reduced.

For frost injury, ice must form between or inside the cells. Water surrounding the plant cells will freeze at 0°C, but water inside the cells needs to be a few degrees cooler to freeze. The length of exposure of the plant to cold is another important factor. Plants can be cold-hardened by repeated exposure over several days. They can survive –8°C to –12°C in Canada, but exposure to warm weather will reverse this hardening, making the plants susceptible to temperatures of –3°C to –4°C. [19]

14.2 Waterlogging and flooding

14.2.1 Symptoms of waterlogging

Paddock symptoms:

- Poor germination or purple-yellow plants can occur in areas that collect water, particularly on shallow duplex soils.
- Bare wet soil and/or water-loving weeds are present.
- Plant lodging and early death occur in waterlogging-prone areas.
- Saline areas are more affected.

Plant symptoms:

- Waterlogged seedlings can die before emergence or show symptoms similar to nitrogen deficiency.
- Lower leaves turn purple-red to yellow, then die.
- Prolonged waterlogging causes root death and eventually death of the whole plant; plants are more susceptible to root disease.
- Waterlogging of adult plants causes yellowing of lower leaves.
- Salinity magnifies waterlogging effects, with more marked stunting and oldest leaf marginal necrosis and death. [20]

More information

GRDC Ground Cover: All not lost if dry spring thwarts N uptake

14.2.2 Effect on yield

Canola roots need a good mix of water and air in the soil. When the amount of water exceeds the soil's water-holding capacity, waterlogging may occur. Canola is susceptible to waterlogging and shows a yield reduction after only 3 days.

The severity of yield loss depends on the growth stage at the time of waterlogging, the duration of waterlogging, and the temperature (Figure 10).

More information

GRDC Update Papers: Should waterlogged crops be topdressed with N fertiliser?

GRDC: Over the bar with better canola agronomy

[19] J Edwards, K Hertel (2011) Canola growth and development. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

[20] DAFWA. Diagnosing waterlogging in canola. MyCrop. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-canola

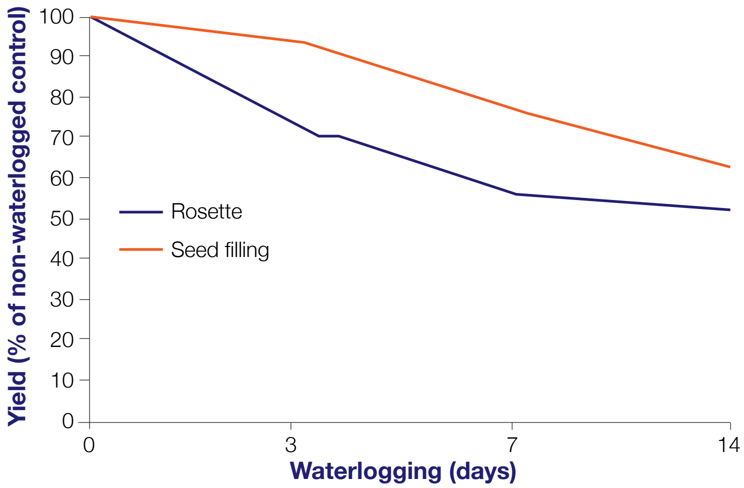


Figure 10: Effect of waterlogging on yield. (Source: Canola Council of Canada 2003)

Wet soils will be slow or prevent gas exchange between the soil and atmosphere, causing oxygen deficiency. High temperatures cause high respiration rates in roots and soil microorganisms, so soil oxygen is consumed more quickly.

Soil texture also affects the time at which critical levels of soil oxygen are reached. This is due to the oxygen-carrying capacity of soils. Coarser textured soils can hold more oxygen, increasing the amount of time before oxygen levels are reduced to a critical point.

Other effects of waterlogging are reductions in root growth, plant growth, plant height, dry matter production and nutrient uptake. [21]

14.2.3 Germination

Canola is sensitive to waterlogging during germination. When soils become waterlogged, the oxygen supply in the soil solution rapidly decreases. Oxygen is essential for seed germination. Without oxygen, seeds cannot continue their metabolic processes, and germination ceases. Prolonged waterlogging can kill canola seeds and seedlings. [22]

14.2.4 Seedfill

During seed-filling, waterlogging for >7 days decreases individual seed weight and oil content. High temperatures exacerbate the effects of waterlogging on canola yield.

The impact of waterlogging is greater if it occurs at the rosette stage. The longer the period of waterlogging, the greater the impact. [23]

More information

DAFWA: Diagnosing waterlogging in canola

Research paper: Alleviation of waterlogging damage by foliar application of nitrogen compounds and tricyclazole in canola

Research paper: Growing canola on raised beds in south-west Victoria

IPNI: Nitrogen and sulfur for wheat and canola—protein and oil

APSIM Canola

Text: Waterlogging and canola

Research paper: Waterlogging in Australian agricultural landscapes: a review of plant responses and crop models

CResearch paper: Crop production potential and constraints in the high rainfall zone of southwestern Australia: Yield and yield components

MCMA: Improving canola establishment to reduce wind erosion

21 J Edwards, K Hertel (2011) Canola growth and development. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

22 J Edwards, K Hertel (2011) Canola growth and development. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

23 J Edwards, K Hertel (2011) Canola growth and development. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/516181/Procrop-canola-growth-and-development.pdf

SECTION 15

Marketing

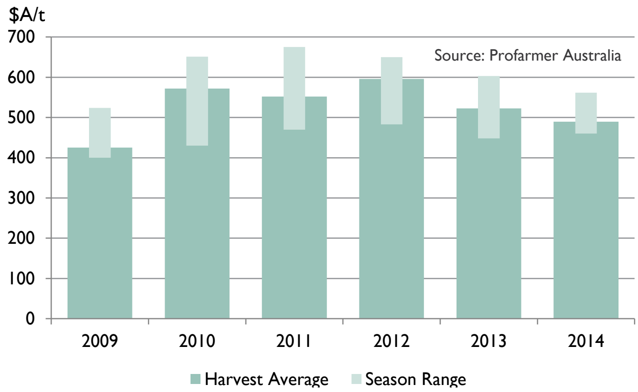
The final step in generating farm income is converting the tonnes of grain produced per hectare into dollars at the farm gate. Please seek professional advice on individual circumstances.

15.1 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several factors that are difficult to quantify, in order to establish the target price and then working towards achieving that target price.

These factors include the amount of grain available to sell (production variability), the final cost of that production, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond our control and difficult to predict (Figure 1).

The skills that growers have developed to manage production variability and costs can be used to manage and overcome price uncertainty.



Note to figure: Kwinana canola prices have varied A$100-$230/t over the past 6 years (20-40% variability). For a property producing 500 tonne of canola this means $50,000-$115,000 difference in income depending on price management skill.

Figure 1: Annual price variation (season average and range) for Kwinana canola.

15.1.1 Be prepared

Being prepared and having a selling plan are essential for managing uncertainty. The steps involved are forming a selling strategy, and having a plan for effective execution of sales. A selling strategy consists of when and how to sell.

When to sell

This requires an understanding of the farm's internal business factors including:

- production risk
- a target price based on cost of production and a desired profit margin
- business cash-flow requirements

How to sell

This depends more on external market factors including:

- time of year, which determines the pricing method
- market access, which determines where to sell
- relative value, which determines what to sell

The key selling principles when considering sales during the growing season are described in Figure 2.

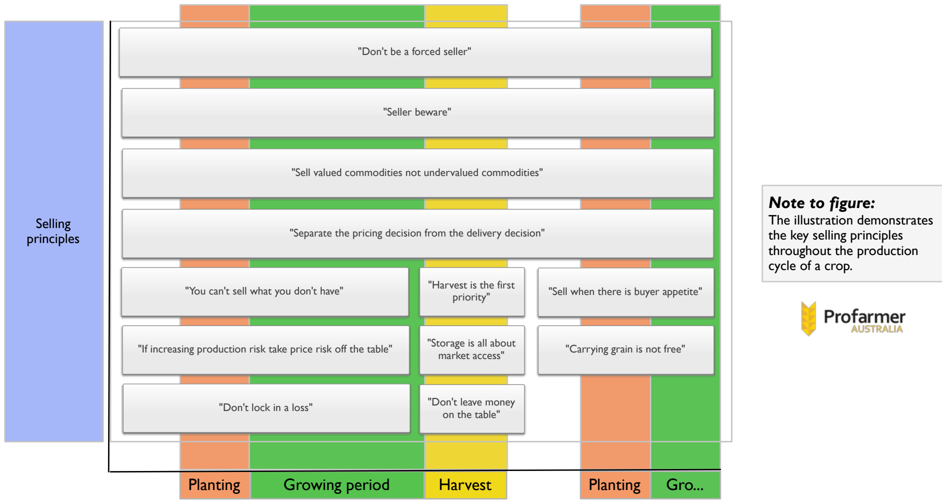


Figure 2: Grower commodity selling-principles timeline.

15.1.2 Establishing the business risk profile—when to sell

Establishing your business risk profile allows the development of target price ranges for each commodity and provides confidence to sell when the opportunity arises. Typical business circumstances of a cropping enterprise, and how the risks may be quantified during the production cycle, are described in Figure 3.

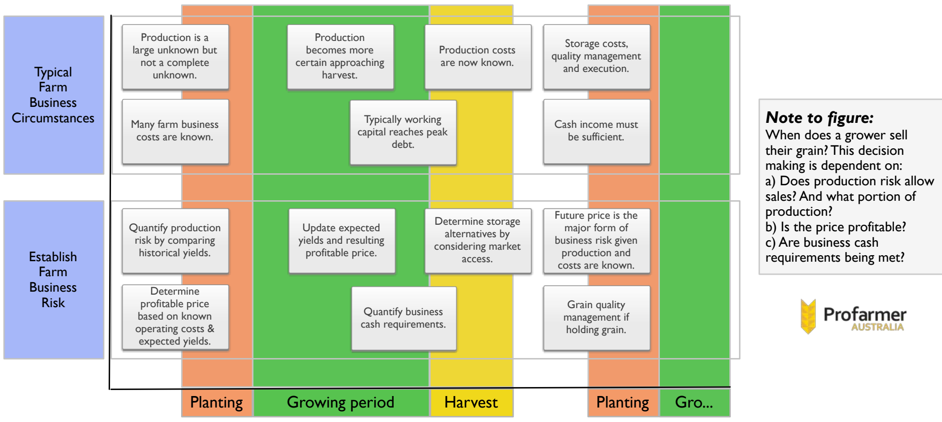


Figure 3: Typical business circumstances and risk.

Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate and soil type), crop type, crop management, and time of the year.

Principle: 'You can't sell what you don't have.' Do not increase business risk by over-committing production.

Establish a production risk profile (Figure 4) by:

- collating historical average yields for each crop type and a below-average and above-average range
- assessing the likelihood of achieving average based on recent seasonal conditions and seasonal outlook
- revising production outlooks as the season progresses

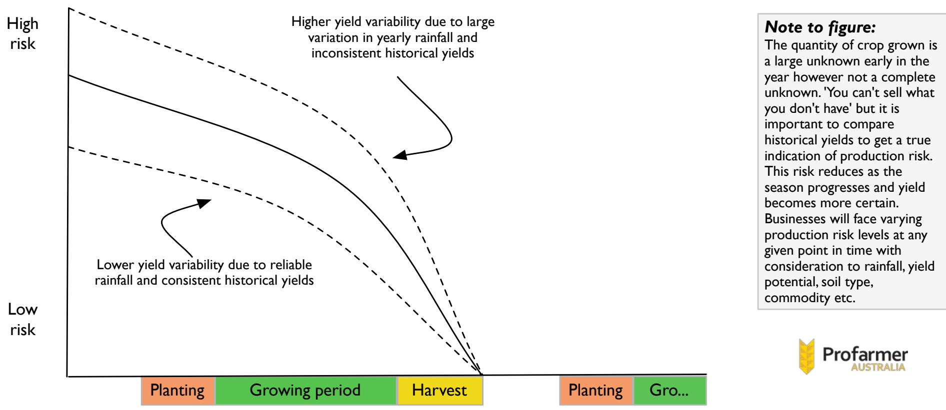


Figure 4: Typical production risk profile of a farm operation.

Farm costs in their entirety, variable and fixed costs (establishing a target price)

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business.

Principle: 'Don't lock in a loss.' If committing production ahead of harvest, ensure that the price is profitable.

Steps to calculate an estimated profitable price based on total cost of production and a range of yield scenarios are provided in Figure 5.

Estimating cost of production - Canola	
Planted Area	1,200 ha
Estimate Yield	1.45 t/ha
Estimated Production	1,740 t
Fixed costs	
Insurance and General Expenses	$100,000
Finance	$80,000
Depreciation/Capital Replacement	$70,000
Drawings	$60,000
Other	$30,000
Variable costs	
Seed and sowing	$48,000
Fertiliser and application	$168,000
Herbicide and application	$84,000
Insect/fungicide and application	$36,000
Harvest costs	$48,000
Crop insurance	$18,000
Total fixed and variable costs	$742,000
Per Tonne Equivalent (Total costs ÷ Estimated production)	$426 /t
Per tonne costs	
Levies	$3 /t
Cartage	$12 /t
Freight to Port	$22 /t
Total per tonne costs	$37 /t
Cost of production Port track equiv	$463.44
Target profit (ie 20%)	$93.00
Target price (port equiv)	**$556.44**

Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.

Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Krause "Farming your Business") but the most important thing is that in the end all costs are accounted for.

Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.

Step 4: Add together fixed and variable costs and divide by estimated production

Step 5: Add on the "per tonne" costs like levies and freight.

Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4.

Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.

Figure 5: Steps to calculate an estimated profitable price for canola.

The GRDC manual 'Farming the business' also provides a cost-of-production template and tips on skills required for grain selling, as opposed to grain marketing. [1]

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables grain sales to be timed so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Principle: 'Don't be a forced seller.' Be ahead of cash requirements to avoid selling in unfavourable markets.

1 M Krause (2014) Farming the business. Sowing for your future. GRDC, http://www.grdc.com.au/FarmingTheBusiness

A typical cash flow to grow a crop is illustrated in Figure 6. Costs are incurred upfront and during the growing season, with peak working capital debt incurred at or before harvest. This will vary depending on circumstances and enterprise mix. Figure 7 demonstrates how managing sales can change the farm's cash balance.

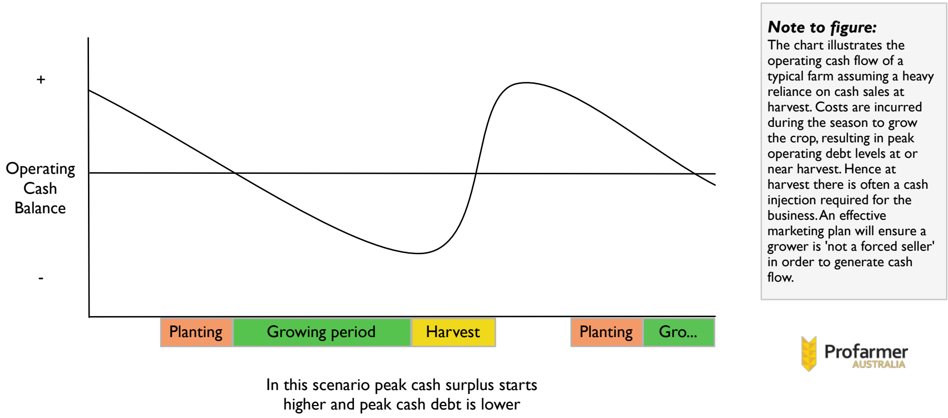


Figure 6: Typical farm operating cash balance, assuming harvest cash sales.

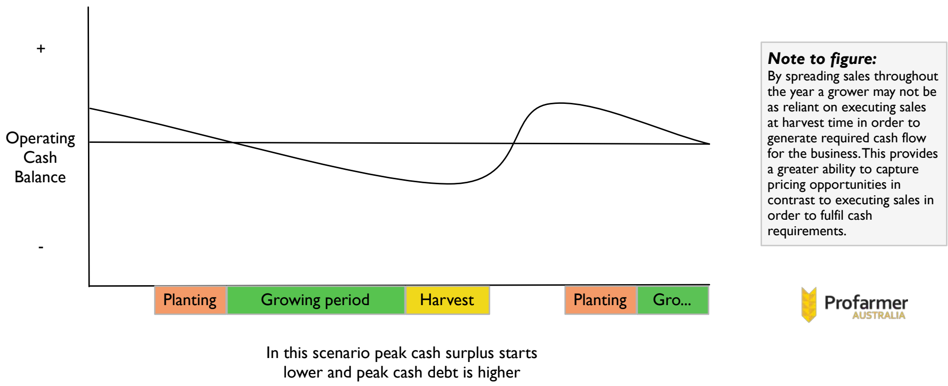


Figure 7: Typical farm operating cash balance, with cash sales spread throughout the year.

Summary

The when-to-sell steps above result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.1.3 Managing your price—how to sell

This is the second part of the selling strategy.

Methods of price management

The pricing methods for products provide varying levels of price risk coverage (Table 1).

Table 1: Pricing methods and how they are used for various crops

	Description	Wheat	Barley	Canola	Sorghum	Maize	Faba beans	Chick peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	Options on futures	Options on futures	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

Figure 8 below provides a summary of when different methods of price management are suited for the majority of farm businesses.

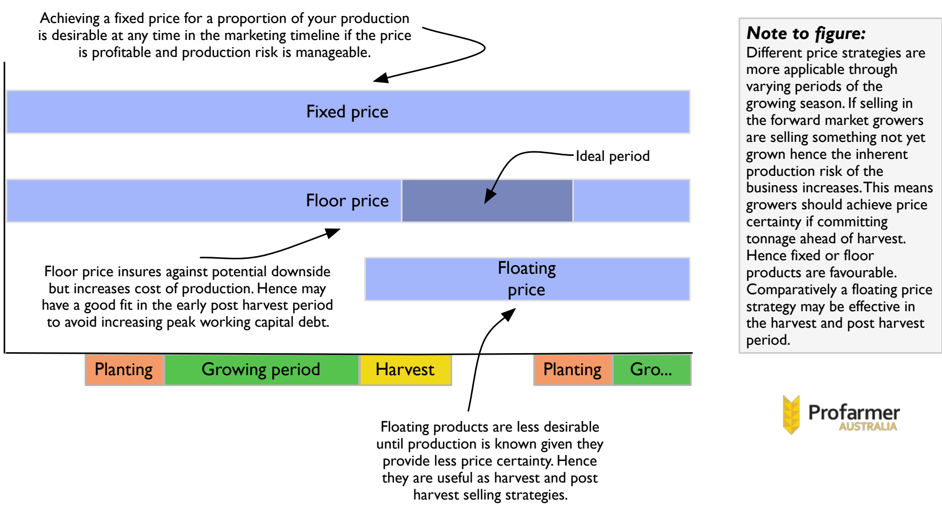


Figure 8: Price strategy timeline through the growing season.

Principle: 'If increasing production risk, take price risk off the table.' When committing unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: 'Separate the pricing decision from the delivery decision.' Most commodities can be sold at any time with delivery timeframes negotiable; hence, price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 9). It provides some certainty around expected revenue from a sale because the price is largely a known, except when there is a floating component in the price, for example, a multi-grade cash contract with floating spreads or a floating basis component on futures positions.

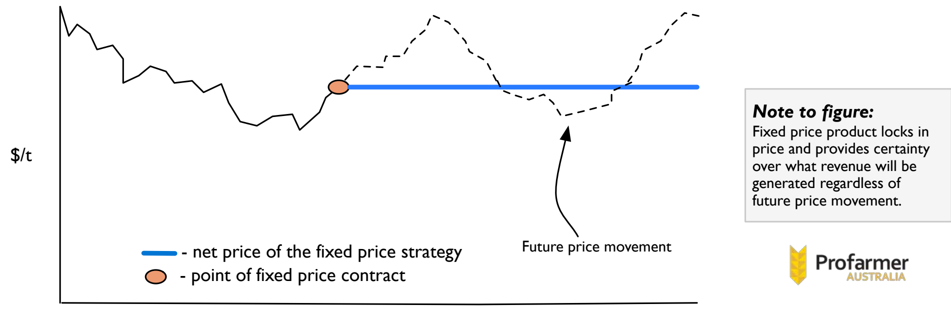


Figure 9: Fixed-price strategy.

Floor price

Floor-price strategies can be achieved by utilising 'options' on a relevant futures exchange (if one exists), or via a managed sales program product by a third party (i.e. a pool with a defined floor-price strategy). This pricing method protects against potential future downside while capturing any upside (Figure 10). The disadvantage is that the price 'insurance' has a cost, which adds to the farm businesses cost of production.

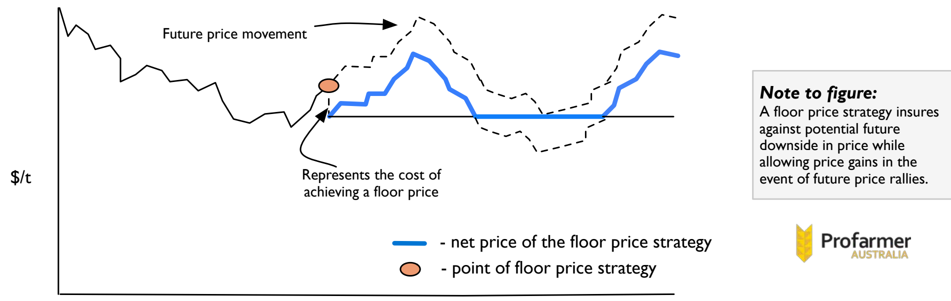


Figure 10: Floor-price strategy.

Floating price

Many of the pools or managed sales programs are a floating price where the net price received will move both up and down with the future movement in price (Figure 11). Floating-price products provide the least price certainty and are best suited for use at or after harvest rather than pre-harvest.

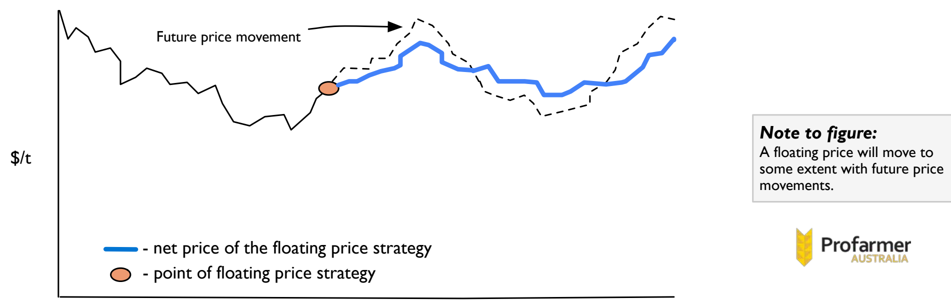


Figure 11: Floating-price strategy.

Summary

Fixed-price strategies include physical cash sales or futures products and provide the most price certainty; however, production risk must be considered.

Floor-price strategies include options or floor-price pools. They provide a minimum price with upside potential and rely less on production certainty; however, they cost more.

Floating-price strategies provide minimal price certainty and they are best used after harvest.

15.1.4 Ensuring access to markets

Once the selling strategy is organised, the storage and delivery of commodities must be planned to ensure timely access to markets and execution of sales. At some point, growers need to deliver the commodity to market; hence, planning where to store the commodity is important in ensuring access to the market that is likely to yield the highest return (Figure 12).

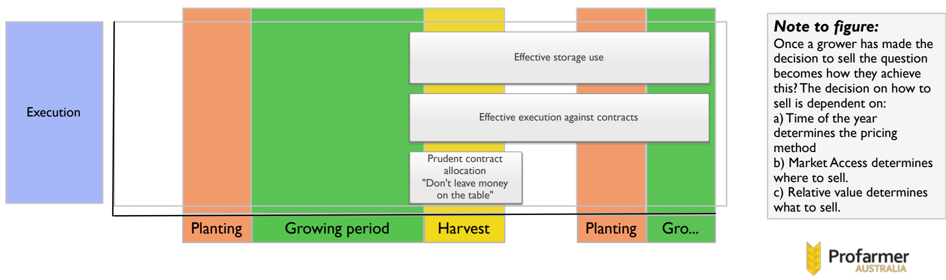


Figure 12: Effective storage decisions.

Storage and logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk-handling system, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 13).

Principle: 'Harvest is the first priority.' Getting the crop into the bin is most critical to business success during harvest; hence, selling should be planned to allow focus on harvest.

Bulk export commodities requiring significant quality management are best suited to the bulk-handling system. Commodities destined for the domestic end-user market (e.g. feedlot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means that the grower may have to suffer the cost of taking the load elsewhere, while also potentially finding a new buyer. Hence, there is potential for a distressed sale, which can be costly.

On-farm storage also requires prudent delivery management to ensure that commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: ‘Storage is all about market access.’ Storage decisions depend on quality management and expected markets.

For more information about on-farm storage alternatives and economics, refer to GrowNotes Canola Western Region. Chapter 13. Grain storage.

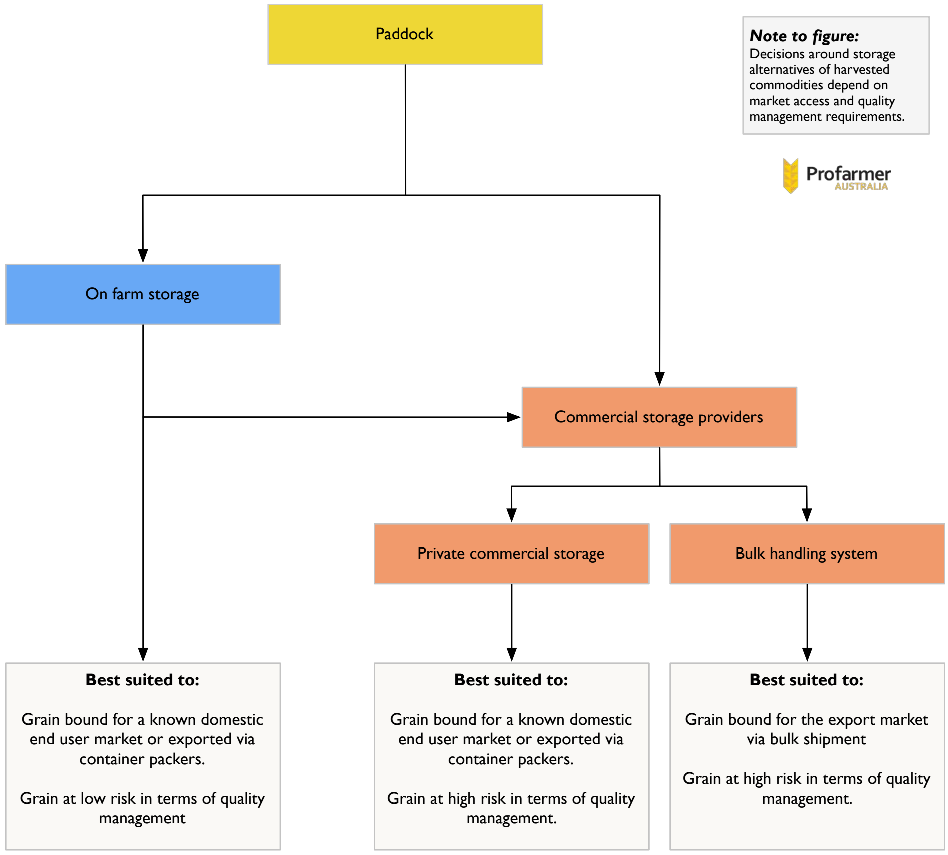


Figure 13: Grain storage decision-making.

Cost of carrying grain

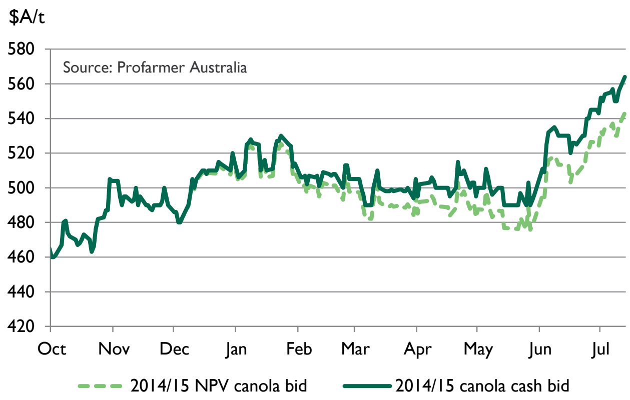
Storing grain to access sales opportunities post-harvest invokes a cost to ‘carry’ grain. Price targets for carried grain need to account for the cost of carry.

Carry costs per month are typically $3–4/t, consisting of:

- monthly storage fee charged by a commercial provider (typically ~$1.50–2.00/t)
- monthly interest associated with having wealth tied up in grain rather than in cash or against debt (~$1.50–2.00/t, depending on the price of the commodity and interest rates)

The price of carried grain therefore needs to be $3–4/t per month higher than was offered at harvest. The cost of carry applies to storing grain on-farm because there is a cost of capital invested in the farm storage plus the interest component. A reasonable assumption is $3–4/t per month for on-farm storage.

Principle: 'Carrying grain is not free.' The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy (Figure 14).



Note to figure:
If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example in the case of a March sale of canola for March-June delivery on buyers call at $550/t + $5/t carry per month, if delivered in June would generate $565/t delivered.

Figure 14: Kwinana canola cash v. net present value (NPV).

Summary

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

15.1.5 Executing tonnes into cash

Below are guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the toolbox

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox includes:

1. Timely information. This is critical for awareness of selling opportunities and includes: market information provided by independent parties; effective price discovery including indicative bids, firm bids, and trade prices; and other market information pertinent to the particular commodity.
2. Professional services. Grain-selling professional service offerings and cost structures vary considerably. An effective grain-selling professional will put their clients' best interests first, by not having conflicts of interest and by investing time in the relationships. Return on investment for the farm business through improved farm-gate prices is obtained by accessing timely information, greater market knowledge and greater market access from the professional service.
3. Futures account and bank swap facility. These accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies that utilise exchanges such as CBOT (Chicago Board of Trade) can add significant value.

For current financial members of Grain Trade Australia, including buyers, independent information providers, brokers, agents, and banks providing over-the-counter grain derivative products (swaps), go to: http://www.graintrade.org.au/membership.

For a list of commodity futures brokers, go to: http://www.asx.com.au/prices/find-a-futures-broker.htm.

How to sell for cash

Like any market transaction, a cash grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components, with each component requiring a level of risk management (Figure 15):

- **Price**. Future price is largely unpredictable; hence, devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- **Quantity and quality**. When entering a cash contract, you are committing to delivery of the nominated amount of grain at the quality specified. Hence, production and quality risk must be managed.
- **Delivery terms**. Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users, it relies on prudent management of execution to ensure delivery within the contracted period.
- **Payment terms**. In Australia, the traditional method of contracting requires title of grain to be transferred ahead of payment; hence, counterparty risk must be managed.

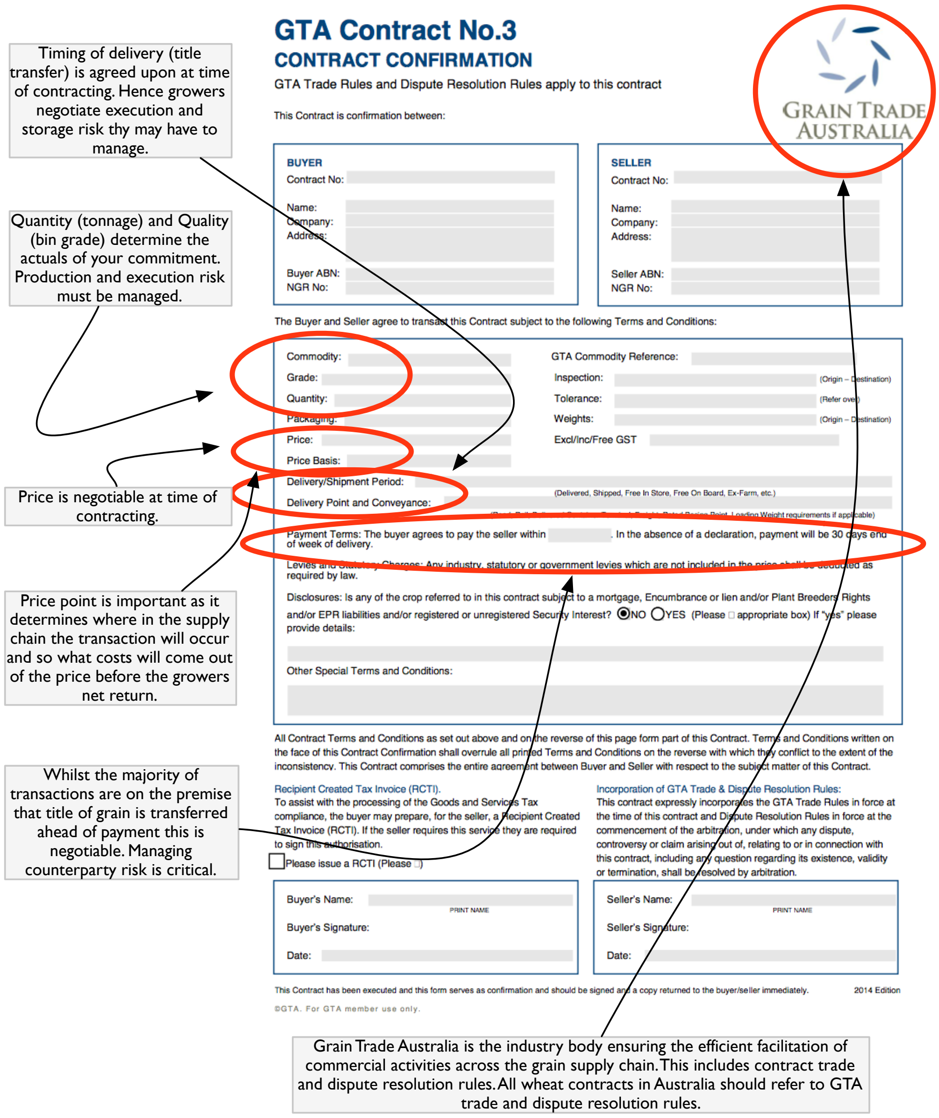


Figure 15: Typical cash contracting as per Grain Trade Australia standards.

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 16 shows the terminology used to describe pricing points along the grain-supply chain and the associated costs to come out of each price before growers receive their net farm-gate return.

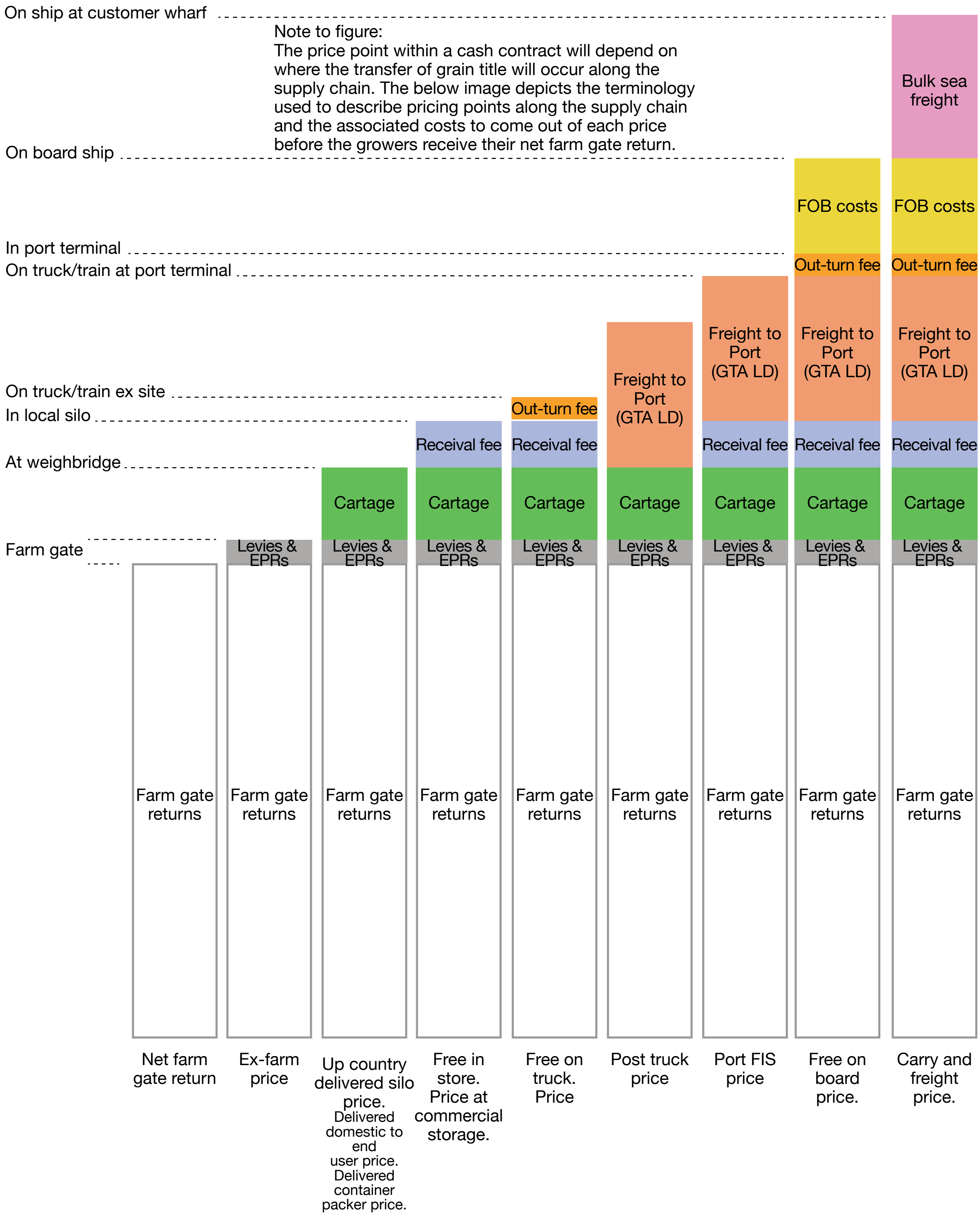


Figure 16: Costs and pricing points throughout the supply chain.

More information

GTA Guide to taking out contracts

GTA Contracts and vendor declarations

GTA Trading standards

GrainTransact Resource Centre

GrainFlow Network

Emerald Grain customer and grower logins

Clear Grain Exchange terms and conditions

Clear Grain Exchange—getting started

Cash sales generally occur through three methods:

1. **Negotiation via personal contact**. Traditionally prices are posted as a 'public indicative bid'. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and available for all commodities.
2. **Accepting a 'public firm bid'**. Cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transferring the grain online to the buyer. The availability of this depends on location and commodity.
3. **Placing an 'anonymous firm offer'**. Growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent, online exchange. If the firm offer and firm bid match, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: 'Seller beware.' Selling for an extra $5/t is not a good deal if you do not get payment.

Counterparty risk management includes the following principles:

- Deal only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer you are unsure of.
- Sell only a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting; alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title of grain until payment is received from the buyer, and then title and payment are settled simultaneously.

Above all, act commercially to ensure that the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not receiving payment is a disastrous outcome.

More information

GTA Grain contracts—managing counterparty risk

Clear Grain Exchange title transfer model

GrainGrowers Guide to managing contract risk

Counterparty risk management: A producer perspective—Leo Delahunty

Relative commodity values

Grain sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well and to hold commodities that are not well priced at any given time; that is, give preference to the commodities of the highest relative value. This achieves price protection for the overall farm business revenue and enables more flexibility to a grower's selling program while achieving the business goals of reducing overall risk.

Principle: 'Sell valued commodities, not undervalued commodities.' If one commodity is priced strongly relative to another, focus sales there. Do not sell the cheaper commodity for a discount.

An example based on a wheat and canola production system is provided in Figure 17.

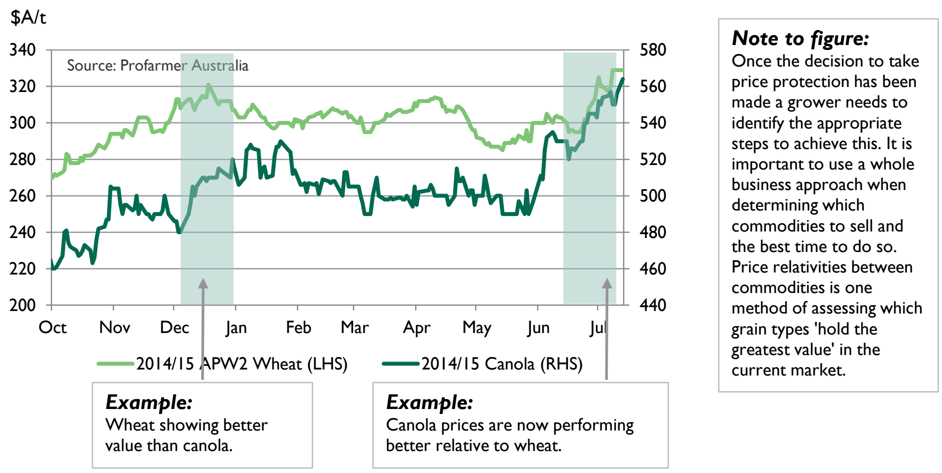


Figure 17: Kwinana Australian Standard White (ASW) wheat v. canola (AU$/t).

If the decision has been made to sell canola, Intercontinental Exchange® (ICE) canola may be the better alternative if the futures market is showing better value than the cash market (Figure 18).

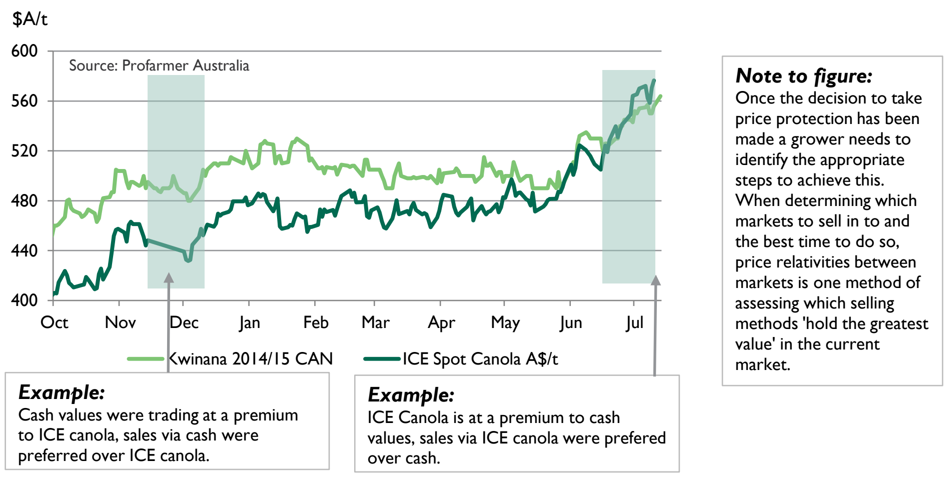


Figure 18: Kwinana CAN v. Intercontinental Exchange® ICE canola (AU$/t).

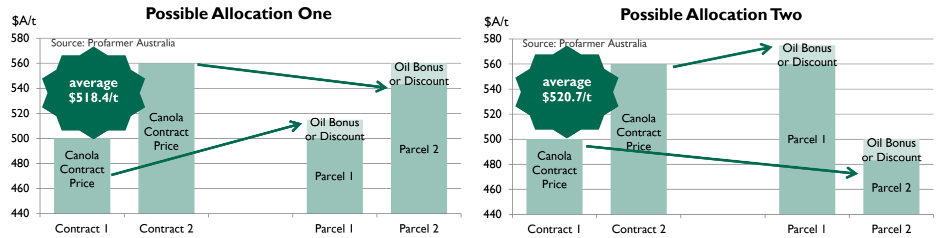
Contract allocation

Contract allocation means choosing which contracts to allocate your grain against at delivery time. Different contracts will have different characteristics (price, premiums–discounts, oil bonuses, etc.), and optimising your allocation reflects immediately on your bottom line (Figure 19).

Principle: 'Don't leave money on the table.' Contract allocation decisions do not take long, and can be worth thousands of dollars to your bottom line.

Because the majority of Australian canola cash contracts pay price premiums and discounts based on oil for clean seed tonnes, to achieve the best average canola price, growers should:

- Allocate their worst loads (lowest oil and highest admix) to lower priced contracts.
- Allocate their best loads (highest oil and lowest admix) to higher priced contracts.



Note to figure:
In these two examples the only difference between acheiving an average price of $518.4/t and $520.7/t is which contracts each parcel was allocated to. Over 400/t that equates to nearly $1,000 which could be lost just in how parcels are allocated to contracts.

Figure 19: Examples of contract allocation of grain.

Read market signals

The appetite of buyers to purchase a particular commodity will differ over time depending on market circumstances. Ideally, growers should aim to sell their commodity when buyer appetite is strong and stand aside from the market when buyers are not as interested in buying the commodity.

Principle: 'Sell when there is buyer appetite.' When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

1. The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However, if there is one buyer at $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
2. Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

Summary

The selling strategy is converted to maximum business revenue by:

- ensuring timely access to information, advice and trading facilities

- using different cash-market mechanisms when appropriate
- minimising counterparty risk by effective due diligence
- understanding relative value and selling commodities when they are priced well
- thoughtful contract allocation
- reading market signals to extract value from the market or prevent selling at a discount

15.2 Western canola—market dynamics and execution

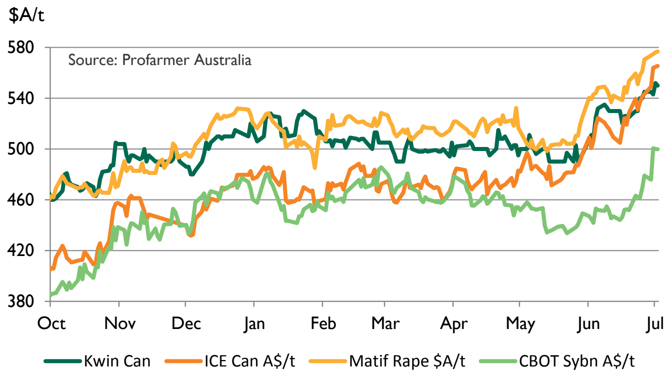
15.2.1 Price determinants for Western Australian canola

Australia is a relatively small player in terms of world oilseed production, contributing about 5% to global canola production. However, in terms of world trade, Australia is a major player, exporting approximately 75% of the national canola crop, which accounts for about 23% of global canola trade.

Western Australia is Australia's largest canola-producing state, and exports ~90% of the crop.

Given this dynamic, WA farm-gate prices are influenced by global price volatility. This makes offshore markets such as the ICE canola contract and Euronext (often referred to as Matif) rapeseed useful indicators of where the Australian canola price will trade (Figure 20).

In addition, global canola values are influenced by supply and demand of other global oilseeds such as soybeans and palm oil. This is due to the substitutable nature of the different oilseed types for various uses.



Note to figure: Global canola values and soybeans often trade in similar directions as they act as substitutes for various uses.

Figure 20: Kwinana canola v. offshore markets (AU$/t).

Figure 21 highlights some of the seasonal factors influencing global canola prices throughout each year. Because of WA's export focus, the timing of harvest in major exporting and importing countries is a considerable influencer of prices.

Prices can be compared with historic values by consulting decile charts (Figure 22).

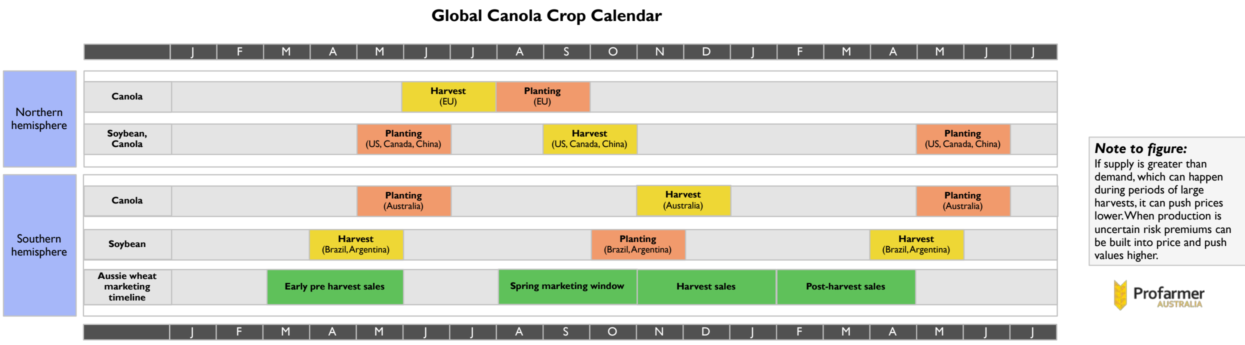
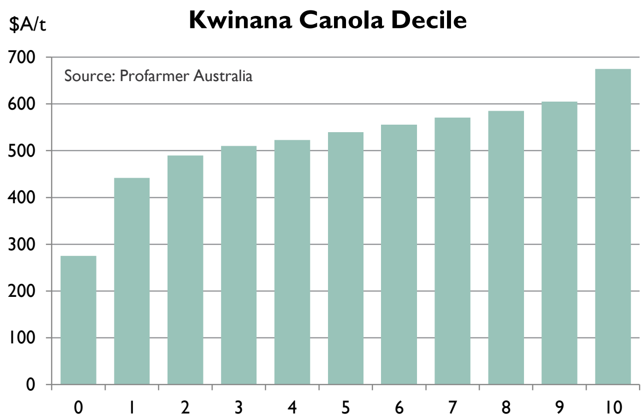


Figure 21: Seasonal factors influencing global canola prices.



Note to figure:
Appetite to accumulate WA canola often peaks during and shortly after harvest as off-shore demand kicks in to make the most of more abundant supply, as well as cost savings by shipping immediately post-harvest. Off-shore buyers are focused on Australia during this period given supply from the northern hemisphere harvest was some months prior and ahead of the South American soybean harvest.

Figure 22: Decile chart illustrating the price distribution for Kwinana canola (AU$/t).

15.2.2 Ensuring market access for WA canola

The majority of canola in WA is exported in bulk for human consumption (Figure 23); therefore, the bulk handling system is often the most cost-effective pathway to get canola to offshore customers. The bulk storage provider should gain scale efficiencies when moving the bulk commodity grade CAN1.

	Western Australia		National Total	
	Implied tonnes	% of production	Implied tonnes	% of production
Bulk	1,100,000	91%	2,300,000	74%
Container	50,000	4%	90,000	2%
Domestic Use	60,000	5%	750,000	24%

Source: Australian Crop Forecasters

Figure 23: Market destinations for canola—Western Australian and national 5-year averages.

Although the majority of WA canola will be stored and sold from within a bulk-handling system, private commercial and on-farm storage is a reasonable alternative for accessing container export and domestic end-user markets. The proportion of canola exports in containers from WA has grown to ~4% of production and can provide price premiums for specific grades because a container can access niche offshore markets; this particularly applies to off-spec (i.e. low oil, high admix) or genetically modified canola.

Domestic consumers in WA demand a relatively small proportion of the crop, at ~ 5%; however, for growers who are well positioned to service these markets, they can sometimes return premiums over the bulk export markets. Private commercial or on-farm storage can be a more effective method of accessing these markets. WA canola crushers are located at Pinjarra and Kojonup.

Supply-chain flow options are illustrated in Figure 24.

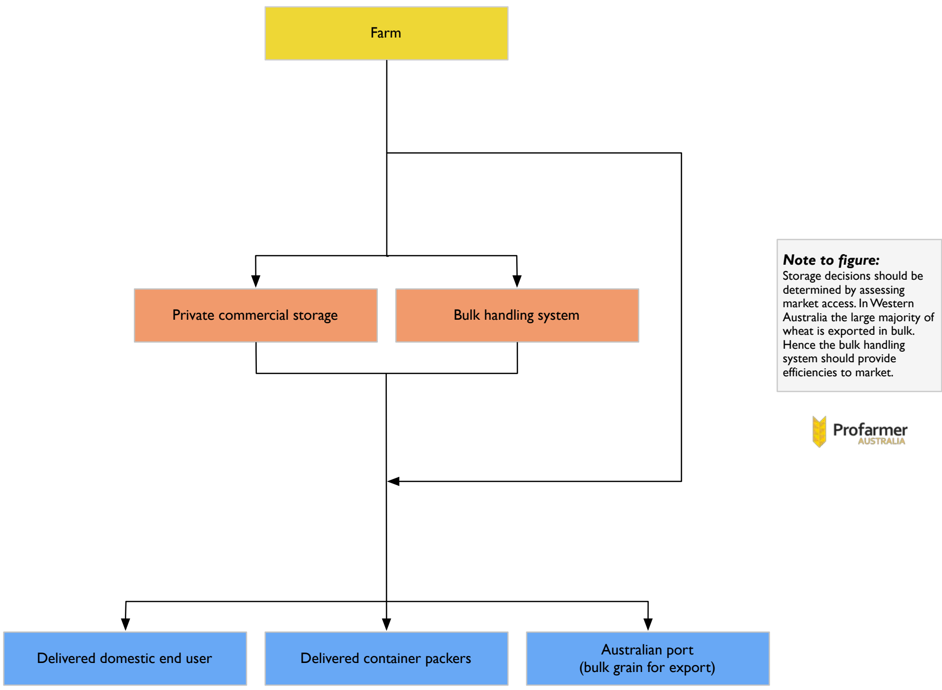
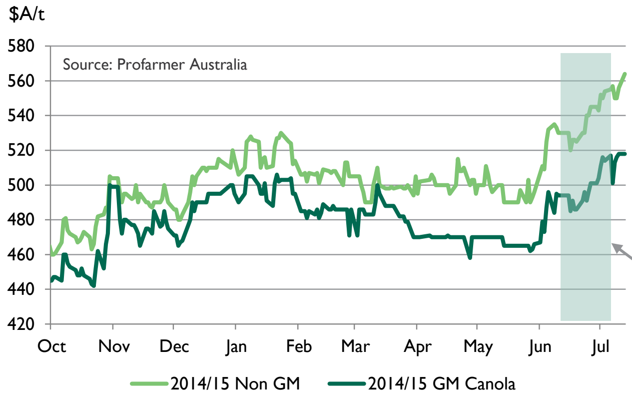


Figure 24: Australian supply-chain flow for canola.

15.2.3 Executing tonnes into cash for WA canola

The key to effectively executing sales is determining which grades to sell and which grades to hold. Niche canola grades such as genetically modified (GM) and Clearfield® canola are often best sold during harvest or shortly after because buyer appetite often drops away post-harvest, there being fewer buyers for GM canola than conventional. For example, the EU, a major offshore market for WA canola, does not accept GM canola. Hence, once buyers with a specific use for these canola grades have filled their requirements, price discounts to conventional CAN1 can increase (Figure 25).

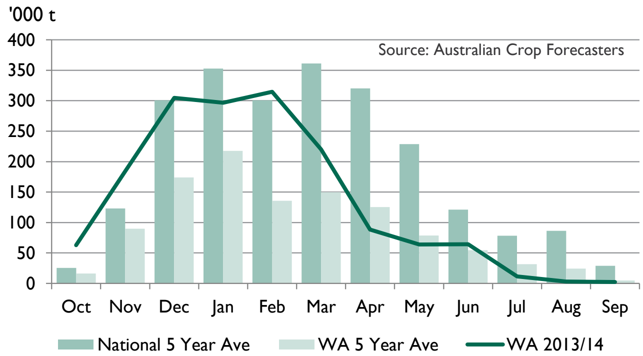
Export pace is strongest shortly after harvest (Figure 26).



Note to figure:
When deciding which grades to sell it is all about identifying which are showing the best value and selling those whilst the value is present. This relates back to the principle of "selling valued commodities".

Example:
GM canola discount to non GM canola has increased due to less buyers.

Figure 25: Kwinana genetically modified (GM) v. non-GM canola price (AU$/t).



Note to figure:
Australian canola export pace is typically strongest shortly after our harvest as buyers seek to take advantage of more abundant supplies and minimise costs by shipping immediately after harvest.

Figure 26: Monthly export pace of canola.

15.2.4 Risk-management tools available for WA canola

An Australian cash price has three components: futures, foreign exchange, and basis (Figure 27). Each component affects price. A higher futures and basis and a lower exchange rate will create a higher Australian grain price.

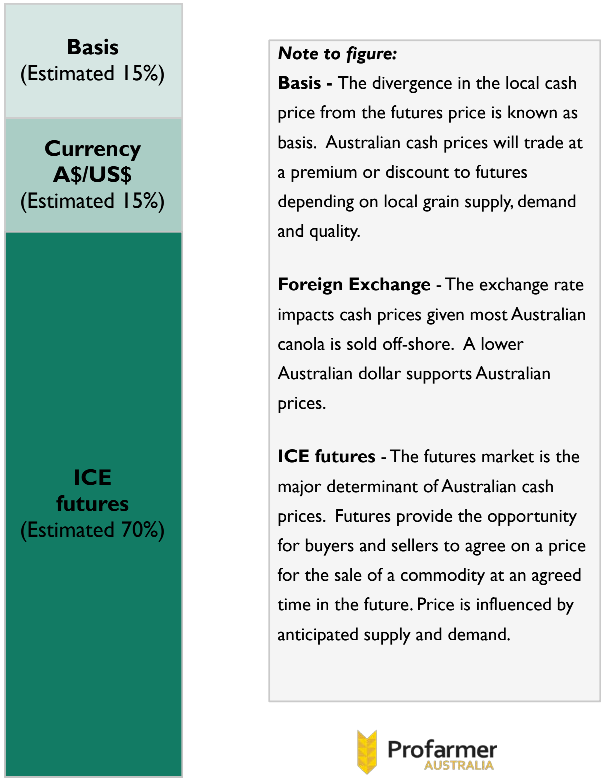


Figure 27: Components of pricing.

Table 2 outlines products available to manage WA canola prices; the major difference in products is the ability to manage the individual components of price.

Table 2: Advantages and disadvantages of the products available to manage canola prices

	Description	Advantages	Disadvantages
Spot cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price. Cash is received almost immediately (within payment terms).	Immediate grain delivery required. Sales after harvest require storage which incur costs. Locks away three pricing components at the same time. Risk of counterparty default between transfer and payment.
Forward cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price (no uncovered price risk). No storage costs. Cash income is a known ahead of harvest	Often inflexible and difficult to exit. Locks away the three pricing components at the same time. Future delivery is required resulting in production risk. Counterparty default risk must be managed.
Futures contracts	Futures, foreign exchange, basis are able to be managed individually	Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Price determined by the market, and is completely transparent. No counterparty risk due to daily clearing of the contracts.	Requires constant management and monitoring. Margin calls occur with market movements creating cash-flow implications. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move in line with futures, hence some price risk. You still have to sell the underlying physical grain.
Over-the-counter bank swaps on futures contracts	Futures, foreign exchange, basis are able to be managed individually	Based off an underlying futures market so reasonable price transparency. Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Counter party risk is with the bank, hence it is low. The bank will manage some of the complexity on behalf of the grower, including day to day margin calls.	Costs vary between $5-10/t at the providers discretion. Requires constant management and monitoring. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move in line with futures, hence some price risk. You still have to sell the underlying physical grain.
Options on futures contracts	Futures, foreign exchange, basis are able to be managed individually	No counterparty risk due to daily clearing of the contracts. No margin calls. Protects against negative price moves but can provide some exposure to positive moves if they eventuate. Liquid markets enable easy entry and exit from the marketplace. Price risk can be reduced without increasing production risk. Price determined by the market, and is completely transparent.	Options can be costly and require payment upfront. The value of options erode overtime as expiry approaches - depreciating asset. Perceived to be complicated by growers. Move in option value may not completely offset move in cash markets. You still have to sell the underlying physical grain.

For more information and worked examples on how each pricing component affects canola price, refer to the GRDC publication: Grain Market Lingo—what does it all mean?

More information

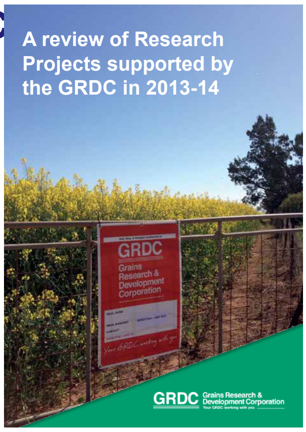
AOF: Oilseeds industry—delivering high quality products to local and global markets

DAFWA: Grain market lingo—what does it all mean?

SECTION 16

Current projects

Section Project Summaries of GRDC supported projects in 2013-14



Each year the GRDC supports several hundred research and development, and capacity building projects.

In the interests of improving awareness of these investments among growers, advisers and other stakeholders, the GRDC has assembled summaries of projects active in 2013-14.

These summaries are written by our research partners as part of the Project Specification for each project, and are intended to communicate a useful summary of the research activities for each project investment.

The review expands our existing communication products where we summarise the R&D portfolio in publications such as the Five-year Strategic Research and Development Plan, the Annual Operating Plan, the Annual Report and the Growers Report.

GRDC's project portfolio is dynamic with projects concluding and new projects commencing on a regular basis. Project Summaries are proposed to become a regular publication, available to everyone from the GRDC website.

Projects are assembled by GRDC R&D investment Theme area, as shown in the PDF documents available. For each Theme a Table of Contents of what is contained in the full PDF is also provided, so users can see a list of project titles that are covered. The GRDC investment Theme areas are:

- Meeting market requirements;
- Improving crop yield;
- Protecting your crop;
- Advancing profitable farming systems;
- Maintaining the resource base; and
- Building skills and capacity.

The GRDC values the input and feedback it receives from its stakeholders and so would welcome your feedback on any aspect of this first review. This way we can continue to improve and extend this summary.

To send us your feedback please email us at feedback@grdc.com.au

SECTION 17

Key contacts

Section Manager Regional Grower Services – West

Roger States

Before joining the GRDC earlier this year Roger had been working for 7 years with Sipcam Pacific Australia in product development and sales. He has also worked for Summit Agro Australia as well as Elders as an agronomist. He has extensive knowledge of farming systems and networks across the Western Region.

Suite 4, Petroleum House
12 Brodie Hall Drive
Technology Park
Bentley WA 6102
M 0427 565 780
E roger.states@grdc.com.au

Western Regional Panel

Section Panel Chairman

Peter Roberts

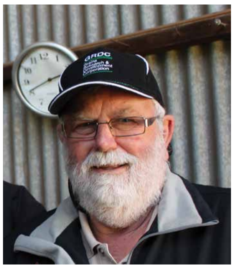
Peter Roberts, who farms at Dunn Rock, in the Esperance Port Zone, has been a member of the GRDC Western Panel since 2008 and was appointed Chairman in April 2011.

A key focus for Peter as Panel Chairman is for the panel to have a strong level of engagement with the WA grains industry. Peter was Chairman of the South East Premium Wheat Growers Association for three years before joining the GRDC's Western Panel. Other organisations he has been involved with in recent years include the Grains Industry of WA, Barley Council and Barley Australia.

M 0428 389 060
E kpeterroberts@gmail.com

Section Deputy Panel Chairman

Dr Mike Ewing



Mike has had a long career in agricultural research in Western Australia, having started his career in 1972 as an agronomist and advisor for the then WA Department of Agriculture in Geraldton.

He is a former CEO of the Cooperative Research Centre (CRC) for Legumes in Mediterranean Agriculture and was Deputy Director of the Salinity CRC before taking on the position of Research Director for the Future Farm Industries CRC. After relinquishing this role, Mike joined the GRDC Western Panel in 2011. He retired from his role at the Department of Agriculture and Food WA at the end of 2013.

M 0409 116 750
E mike.ewing25@gmail.com

Panel Members

John Even

John farms on a mixed sheep and grain farm between Goomalling and Calingiri, 135 kilometres north-east of Perth.

He took up full-time farming in 2009 following a 20-year career as an accountant with Byfields, serving mainly grain growers in the central Wheatbelt of WA.

John, who has a Bachelor of Commerce from Murdoch University, joined the GRDC Western Panel in 2011.

E johneven@bigpond.com

Dr William (Bill) Ryan

Bill has accumulated extensive research and corporate experience during a long career in Australian agriculture.

With a degree in Agricultural Science and PhD in animal science from the University of Western Australia, his career includes overseeing the complete restructure and refinancing of the Kondinin Group, of which he was Chief Executive Officer from 2002 to 2008, seven years with the Heytesbury Group and 21 years with the then WA Department of Agriculture, focused in research.

Bill joined the GRDC Western Panel in 2011 and also chairs the Agricultural Produce Commission.

M 0409 791 997
E wryan@iinet.net.au

Paul Kelly

Mingenew farmer Paul Kelly, who joined the GRDC western panel in 2011, has many years of experience as a primary producer and grower representative on numerous organisations. His family came to the Mingenew area in 1950 and Paul has farmed in his own right for more than 35 years with his wife and daughters.

He has completed the Australian Institute of Company Directors course, as well as an export management course.

M 0427 275 022
E paulsuekelly@westnet.com.au

Susan Hall

Originally from a farm at Quairading, Susan has worked in recent years as the project leader of the Grower Group Alliance which connects grower groups, research organisations and agribusiness in WA. One of her main priorities as a panel member is capacity building – understanding the obstacles stopping the grains industry from achieving improved grower profitability, and addressing them.

Susan joined the Western Panel in 2012, the same year that she completed a Master of Business Administration (MBA) at the University of Western Australia.

Susan is the Acting Chair of the Australian Grains Institute (WA) and sits on the Grains Industry WA (GIWA) executive.

M 0400 889 036
E susanhall@iinet.net.au

Shauna Stone

Shauna is a full-time farmer at Quairading in WA's central Wheatbelt, with her involvement in running the farm having increased as her three children grew up.

The farm, which comprises owned, share farmed and leased land, has been 100 per cent cropped since the Stone family sold their last line of commercial sheep in 2007.

Shauna brings communication and leadership skills to the Western Panel, in addition to practical skills as a producer and a sound knowledge of cropping systems. She joined the Western Panel in 2011.

T 08 9645 5218
E shauna@wn.com.au

Chris Wilkins

Based in Badgingarra, Chris is an agronomic and agribusiness advisor who joined the GRDC Western Panel in July, 2013.

He has 22 years of experience in WA's agricultural industry, including offering farm business, agronomy, farming systems and crop protection advice through his Vision Agribusiness Services company for the past 15 years.

Chris is also a director of one of the State's leading agricultural consultancy businesses, Synergy Consulting WA, the Deputy Chairman of the Council of Grain Grower Organisations Ltd (COGGO) and a member of WA Agriculture Minister Ken Baston's Ministerial Agricultural Advisory Council.

M 0427 940 925
E cwilkins@synergyco.com.au

Darrin Lee

Darrin is managing partner of a family farming business located 15km north-east of Mingenew in WA's Northern Agricultural Region.

The business is predominantly focused on grain growing, including production of wheat, barley, canola, and both albus lupin and narrow-leafed lupin. It also produces wool and prime lambs.

He has added value to his albus lupin production through an Australian 'paddock to plate' joint venture initiative. He started farming in 1998 after nearly 15 years in the banking and finance industry, mainly in agribusiness.

Darrin is represented on the CBH Group's Growers Advisory Council and is a Mingenew Irwin Group board member.

M 0427 281 021
E blighleefarms@bigpond.com.au

Brondwen MacLean

Brondwen was appointed to the Western Panel in October 2013 and is GRDC executive manager for research programs. She has primary accountability for managing all aspects of the GRDC's nationally coordinated R&D investment portfolio and aims to ensure that these investments generate the best possible return for Australian grain growers. Prior to her current appointment, Brondwen was senior manager, breeding programs, and theme coordinator for Theme 6, Building Skills and Capacity.

T 02 6166 4500
E brondwen.maclean@grdc.com.au

Gemma Walker

Gemma has extensive experience in broadacre cropping and livestock systems gained through managing the tri-state Mallee Sustainable Farming and her hands-on involvement in her family farm near Munglinup in WA's Esperance region.

She is the national vice chairwoman of Partners in Grain, which she also chaired for two years. Gemma holds a Bachelor of Agribusiness (Hons) and has furthered her education through opportunities such as the Northern Mallee Leaders Program.

M 0428 751 095
E hamiltondowns@hotmail.com

Section Panel Support Officer

Dr Julia Easton

Julia Easton has lived in Perth for over 30 years, and married into a farming family from the South Stirlings. She has a PhD in Plant Biology from Edith Cowan University and a BSc (Hons) Environmental Biology from Curtin University of Technology.

Julia joined GRDC as the Regional Coordinator West (including Panel Support) in August 2013. She has worked as a researcher on GRDC grants at the Centre for Legumes in Mediterranean Agriculture at UWA in pre-breeding of chickpea, field pea and lupins (2003-2008). More recently (2007-2013), Julia worked as the Research Manager for Future Farm Industries CRC and managed research projects funded by GRDC. She has excellent intellectual property as well as contracts management skills plus a good working knowledge of plant based research in Western Australia.

M 0403 311 395
E GRDCWesternPanel@gmail.com

SECTION 18

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