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GROUNDCOVER SUPPLEMENT

CANOLA SUCCESS – AN EXERCISE IN RISK MANAGEMENT

GRDC INVESTS IN LIFTING CANOLA RELIABILITY

By Dr Kaara Klepper

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■ All crops face production risks from seasonal uncertainties – adverse weather, pests, weeds and diseases – but as canola is a high-return, high-cost crop, these risks are magnified, particularly as Australian production environments continue to evolve as farm size increases and climate changes. GRDC investment in research is critical to advance this risk-management knowledge. This research support continues to see the development of tools, techniques and recommendations offering growers choices and information to manage canola production risks to maximise their overall profitability. The following is a snapshot of investments underway to address some of these risks.

CLIMATE RISK

The main driver of crop production is climate, which can be highly variable and unpredictable. Crucial to managing this risk is to understand crop adaptation. At the heart of this is the plant growth cycle, or phenology, including switching from vegetative to reproductive phases.

If the traits involved in the plant growth cycle are matched better to a particular environment, frost, heat and drought risks can be reduced and yields improved.

Optimising canola flowering time in different environments was a key theme of the GRDC-supported 'Optimising Canola Profitability' project (2014–19) and has resulted in canola sowing times moving earlier in all production areas, with the best phenology types identified for the different environments.

Earlier sowing may require sowing into less-than-ideal conditions, which can compromise reliable establishment. Consequently, genetic and physiological traits appropriate for early sowing are being identified and a closer look is being taken at how growers can improve retained open-pollinated canola seed performance.

Grazing canola is one way to de-risk early sowing as this practice can slow development and crops can yield the same as ungrazed crops, with the added livestock income. The rotational benefit of grazing canola is being investigated further, together with other crop sequences to improve system health and fertility.

New methods are being developed to assess and improve the heat tolerance of canola and quantify frost damage, and decision-support tools are being fine-tuned to better match canola varieties to production environments.

Management of high-rainfall canola across the western and southern regions is being tweaked while benchmark metrics for irrigated canola are being developed.

Meanwhile, harvest efficiencies are being improved via satellite and drone-based, remotely sensed, multispectral imagery. This will better predict canola maturity and, therefore, optimal windrowing and desiccation timing.

PEST AND WEED RISK

Insect pests and weeds compete for resources in canola production systems. Surveillance is important to monitor changes in both pest and weed occurrence and for resistance to chemical management options. To reduce the reliance on herbicides, GRDC is supporting agronomic methods of boosting canola's weed competitiveness.

DISEASE RISK

Canola suffers from several destructive fungal diseases that are adept at evolving with changing production environments, including Sclerotinia stem rot and blackleg. GRDC-invested field surveillance is identifying changes in these pathogen populations and distribution to warn of risks.

To continue to provide up-to-date management tools, genetic knowledge of both plant resistance and the evolving pathogens is being researched and markers developed and provided to breeding programs to continually develop robust, resistant canola varieties.

New investments to address canola production risks are continuously coming on stream as GRDC works with growers to close the gap in water-limited yield potential by reducing the occurrence of existing risks and identify evolving risks. □

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COVER IMAGE: A thorough production risk management plan can ensure success with canola.

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Canola record offers broad lessons

Agronomist James Cheetham of Delta Agribusiness showing the size of the crop at the start of flowering.

Photo: Peter Brooks

When science and a production system align, rewards are reaped for canola

By Dr Sue Knights

KEY POINTS

- Match canola variety to environment and production system
- Keep up to date on blackleg resistance packages
- Fine-tune harvest procedures
- Consider long-term fertility of production system

■ It has gone down in history as a triumph of "bold science meeting excellent agronomy and brave farming to push the envelope", but what can other growers learn from the production of a record 7.16-tonne-per-hectare canola crop?

The crop was produced at the Hawkins' family farm 'Mayfield' at Oberon in the Central Tablelands of New South Wales working with James Cheetham from Delta Agribusiness, who has been providing agronomic advice to farm manager Peter Brooks for many years.

The pair also have a long-standing working relationship with Dr John Kirkegaard and his team from CSIRO, who have pioneered practices to graze dual-purpose canola, which was the approach used for this crop.

"Dr Kirkegaard's approach to systems management is visionary and will become more relevant to growers' enterprises as we see spiralling fertiliser costs and a push for more-sustainable production systems," Mr Cheetham says.

The record-achieving canola yield was harvested in 2020, a year which received 889 millimetres of rainfall in a region that averages 708mm. The farm is on fertile basalt soils at quite high elevation and in 2020 incurred no frost damage and a very mild finish to the season.

The dual-purpose canola variety Hyola 970CL was sown on 28 February into a paddock with no cropping history; in fact, it had been used as an intensive cattle feedlot, so it had high soil fertility.

Eighty kilograms per hectare of monoammonium phosphate (MAP) was applied at sowing and the crop was top-dressed in September with 200kg/ha of urea. Grazing occurred in late April when dry matter yields were about 4000 to 5000kg per hectare for 59 days (27 April to 25 June) with 20 Merino lambs per hectare giving 1180 dry sheep equivalents per hectare.

KEYS TO SUCCESS

Mr Cheetham says there are risks associated with growing dual-purpose canola in a high-rainfall environment such as Oberon and there is often more at stake as it can be expensive to grow.

There is the risk of waterlogging in wet winters and the risk of frosts during the critical flowering and grain fill periods. The risks can, however, be offset by supplementary income from the grazing component of the crop.

"The choice of variety is really important – not only to match it to your production environment but also to the particular purpose," Mr Cheetham says.

"Hyola 970CL is a longer-season winter type, well-suited to this high-rainfall, long-season environment and particularly for early sowing and grazing. It is Clearfield® herbicide-tolerant to aid weed management and also has a very good disease package.

"Regular crop inspections for disease are imperative, especially for a high-yielding crop and this crop was sprayed for blackleg during flowering.

"With a large crop like this, windrowing and harvest was a huge job and had to be done slowly and carefully, so patience is a priority. Taking a long-term view to your business is key, considering both crop sequences and the fertility of your whole-farm system."

Pastures are still the basis of many farms in the NSW Central and Southern Tablelands and building crops into the sequence aids weed and disease management. The pasture legume content aids in building soil nitrogen levels, which can be utilised in the cropping phase.

"For this region, dual-purpose canola is a boon," Mr Cheetham says. "We have high-rainfall, mixed-farming systems and land prices that are rocketing. Many growers are really focusing on increasing the productivity and sustainability of what land they have, and this is where dual-purpose canola fits the bill." □

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https://groundcover.grdc.com.au/crops/oilseeds/hard-yards-pay-off-with-record-yield

Advanced genomic model to drive canola decision support

Brett Cocks scoring phenology as part of a multidisciplinary CSIRO team working to improve a canola grower decision tool.

Photo: CSIRO

■ To reduce the risk of losses from extreme heat and frost, particularly during flowering, it is important to match canola phenology – the annual sequence of plant development – to the optimal flowering window. Decision-support tools help growers achieve this – to better match canola varieties to their production environments. But such tools first need considerable data and ground-truthing by experts.

New knowledge and methods are now coming onstream to make these tools even more effective for growers pursuing improved canola productivity.

Phenology is driven by genetics and environment. In canola, thermal (temperature) and vernal (cold) responses in phenology across representative environments can be reduced to a set of parameters unique to each variety.

Representing flowering time in this way exploits existing biological knowledge that can be linked to process-based simulation models (for example, the Agricultural Production Systems sIMulator, or APSIM) to predict when a variety will flower in a given environment.

The Canola Flowering Calculator is an example of this.

However, up to now, such phenology modelling across different environments has required time-costly field-based assessments of new varieties as they are released, delaying variety optimisation. A better understanding and integration of phenology genetics into the modelling process is needed to support the development of a flexible and widely applicable tool.

MULTIDISCIPLINARY APPROACH

In response to this need and building on prior GRDC investments with CSIRO, the Optimising Canola Phenology project was initiated in 2019 to increase understanding of phenology genetics. The objective was to use this knowledge to shorten the cycle for evaluation of key phenology parameters of new varieties based on their genome. This would reduce the dependence on field-based assessments and enable growers to use the latest available germplasm more effectively.

The knowledge being developed in this project will help canola breeders develop new varieties with targeted phenology genetics.

The project has tackled this challenge with a collaborative, multidisciplinary approach that has brought together expertise in crop process modelling, agronomy, genomics, phenomics and machine learning from across CSIRO.

The team has surveyed phenology, genomic and transcriptomic variation in 350 diverse canola varieties in field and controlled environments, amassing more than 300,000 measurements from 14 field environments spanning Australian canola growing regions.

Using this data, genomic-based models were developed to predict phenology traits and derive parameters, which will be used in crop process models (in APSIM) to predict flowering time for varieties across environments.

Assessments of field and controlled-environment experiments have revealed considerable diversity in canola phenology under Australian conditions.

Using machine-learning-based, genome-wide association analysis, genome variation influencing key phenology developmental stages has been identified. This has confirmed the involvement of a number of known phenology genes, but also potentially novel candidates that will be further explored for marker development.

Phenology traits have been reliably predicted for varieties observed in field experiments from their genome, consistent with high heritability of phenology traits detected in the study.

To build a genomic model that is applicable to a broad range of environments, this genomic prediction step will be linked with the APSIM simulation model and a prototype should be available for further field-based validation in 2022. □

GRDC Code CSP1901-002RTX

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HRZ canola canopy manipulation

Crop yield depends on its total biomass production and how efficiently it converts this growth into yield – termed the harvest index – but for canola in high-rainfall zones it is a balance of risks and rewards

By Dr Jens Berger, Dr Andrew Fletcher, Sam Flottmann, Adam Brown, Jeremy Curry and Mark Seymour

■ While high canola biomass generally leads to improved yield, high biomass production can also present challenges – higher input costs and associated financial risk, harvesting difficulties associated with tall crops, high stubble loads and in-season water use, and an increased Sclerotinia risk.

These challenges promote vigorous discussion among canola growers pursuing the optimal strategy that balances risk against reward in the relationship between biomass and harvest index.

How these relationships can be managed to achieve greater returns is the perennial question.

Previous research has shown that canola productivity in the high-rainfall zone (HRZ, 450-millimetre-plus annual rainfall) is dependent on biomass accumulation, with high yields coming from high-biomass crops despite an associated reduction in harvest index.

Hybrid canola, in particular, accumulates high biomass at a reduced harvest index to produce a high yield, which is rarely matched by the lower biomass open-pollinated cultivars (despite their higher harvest index).

With GRDC investment, Western Australian Department of Primary Industries and Regional Development and CSIRO researchers are investigating ways to manipulate the biomass and harvest index relationship while maintaining high yields to reduce the trade-offs associated with high-biomass canola crops.

Trials in the Kojonup-Boyup Brook district and at Esperance tested ways to manipulate canola canopy size using a combination of genetics and agronomy.

These included different nutrition levels (high versus very high nitrogen and sulfur – 150 kilograms of nitrogen per hectare and 12kg sulfur/ha versus 300kg nitrogen/ha and 44kg sulfur/ha), in combination with plant density (20 and 40 plants per square metre), grazing (grazed before flowering versus ungrazed) and plant growth regulators in high-vigour Roundup Ready® (RR) hybrids versus lower-vigour triazine-tolerant (TT) hybrids.

These treatments had a huge impact on plant height (119 to 176 centimetres), biomass (8.2 to 15.7 tonnes/ha) and yield (1.9 to 6.2t/ha).

The data shows that while biomass and canopy size are strongly influenced by agronomy, it is much harder to move harvest index, which is stable in most cultivars (see slopes in Figure 1).

This is important because yield differences are driven by harvest index, while harvest index itself is dominated by genetics and its interaction with agronomy. Thus, harvest index tends to be lower in RR than TT canola, with some additional important differences within both groups.

In another round of experiments, canola canopy growth was further manipulated with plant growth regulators (PGRs). While PGR application reduced canopy height in both Esperance and Kojonup trials, the effects on yield, biomass and harvest index were inconsistent. More work was undertaken at both locations in 2021 to better understand the role and modes of action of PGRs.

The 2020 results suggest that varieties such as NuSeed® G-T53, InVigor® 4510TT or NuSeed® HyTTec® Trophy, which have a stable harvest index, showed no harvest index trade-offs across their agronomic treatments. They will not produce excessive vegetative biomass as they increase their input levels.

This indicates that growers can use whatever input level they are comfortable with, knowing their canola will produce its genetic potential at that input level (assuming they are growing stable, high-harvest-index varieties).

2021 was ideal for the team to conduct more experiments to unravel crop biomass interactions due to the long, relatively high-rainfall season in both locations.

In-season height measurements showed the treatments had a big impact on canopy size but, at the time of writing, harvest had not yet occurred. □

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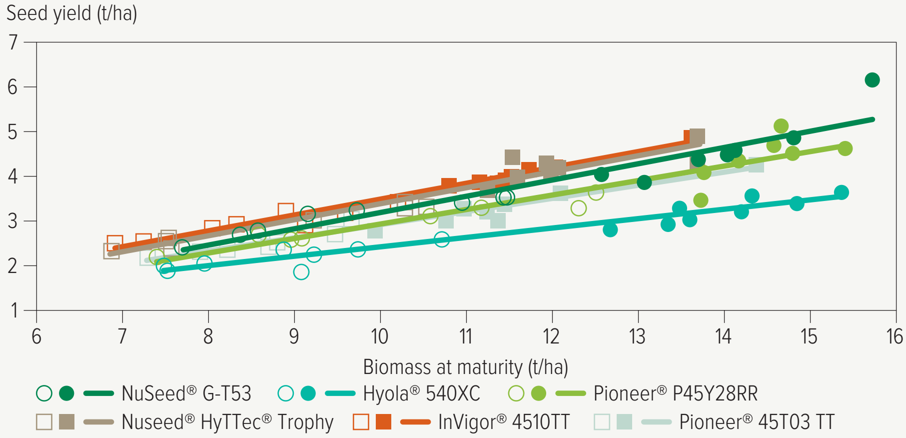
Figure 1: Changes along the yield-biomass progression at Qualeup, WA, in 2020. Most cultivars had stable harvest index with similar yield-biomass slopes, while some got worse as biomass increased. (Grazed treatments: empty markers; ungrazed treatments: full markers. RR canola varieties are represented by circles, TT types by squares.) (P<0.001, LSD=0.01)



Source: CSIRO

Canola being set to beat the heat

GRDC has invested in a coordinated national project to protect the Australian canola industry against the risk of more frequent heatwaves and potential yield losses due to climate change

By Dr Sheng Chen and Dr Rajneet Uppal

■ Australian researchers are tackling canola heat stress tolerance with strategic pre-breeding research. This renewed effort to strengthen canola's climate resilience is drawing on results and background intellectual property from previous GRDC co-invested projects with the New South Wales Department of Primary Industries (DPI) and University of Western Australia (UWA). That earlier research showed a few hours of daily heat stress for three days during first flower could reduce canola grain yield by up to 30 per cent.

The new GRDC-supported UWA and NSW DPI project aims to:

1. screen new germplasm for heat tolerance, develop screening procedures and genetic analysis;
2. identify genes and molecular markers for use by canola breeders;
3. field-validate the heat-tolerant genotypes in trials and improve trial design for measuring heat tolerance;
4. evaluate stability and repeatability of heat-tolerant genotypes in portable heat chambers; and
5. distribute confirmed heat-tolerant canola genotypes to Australian canola breeders.

CONTROLLED-ENVIRONMENT RESEARCH

A new prototype heat-stress facility has been established for large-scale heat tolerance screening of canola germplasm, based on results of experiments at UWA since 2013. Significant heat tolerance in canola was found in 2020 in this heat tolerance facility:

- Canola is sensitive to heat stress during the entire flowering period, but heat stress was applied only for seven days following first open flower on the main stem, when plants were exposed to a simulated heat wave of 32°C maximum daily temperature and 22°C nightly temperature.
- This heat wave reduced grain yield and pod numbers on the main stem by an average of 29.6 and 18.3 per cent, respectively, over 200 lines tested in 2020. The top 10 heat-tolerant lines experienced 9.5 per cent reduction in yield and 11.2 per cent reduction in pod numbers on the main stem following heat stress, compared with 79.7 per cent reduction in yield and 44.4 per cent reduction in pod numbers in the most heat-sensitive line.

The prototype heat-stress facility would be useful to commercial canola breeding programs that are seeking to screen early generation lines for heat tolerance.

FIELD VALIDATING HEAT-TOLERANT GENOTYPES

In 2020, the heat tolerance of 30 selected genotypes was validated in irrigated field trials with two replicates at five sowing times at Narrabri and Leeton in NSW. Results aligned with the UWA prototype screening, with three genotypes – YM11, Charlton-NCA18 and Yudal – performing well (Figure 1). In 2021, field testing of selected genotypes was repeated at four sites: Leeton and Condobolin in NSW, Kerang in Victoria and Dongara in Western Australia.

STABILITY OF HEAT-TOLERANT GENOTYPES

Novel, portable heat chambers have been used to assess heat tolerance of canola in field environments since 2017 at NSW DPI, Wagga Wagga.

This has enabled heat tolerance of varieties in natural field environments to be captured. Daily maximum temperatures of up to 35°C are imposed in these chambers for a few days while keeping moisture and nutrient levels at optimum levels.

Heat stress in these chambers has significantly reduced seed yield, harvest index and seed number per pod in canola varieties that were selected from multi-location trials. So far, wide genetic variation in heat tolerance has been observed with a few promising lines with good mean yield and good heat tolerance. ☐

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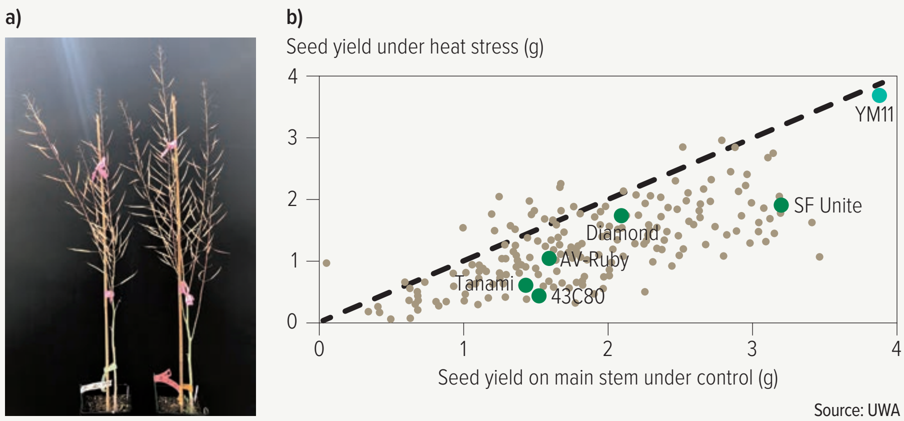
Figure 1: YM11, a heat-tolerant canola line originally from China, showed highest seed yield among 200 genotypes under both control and heat stress conditions in 2020. (a) YM11 showed excellent pod and seed set at maturity after seven days of control treatment (25/15°C, left plant with white tag) and heat stress treatment (32/22°C, right plant with red tag) at the early flowering stage. (b) Broad genetic variation existed in 200 genotypes. Some genotypes performed better than three OP cultivars (43C80, Tanami and AV-Ruby) and two hybrid cultivars (Ignite and Diamond).



Source: UWA

Mobile shelters create a controlled frost laboratory

Canola frost risk is the target for a research team that is prototyping mobile 'frost-excluding' shelters to improve the commercial relevance of frost field trials

By Dr Rajneet Uppal

KEY POINTS

- Frost is a major risk for canola production
- The impact of frost has proven difficult to research
- New methods for crop 'frost exclusion' are being developed

Photo: NSW DPI

Mobile frost shelters in an experiment at Wagga Wagga Agricultural Institute.

■ A pilot research project has tested the use of mobile shelters as a way to develop more field-relevant methods of quantifying frost damage to canola crops. The research has been made possible through a Grains Agronomy and Pathology Partnership co-investment project supported by NSW DPI and GRDC. The two-year project is addressing knowledge gaps in frost risk management.

Frost has become a major impediment for the Australian canola industry due to increased frequency of extreme climatic events and exposure of early sown canola to greater frost risk. Although agronomic solutions for frost are evolving, a genetic solution has proven more elusive. This may have been partly due to the challenge of developing field-relevant methods of quantifying frost damage with reference to frost-free control plots.

Previous research in frost used multiple sowing dates to create a range of flowering times to examine the impact of frost. However, commercial relevance of the experimental results was questioned as true 'non-frost' treatments were usually missing. Recently, automated diesel heat pumps were developed as frost-free controls in cereals. However, actively heating larger canola canopies would be too demanding for the pumps at flowering.

Instead, purpose-built mobile frost shelters (three metres long by 1.8m wide by 1.2m adjustable height) were constructed from black plastic layered with insulation sheets fitted on a metal frame. These shelters were rolled over designated 'control' plots in field trials when frost was forecast to enable a side-by-side in-field comparison between frost-affected and non-affected crops.

As temperatures at crop canopy height can be two or more degrees lower than forecasts, frost damage can occur when 2°C or lower temperatures are forecast by the Bureau of Meteorology.

Canola is most susceptible to frost damage during reproductive development from bud to grain-filling stage, but frosts at late flowering or grain-filling can be severely detrimental. Spring frosts that occur in September at grain-filling are the most economically damaging, resulting in reduced grain yield and oil quality. In 2017, frost reduced canola grain yield by approximately 0.3 tonnes per hectare in NSW alone – a total of 120,000t valued at $63 million (estimated farmgate at $525/t).

In a replicated field experiment, four canola varieties with two temperature treatments (frost and non-frost) were investigated in growing season 2021. Frost exclusion treatments were imposed during the entire reproductive growth stage and pods were tagged to mark any frost events to capture the effect of frost on seed development. This research will be critical to quantify direct yield loss due to frost and the commercial implications of frosted crops.

Preliminary results demonstrated that mobile shelters successfully insulated crop canopies in mild frost (minus 2°C), enabling field-based comparison between frosted and unfrosted plots. The shelters now need to be tested under severe frost conditions when temperatures fall below minus 4°C.

Along with frost shelters, the research team is using a controlled-environment facility to further understand frost damage using different intensity and duration of frost at critical growth stages of canola.

By developing a greater understanding of temperature thresholds for frost stress and the impact of frost during optimum canola flowering dates, growers will be able to better mitigate frost risk.

The methods and protocols developed in this pilot project will be useful for frost/chilling tolerance in all grain crops, not just canola. □

GRDC Codes DAN00213, DPI2003-014BLX (BLG114)

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Taking a longer-term view of canola in cropping systems, a team of researchers led by CSIRO's Dr John Kirkegaard is honing southern NSW farming systems.

Photo: CSIRO

Canola looks less risky through a longer lens

Canola production has a risky reputation but taking a longer-term view of its role in farming systems and underpinning this with up-to-date research can mitigate risk

By Dr John Kirkegaard

■ Although canola is Australia's third-most-important grain crop, it is often perceived to be riskier to produce than cereals due to its lower water use efficiency, higher nitrogen requirement and extra machinery costs.

The need to de-risk canola production led GRDC to invest in a sequence of large projects. These were to, firstly, optimise canola production by understanding canola physiology and matching tactical agronomic management to improve production and, secondly, to learn how to position canola in the cropping sequence to improve farming efficiency, specifically in central and southern New South Wales.

Since 2014, CSIRO, with GRDC investment, has been working with researchers from the NSW Department of Primary Industries (DPI), South Australian Research and Development Institute (SARDI) and regional advisers and growers to address canola production issues. It began with the 'Optimised Canola Profitability' (OCP) project and subsequently the 'Improving farming systems efficiency in southern NSW' project.

OPTIMISED CANOLA PROFITABILITY

This project incorporated both research and extension components and spanned nine regions across eastern Australia. Annual intensive experiments in specified regions at well-characterised field sites investigated phenological development, physiological adaptation, response to stress timing and severity and windrowing timing to improve agronomic understanding, varietal adaptation and profitability.

Experimental outcomes were incorporated and validated into the modelling platform Agricultural Production Systems sIMulator (APSIM) and used to extrapolate the outcomes over more sites and seasons.

Several canola production resources were developed and further extension occurred at GRDC Updates, field days and a roadshow series at the end of the project.

By better understanding the drivers of development, flowering time and the critical period for grain yield development, tactical agronomy advice was delivered for robust, high-yielding, early sowing systems, reduced production risk and improved harvest management.

An independent impact survey of 90 consultants at the end of the OCP project indicated that about 68 per cent had made significant practice changes with their clients as a result of the research, with improvements in profitability estimated to be worth $74 million per annum to the Australian industry.

The earlier-sowing systems developed in the project provided variety and sowing date advice and agronomic packages for sowing in early to mid-April rather than in late April. These systems have been shown to provide average yield benefits of about 0.4 tonnes per hectare (often up to 1t/ha).

Major yield penalties occurred when fast-maturing varieties were sown too early, and the industry was alerted to this risk.

Regression tree analysis suggested early sowing systems with an appropriate agronomy package could improve gross margin by $60 to $100/ha. Consultants reported the improved agronomic advice related to early sowing systems was worth up to $200/ha.

To reduce risk in the low-rainfall zones, the focus was on maintaining profit rather than pursuing higher yield. It was determined that sowing opportunistically using a set of rules on conditions for successful establishment increased profit and reduced risk. In these riskier environments, the yield advantage for hybrid varieties had to be 20 per cent above open-pollinated varieties to justify the increased seed costs.

The project also determined that simple changes to nitrogen management in response to season type offered significant advantages for both profit and risk, despite an overall need to increase nitrogen inputs in most season types.

New harvest recommendations from the project showed that windrowing should occur when 60 to 80 per cent of seed sampled from the middle third of branches and main stem have changed colour – a revelation emerging from the fact that 80 per cent of the yield arises from branches and not the main stem.

Yield increases of up to 55 per cent and oil increases of eight per cent could arise from these new recommendations. Delaying harvest past that stage could reduce seed size and increase shattering (less in shatter-tolerant varieties).

IMPROVING FARMING SYSTEMS EFFICIENCY

To further de-risk canola production and capture full value from the crop, the OCP findings have been followed up in the context of longer-term crop sequence/farming systems in the 'Improving farming systems efficiency' project, which began with GRDC investment in 2017.

Canola plays a valuable role in crop sequences as a break crop reducing pest, weed and disease levels. In this respect, canola's profitability needs to be put in context with the farm gross margin over more than one season. Related decision-making (such as nitrogen supply) needs to be considered for better managing production risk of the entire farming system.

With GRDC investment, CSIRO collaborated with NSW DPI to establish farming systems experiments at four sites across southern and central NSW, Wagga Wagga, Greenethorpe, Condobolin and Urana. Grower and adviser collaborators nominated the baseline systems for each site, which included either canola/wheat/wheat or canola/wheat/barley sequences sown from late April to early May (timely) and a conservative or low (decile-two) nitrogen strategy.

These were compared with a range of more-diverse cropping sequences that involved legume/canola/wheat and compared different legume options. These were high-value legumes (lentils and chickpeas), low-value legumes (lupins and faba beans) and a multiple-end-use forage option (vetch) grazed and/or cut for hay.

This 'double-break' provides improved weed management options and positions canola after the legume to provide legacy water and nitrogen benefits to de-risk the canola.

As a measure of profitability, the average annual earnings before interest and tax (EBIT) were calculated over three seasons for the different farming systems; this ranged from $200 to $1200 per hectare.

From 2018 to 2020 at Wagga Wagga, Greenethorpe, Condobolin and Urana, the experiments showed there were diverse farming systems involving legumes that achieved $150 to $250/ha more than the baseline May-sown and grain-only canola/wheat/barley or grain-only canola/wheat/wheat.

Table 1 shows examples for a low-value and a high-value diverse cropping sequence compared with the baseline.

Despite some extreme seasonal differences – 2018 and 2019 had very low rainfall (decile 1-2) whereas 2020 was high (decile 8-9) – the profit and efficiency in terms of dollars per millimetre of rainfall can be lifted by making some simple, but targeted, changes to cropping sequence, sowing time and nitrogen strategy.

There is no single recipe to improve returns, but a range of ways to achieve a profit lift that will be suitable for farms with and without livestock, and operators who may or may not be willing to grow pulse crops.

Of the non-grazed farming systems, the most consistently profitable systems generally were the timely sown legume/canola/wheat with a decile-two nitrogen strategy, which were more profitable than the baseline, had lower risk, lower input costs (nitrogen and herbicides) and maintained lower levels of weeds and disease. ☐

GRDC Codes DPI1406-001RMX (CSP00187), CSP1703-007RTX (CFF00011)

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Resources: see back page of this Supplement

There is no single recipe to improve returns, but a range of ways to achieve a profit lift that will be suitable for farms with and without livestock, and operators who may or may not be willing to grow pulse crops.

Table 1: Profitability (average annual earnings before interest and tax, EBIT $/ha) for the baseline systems (wheat/canola/wheat or wheat/canola/barley) compared with diverse crop sequences, which include either low-value (lupins/faba beans) or higher-value (lentils/chickpeas) in a double-break with canola.

All systems sown in early May with conservative nitrogen strategy (targeting decile 2 yield). The economics have been calculated based on the actual costs and process (spot) for the years 2018–20, or the long-term average costs and process (LTA).

		Greenethorpe		Wagga Wagga		Urana		Condobolin	
System	Sequence	Spot	LTA	Spot	LTA	Spot	LTA	Spot	LTA
Baseline	W–C–W	$720	$745	–	–	–	–	–	–
	W–C–B	–	–	$528	$582	$488	$501	$534	$491
Diverse (low value)	Lu–C–W	–	–	$626	$629	–	–	$517	$487
	Fa–C–W	$739	$742	–	–	$655	$661	–	–
Diverse (high value)	Le–C–W	–	–	–	–	$775	$716	$522	$680
	Ch–C–W	–	–	$588	$559	–	–	–	–

Source: CSIRO

Dual-purpose canola: from inspiration to impact

Photo: CSIRO

Dr John Kirkegaard (with plaque) accepting the 2021 Sir Ian McLennan Impact for Science and Engineering Medal on behalf of his team for the many years working to deliver grazing management strategies to growers for dual-purpose canola. (L-R) Bruce Isaac, Scott McDonald, Tony Swan, Dr Susie Sprague and Dr Julianne Lilley. Not present: Dr Lindsay Bell, Dr Hugh Dove (posthumous), Mel Bullock and industry collaborators Tim Condon, James Cheetham (both Delta Agribusiness), Peter Hamblin (Kalyx Australia), Peter Brooks (Princess Pastoral Company), Rod and Nick Kershaw (Iandra Pastoral Estate).

If someone had told Dr John Kirkegaard 17 years ago that grazing canola crops was too risky – what would Australian growers have missed out on?

By Dr Sue Knights

■ Enhanced flexibility and resilience of mixed farming systems and greater profits for Australian growers are some of the outputs from the methods developed for growing and grazing dual-purpose canola.

And for CSIRO's Dr John Kirkegaard, who coordinated the research to undertake the challenge, it has delivered not only satisfaction of delivering a valuable new system to growers but scientific recognition. Most recently his team was awarded the 2021 Sir Ian McLennan Impact for Science and Engineering Medal, an internal CSIRO award that celebrates outstanding practical contributions to industry and recognises exceptional individuals or research teams that have created value through innovation.

"The Millennium drought was the inspiration for this research, as it saw canola drop out of cropping rotations due to its perceived risk," Dr Kirkegaard says. "But growers were missing out on the disease and weed break it provided, so we started thinking about how we could de-risk canola production. Higher-rainfall areas also lacked a profitable rotation crop for the grazing winter wheats.

"Having seen wheat successfully grazed and then taken through to harvest, and given that brassicas closely related to canola (forage rape) were used in animal production systems, we conceived the idea of dual-purpose canola to provide an income source from both stock and grain for growers with mixed farming systems."

Seventeen years on, a CSIRO case study impact assessment has determined that dual-purpose canola is now adopted on an estimated 200,000 hectares and growing across all southern states, lifting profitability, sustainability and resilience. Its estimated value since 2007 is $1 billion – growing at $200 million a year.

Table 1: Typical examples of forage, grain yield and gross margins achieved from well-managed dual-purpose crops by collaborating growers in southern NSW.

Crop type	Grazing achieved (dry sheep equivalent days/ha)	Grain yield (t/ha)	Paddock $GM increase above grain only
Winter wheat	1600 – 2700	4.5 – 6.5	+$600 – $1000
Spring wheat	400 – 800	3.0 – 5.0	+$300 – $500
Winter canola	750 – 2500	2.0 – 4.0	+$600 – $1000
Spring canola	300 – 700	1.5 – 2.5	+$300 – $500

Source: CSIRO

"Credit for this success goes to the multidisciplinary team that embedded growers and consultants with researchers from the start," Dr Kirkegaard says. "Plus, GRDC funding over a decade allowed us to get from inspiration to impact by adapting the concept on-farm with growers as we refined the agronomy."

Significant industry co-investment from GRDC and Meat & Livestock Australia in close collaboration with industry stakeholders (farmers, advisers and breeding companies) has supported the research since 2007, with three back-to-back GRDC-invested projects from 2007 to 2015 and since 2017 ongoing work as part of the southern farming systems project.

RISK AND REWARD

Dual-purpose canola relies on successful early sowing opportunities, varieties being matched to the appropriate phenological window and careful grazing management to balance trade-offs between the value of forage and that of grain.

The overall business value of dual-purpose canola depends upon how it is integrated into enterprises. At the paddock level, grazing can come at no cost to seed yield, so grazing adds value by increasing the availability of autumn and winter feed in the grazing enterprise (Table 1). At the farm system level, this can provide flexibility, profitability and resilience, with different exit options (graze out, hay, silage, grow on for grain) depending upon seasonal conditions. □

GRDC Code CSP2106-009RTX

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https://vimeo.com/650962266

Water-nitrogen interactions could lessen late-season weather risks

By Danielle Malcolm and Mathew Dunn

KEY POINTS

- The risk of drought, heat and frost during flowering is part of sowing decision-making for canola
- A better understanding of both water and nitrogen use efficiency and their interactions could help inform sowing decisions

Many canola growers are locked into crop variety choice and therefore recommended sowing period well before sowing. Consequently, decisions on whether to continue with the planned canola variety or change to a less-risky crop option such as barley are based on summer rainfall and estimated plant-available water.

The risks associated with sowing canola into variable soil water availability scenarios and the implications of nitrogen management in these situations are not well understood.

Previous research supported by GRDC, CSIRO and the New South Wales Department of Primary Industries (DPI) in the 'Optimised Canola Profitability' project has shown that matching cultivar phenology with sowing date to allow varieties to flower within their optimal flowering period, to minimise the risk of exposure to stress events (frost, heat and drought), is a critical factor to maximise yield potential.

However, when longer-season hybrid canola varieties are sown there is a perception that these types may incur yield loss in spring. This is due to their vigorous deep roots extracting more soil water earlier in the season when starting subsoil moisture levels may be low.

This assumption leads to growers taking a conservative nitrogen management approach aiming to limit early biomass accumulation and soil water extraction. This results, potentially, in more soil water being available later in the season to safeguard grain fill.

BALANCING NITROGEN AND WATER USE

This project aims to examine the available soil water and nitrogen interactions to identify the management decisions most conducive to canola profitability in Australia's variable climate.

Under the Grains Agronomy & Pathology Partnership, which has co-investment from NSW DPI and GRDC, this project is utilising rain-out shelters combined with in-crop drip irrigation to implement multiple in-crop soil water availability scenarios. This is being done at two contrasting locations – the NSW DPI Wagga Wagga Agricultural Research Institute, which is in a medium-rainfall environment, and the NSW DPI Yanco Agricultural Institute, which is in a low-rainfall environment.

All treatments started with a full soil water profile from good summer rainfall at both locations. Three water profiles were set up, one which remained full, one which was topped up at flowering and one which was not topped up at all. The soil water treatments were overlaid with a range of nitrogen rates and timings to assess the interaction between these two management factors. One mid-season hybrid cultivar was sown in April to flower within the optimal flowering time at both locations

The results from this experiment, combined with the findings from the 'Optimised Canola Profitability' project, will provide valuable insight into the response of canola to nitrogen and soil water through the critical flowering period. The effect of different nitrogen treatments on biomass accumulation and subsequent conversion into grain yield will be determined across a range of soil water availabilities.

Visual assessment throughout the 2021 season indicated the flowering period was hastened by up to two weeks in plots with a depleted soil water profile compared with well-watered plots.

With increasing fertiliser prices these results will guide growers to better manage their in-season nitrogen management based on profile water and seasonal conditions. Refining nitrogen management strategies will also likely increase confidence to grow canola in low-rainfall regions and provide indirect benefits of a disease and weed break for the cereal dominant rotations of these environments. ☐

GRDC Codes CSP1706-015RMX (CSP00187), DPI2108-003BLX (BLG120)

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Photo: NSW DPI

To improve the understanding of nitrogen and water use efficiency of canola and the implications for the critical growth period of canola, a team of NSW Department of Primary Industries researchers are using semi-controlled environments – rain-out shelters and drip irrigation.

Metrics to help manage irrigated canola

Canola production under irrigation faces unique risks, so metrics are being developed to guide management decisions

By Dr Sue Knights

Irrigated cropping provides opportunities to intensify production, but while technological innovation has increased the efficiency of irrigated agriculture, significant potential still exists for improvement.

That is why GRDC invested in a three-year project with Field Applied Research (FAR) Australia considering ways to lift the productivity and profitability of irrigated farming systems in south-eastern Australia.

"Highly volatile climatic conditions, water costs and water allocations – often linked to seasonal and political contexts – demand more-informed crop and irrigation choices at the outset of the growing season," says FAR Australia's managing director, Nick Poole.

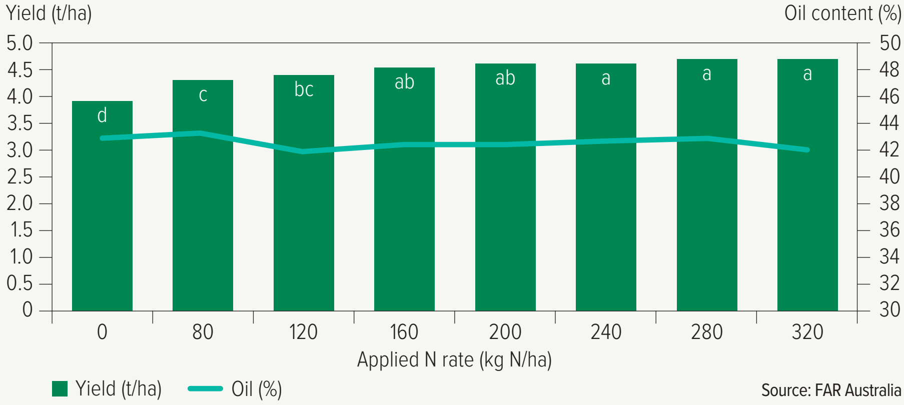
FAR Australia established trials at Finley, New South Wales and – with collaborating partner the Irrigated Cropping Council – at Kerang in Victoria to take a closer look at management practices of cereals, pulses and canola under surface and overhead irrigation.

"We are developing an understanding around what drives yield in irrigated cropping systems and metrics will provide a focus for further improvements," Mr Poole says.

"To do this, we are teasing apart canola's yield and profitability response to different plant populations, nitrogen rates and timing and the effect of plant growth regulators under the two types of irrigation."

The two sites provide contrasting environments as they differ in soil type and temperature profile. But both provide the same risks and challenges for irrigated canola production.

Figure 1: Canola yield and oil content under different nitrogen treatments and overhead irrigation at the Finley, NSW, site. Soil nitrogen available at sowing = 129 kilograms of nitrogen per hectare (0 to 90 centimetres).



Source: FAR Australia

PLANT POPULATION METRICS

"Irrigation does not protect you from establishment risks when growing canola," Mr Poole says.

"If you wet up a profile prior to sowing, you can face the risk of waterlogging come autumn if you get large rainfall events and this will impair canola establishment."

Preliminary results showed varieties performing differently under the two irrigation regimes. Using overhead irrigation (125 millimetres applied in five applications of 25mm), significant plant population and cultivar interactions occurred. For example, Pioneer® 45Y28 RR showed no significant difference in seed yield as plant population increased from 14 to 36 plants per square metre. In contrast, Nuseed HyTTec® Trophy achieved the highest yields with the highest population (3.92 tonnes per hectare from 30 plants/m^2, sown at 80 seeds/m^2).

In contrast, with increasing surface irrigation (240mm from three applications of 80mm) and higher available soil nitrogen (214 kilograms of nitrogen per hectare, zero to 90 centimetres), seed yields were higher and both cultivars achieved highest yields at the highest plant populations (Pioneer® 45Y28 RR – 4.9t/ha, 32 plants/m^2; Nuseed HyTTec® Trophy – 4.01 to 4.11t/ha, 23 to 31 plants/m^2).

NITROGEN METRICS

"A common nitrogen budget metric used for Australian dryland crops is that for every tonne of canola we need approximately 80kg of nitrogen/ha," Mr Poole says.

"So under irrigated conditions, if we consider producing a 5t/ha canola crop, we need to supply 400kg of nitrogen/ha from a combination of either fertiliser and/or the soil. The risk in irrigated systems is spending too much on nitrogen fertiliser with no yield gain."

Nitrogen trials at both the Finley and Kerang sites applied rates of up to 320kg of nitrogen/ha. Preliminary results show it was not possible to produce higher canola yield by simply applying more nitrogen fertiliser; 120 to 160kg/ha was optimum (Figure 1).

"But, importantly, canola takes out more nitrogen with the combined canopy and seed yield than is applied in fertiliser. We have seen this when we grow wheat subsequently on these canola trials, as there are visually deficient plots compared to plots with the highest nitrogen rates.

"This is where we need to consider the fertility of our farming systems as a whole. Whether we apply extra nitrogen, so it will be available for crops the following season, or whether we include other sources of nitrogen such as grain legumes, organic manures or pasture legumes in our crop sequences." ☐

GRDC Code FAR1906-003RTX

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Anvil Media youtube https://www.youtube.com/watch?v=46Dua3lzthQ

Trial reports: faraustralia.com.au/resource

Canola establishment under the scope

By Dr Matthew Nelson

■ Unreliable field establishment leading to difficult weed management, reduced yield potential and, sometimes, resowing is a challenge for canola production. These establishment risks have increased with the trend to earlier sowing. The cause can lie with seed genetics, seed source, environment (soil and rainfall) and management (seeder set-up) factors.

A complex challenge like this calls for multi-pronged solutions. Consequently, with GRDC investment, CSIRO started a project in July 2019 focusing on genetic solutions to help canola breeders develop varieties that better establish in growers' paddocks.

Working with an expert team across CSIRO including Dr Greg Rebetzke, Dr John Kirkegaard, Dr Ian Greaves, Dr Jose Barrero, Dr Andrew Fletcher, Dr Alec Zwart, Karen Treble, Mark Cmiel and Trijntje Hughes, the project started with understanding the challenge from growers' perspective.

From a survey of 63 canola growers and agronomists across the country in February 2020, the most common causes of poor establishment were marginal soil moisture (76 per cent), incorrect sowing depth (65 per cent) and soil crusting (29 per cent).

From previous experience in cereal crops and from a thorough review of the scientific literature, it was concluded that these common causes of poor canola establishment could be overcome by developing canola varieties with enhanced early vigour and longer, stronger hypocotyls – the stem of the germinating seedling – to improve the emergence from deeper sowing to access more moisture.

Seed sown early into moisture at depth could emerge on time and reduce exposure to high soil temperatures, but an additional challenge for canola was identified: the tendency for marginal soil moisture to induce seed dormancy that could delay germination. However, methods to screen large numbers of varieties efficiently had not yet been developed to support a breeding-based solution.

Then began an intense period of method development by the team to facilitate screening large numbers of diverse international varieties (including winter canola, industrial rapeseed and even swede, kale and fodder types) and current Australian canola varieties for establishment traits.

These lab-based methods are high-throughput and highly reproducible – crucial for routine and accurate screening of breeding material. New methods have laid the foundation for gene discovery and molecular marker development, which is the focus of the next phase of the project.

But technical success means nothing unless lab-based screening methods reflect establishment in the field. Subsequently, in 2021, four field experiments were conducted in Western Australia and New South Wales to ground-truth the high-throughput screening methods.

Seeds were sown at two and five-centimetre depths using 20 international varieties and five current Australian hybrid and open-pollinated varieties. The best international varieties outperformed the best Australian variety in their per cent emergence from 5cm depth (Figure 1).

Initial analyses are promising, with early vigour and long hypocotyls being correlated with good field establishment. Strikingly, the best international variety in the field was also one of the most vigorous varieties at germination and cotyledon stages in the lab-based tests, and the second and third-ranked international varieties both had very long hypocotyls.

These results are exciting because it should be possible to combine the early vigour and long hypocotyl traits by breeding to produce varieties with an improved ability to emerge from deep sowing. An additional set of four field experiments will be completed in 2022 to confirm these findings. □

GRDC Code CSP1907-001RTX

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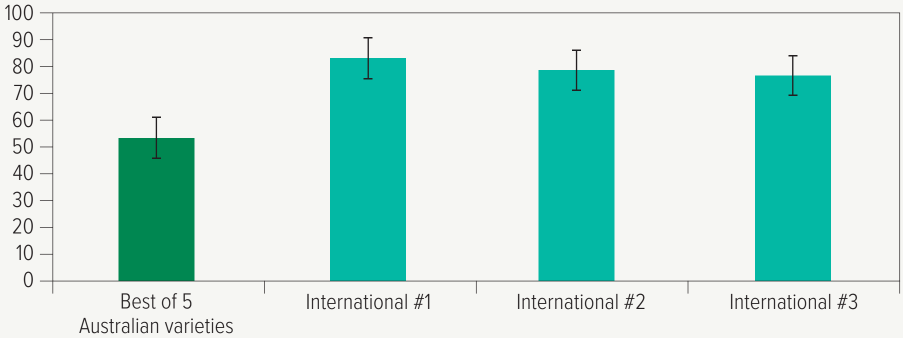
Figure 1: The best international varieties outperformed the best current Australian variety in per cent emergence when sown at five centimetres.

Data from row plots (four replicates) were scored 31 days after sowing at Boorowa Agricultural Research Station, 2021. Photos of representative row plots are shown.



a) Best of 5 Australian varieties

b) International #1 variety

Photos: Stuart Brown

Retained canola seed – handle with care

Tips and tactics are being developed by a research team to improve the quality of retaining open-pollinated canola seed

By Colin McMaster

A new research effort is looking to identify the key seed characteristics that improve open-pollinated (OP) canola establishment and, in parallel, develop in-crop strategies to promote these characteristics in grower-retained OP seed.

OP canola varieties are grown on a significant area of the low to medium-rainfall zone across Australia. Commonly, growers produce these OP canola crops from retained seed, but there is a risk that vigour may decrease over time, affecting germination and establishment.

This is being addressed by a GRDC-supported team led by the NSW Department of Primary Industries, including AgGrow Agronomy and Research and the Grain Orana Alliance.

As canola seed is small, it has less energy reserves than larger-seeded crops and, as a result, is more sensitive to poor establishment across a range of seasonal conditions and agronomic management strategies.

For growers looking to reduce the cost of crop inputs, canola establishment has become an emerging issue over the past decade due to increased seed costs, reduced seeding rates, unreliable autumn rainfall and sowing into marginal seedbed conditions.

Currently, grower-retained canola seed is managed the same as a typical commercial paddock, except the largest seed is screened and retained. The sieve size used is normally determined by the ratio of total seed graded to how much seed is required for the following sowing.

There is little to no understanding about the role of seed composition (oil percentage, protein percentage, starch, seed weight, seed nutrient content and fatty acid profile) to improve seed vigour and establishment.

Areas of investigation include crop and seed nutrition, canopy architecture and harvest management, with the following research questions in mind:

- What is the optimum nutrient strategy to produce high-vigour seed lots?
- Does foliar nutrition allow an opportunity to load up the seed with various nutrients to improve seed vigour/establishment?
- What type of canopy architecture produces larger seed?
- How important is spatial arrangement?
- Does reducing total bud number increase the carbohydrate supply to the remaining buds?
- How will harvest management affect next year's seed vigour?
- Is there any difference between the various desiccation method/products and timings?

FIELD INTELLIGENCE

Seed crop experiments were sown in 2020 across four growing regions (central-eastern New South Wales, central-western NSW, south-eastern NSW and south-western NSW) and included a range of nutrient, canopy and harvest management experiments. The seed harvested from these experiments was graded to various seed sizes and evaluated via seed vigour testing (growth, stress and biochemical testing) and field establishment trials were run in 2021.

Preliminary findings show that field establishment ranged from 23 to 72 per cent, and was affected by seed size, seed crop agronomy and growing environment.

Averaged across all sites, field establishment increased by six percentage points as seed size increased from 1.6 to 2 millimetres diameter; five percentage points with additional phosphorus; four percentage points if the seed lot was largely derived from the main stem as opposed to the lateral branches (that is, high seeding rate); and four percentage points if grown in the regions with a cooler/softer environment.

Early indications are that gains to field establishment via seed crop agronomy are likely through a series of small incremental gains rather than one specific management operation.

However, growers must be aware that harvest management can reduce a high-vigour seed lot to a low-vigour seed lot if the seed crop is desiccated too early and/or glyphosate has been used as a harvest aid/weed control. ☐

Photo: NSW DPI

Example of seed-crop harvest management trials at Tottenham, NSW.

PRELIMINARY TIPS FOR GROWING OPEN-POLLINATED CANOLA SEED (RESEARCH IS ONGOING)

1. Select large-sized seed (grade as big as possible).
2. Ensure seed crop had adequate phosphorus.
3. Ensure seed crop was largely derived from main stem (that is, high plant density, approximately 40 plants per square metre or higher).
4. Source seed from regions of cooler/softer environments (east compared with west).
5. Ensure seed crop was direct-harvested or windrowed late. Avoid seed crops that have had glyphosate applied as harvest aid/weed control.

GRDC Code DPI1906-007RTX

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Tactics to manage diamondback moth

Integrated practices are an important means of managing the significant canola pest diamondback moth – and vigilance is part of this

By Dr Dustin Severtson and Dr Kym Perry

■ Insect damage is a serious production risk for canola – but manageable today with a range of tactics.

Integrated control measures are the most effective and sustainable. These include green bridge management, surveillance, biological control and a judicious use of insecticide given the risk of promoting insecticide resistance.

GRDC-supported research at the Western Australian Department of Primary industries and Regional Development is taking a methodical approach to these issues for the diamondback moth (DBM), *Plutella xylostella* L. This sporadic but serious migratory pest of canola has a voracious appetite and a predisposition to developing resistance to insecticides rapidly.

With GRDC support, DBM surveillance work is determining what role moth and larvae presence in summer green bridges that contain brassica species such as radish, turnip and volunteer canola have in driving the severity of in-crop infestations.

The crop environment also needs consideration, as natural DBM biological control agents that play an important role in population control may be present. For example, outbreaks of an entomopathogenic fungus (*Zoophthora radicans*) can reduce DBM numbers by 90 per cent in some years with warm and humid conditions. Parasitic wasps (such as *Diadegma semiclausum*, *Apanteles ippeus*, *Diadromus collaris* and *Oomyzus sokolowskii*), as well as brown and green lacewings, spiders and other predacious bugs, also reduce DBM populations by feeding on eggs, larvae and pupae.

To reduce yield loss to DBM, growers should monitor canola crops using a sweep net from late winter onwards, noting DBM presence and abundance as well as beneficial insects, and only spraying when threshold levels are exceeded (Table 1) to allow natural predators to aid in control.

If spraying is warranted, select and rotate products according to the industry's Resistance Management Strategy for DBM, to preserve the effective life of these insecticides.

INSECTICIDE RESISTANCE

As part of the GRDC-supported research, the South Australian Research and Development Institute has investigated levels of insecticide resistance in DBM from the five port zone regions of WA. In total, 21 populations were collected between spring 2020 and autumn 2021 from canola crops, forage rape crops, brassica vegetable crops or wild brassicaceous plant species. Populations were screened using phenotypic insecticide bioassays to determine mortality responses to five commercially available insecticides (Table 2).

Among the DBM populations tested, some degree of reduced sensitivity was detected that may indicate a reduction in field efficacy. For example, synthetic pyrethroids (such as alpha-cypermethrin) should be avoided in canola crops where DBM is a problem, as DBM has moderate to high resistance to these insecticides (Table 2). Also, these broad-spectrum products destroy natural enemies, enabling DBM populations to increase more quickly.

The expected registration of Group 28 chemistries (chlorantraniliprole and cyclaniliprole) will provide a new insecticide option; however, due to its registration and use for DBM management in other agricultural commodities, there is already evidence of reduced sensitivity to this insecticide group. ☐

GRDC Code DAW1905-010RTX

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GRDC DBM resistance management strategy https://grdc.com.au/fs-resistancestrategydiamondbackmoth

Table 1: Diamondback moth (DBM) larvae thresholds to guide insecticide spray decisions at various canola growth stages.

Crop stage	Moisture stress	DBM threshold
Rosette*	N	50% leaf area damaged
Pre-flowering extension	Y	30 larvae per 10 sweeps
Pre-flowering extension	N	50 larvae per 10 sweeps
Early to mid-flowering*	N	>50 larvae per 10 sweeps
Mid to late-flowering*	N	>100 larvae per 10 sweeps
Pod maturation*	N	200 larvae per 10 sweeps

*Moisture stress is not listed for these growth stages, but note that moisture-stressed crops are more susceptible to insect damage. A lower threshold may be used if extended dry periods are expected.

Source: GRDC

Table 2: Mortality response ranges for diamondback moth (DBM) populations sourced from five port zones in Western Australia, at a discriminating dose (DD) of each chemistry.

The DD is expected to kill 99.9 per cent of a DBM population that is not resistant, so mortality responses less than this value indicate some development of resistance.

Insecticide product (active ingredient/chemical group)	DBM larvae mortality range (and overall mean)
Dominex (alpha-cypermethrin, Group 3A)	8–30% (15%)
Success Neo (spinetoram, Group 5)	78–100% (89%)
Proclaim/Affirm (emamectin benzoate, Group 6)	58–83% (71%)
Coragen (chlorantraniliprole, Group 28)	53–85% (72%)
Cyclaniliprole, Group 28	63–93% (81%)

Source: SARDI

Methods of improving canola's competitiveness to assist weed control efforts have been investigated with trial work over three years by the Australian Herbicide Resistance Initiative.

Canola primed for enhanced weed control

The fight to manage herbicide-resistant weeds requires agility, and improving canola's competitive ability could play a part in reducing dependence on herbicides

Photo: Mike Ashworth AHRI/UWA

By Dr Mike Ashworth

KEY POINTS

- Canola yield can be significantly reduced when competing against weeds
- Canola competitiveness against weeds can be improved by reducing row spacing, increasing canola seeding rate and using larger seed sizes
- When using wider row spacing, increasing canola density is very important
- Hybrid canola varieties offer vigour advantages; however, the seeding rate should not be reduced

■ Canola is often thought to be a very competitive crop due to its size at harvest, but it is an uncompetitive crop early in its growth due to its small seed size and sparse establishment density.

Allowing weeds to get a foothold contributes to poor establishment and significant yield losses. As there are several weeds resistant to herbicides commonly used in canola, alternative weed management methods are needed.

With GRDC investment, the Australian Herbicide Resistance Initiative (AHRI) conducted trials over three years across the Western Australian grainbelt to see how establishment decisions could improve the competitiveness of canola against its main weed opponents: annual ryegrass and wild radish.

Competitiveness is enhanced when crops are established in a way that uses up all the solar, moisture and space resources so little is left for the weed.

Increasing crop competitiveness against weeds is also vital in reducing the weed seedbank in the soil and the selection for herbicide resistance.

To assess how canola's competitiveness could be improved against weeds, AHRI planted 16 field trials and assessed annual ryegrass and wild radish seed production under various treatments.

A number of options to improve canola competitiveness were tested, such as pollination type – high-vigour hybrid versus open-pollinated (OP) varieties – seed size, seeding rate and row spacing.

Trials compared the effect of canola seeding rate (establishment density 20, 35 and 50 plants per square metre), row spacing (25 or 50 centimetres), hybrid and OP varieties, and seed size on annual ryegrass seed production.

To assess the effectiveness of crop competition on weed seed production, half the trial had no herbicides applied after seeding. The other half was maintained weed-free to see how the establishment densities and distributions affected canola yield and quality. Having both the weedy and weed-free treatments also allowed researchers to calculate the yield loss from weeds in every treatment.

COMPETING WITH ANNUAL RYEGRASS

Results from the trial showed that increasing canola seeding rate was highly effective at reducing annual ryegrass seed production.

There was also an interaction between the effect of canola seeding rate and row spacing, with narrow spacing treatments (25cm) only requiring 35 plants/m^2 to greatly decrease annual ryegrass seed production (Figure 1a) in both the hybrid and OP varieties. This is in keeping with the optimum economic plant density when considering the cost of seed as determined by other GRDC investments.

At the wider, 50cm row spacing, the highest establishment rate of 50 plants/m^2 was required for the OP variety to reduce ryegrass seed production, whereas the hybrid was still able to reduce annual ryegrass seed production at the lower density of 35 plants/m^2 due to its increased early vigour.

As the row spacing widened, a corresponding increase in the minimum canola seeding rate was important to maintain low ryegrass seed production.

Larger canola seed size was also found to be important at reducing ryegrass seed production, confirming previous studies in which larger seeds were shown to increase plant vigour, resulting in higher yields.

The treatments, including larger canola seed sizes, were able to establish a dense canopy earlier, which shaded later-germinating annual ryegrass and suppressed weed set (Figure 1b).

It was found that increasing canola density and/or using narrower row spacing did not reduce canola yield while reducing seed set.

The use of the more-competitive hybrid varieties and increasing canola seed size was found to increase canola yield within both the herbicide and non-herbicide treatments.

COMPETING WITH WILD RADISH

Wild radish and canola plants are very similar in growth and plant architecture, so using a competitive canola to control radish is a real contest – but it can be done.

Increasing canola seeding rate was found to be highly effective at reducing wild radish seed production. At the narrow row spacing of 25cm, a canola establishment of 35 plants/m^2 was sufficient to reduce wild radish seed production, while at the wider, 50cm row spacing, 50 plants/m^2 was required for both OP or hybrid varieties (Figure 2).

Wild radish seed production was further reduced when larger canola seed sizes were used to increase competition.

Narrow row spacing, effective establishment densities and the use of larger seed sizes all increased the rate of canopy closure and took up more space.

Like canola, wild radish requires space to maximise its yield. When the canola crop establishes a dense canopy, late-emerging wild radish plants are outcompeted for light and space, reducing their seed production.

It was also found that increasing canola seeding rate from 20 to 50 plants/m^2 did not reduce canola yield. This study also found that widening the row spacing to 50cm consistently resulted in higher canola yields, which needs to be taken into account when making seeding decisions.

The effect of these treatments on profitability is being assessed; however, it is clear that more-informed decisions around canola establishment can help to reduce herbicide application and, in turn, improve weed control outcomes.

Competitive crops are part of a profitable farming system, while also being an important tool in the weed management kit bag. However, other factors such as herbicide rotation and harvest weed seed control not only play an important role to maximise canola profitability but also in the fight to reduce herbicide-resistant weeds. □

GRDC Code UOA1711-005RTX

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Figure 1: Effect of canola variety (hybrid vs OP), establishment density, row spacing (a) and seed size (b) on annual ryegrass seed production in the absence of herbicides.

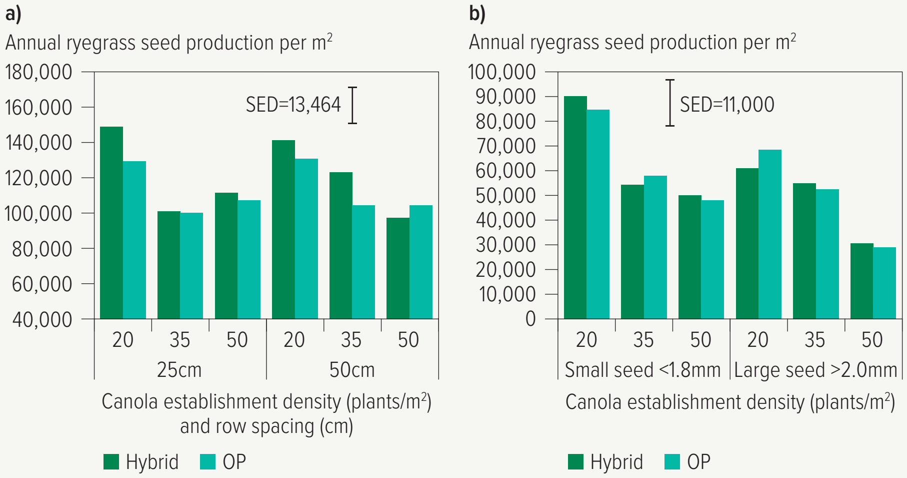
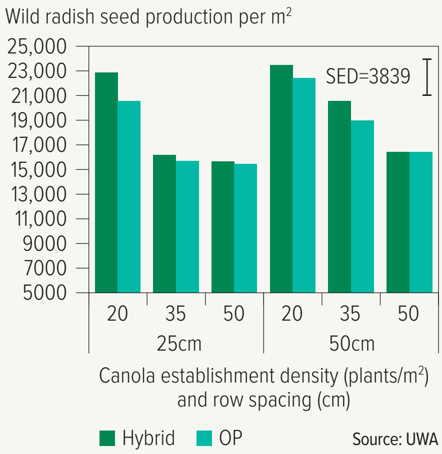


Figure 2: The effect of canola variety (hybrid vs OP), establishment density and row spacing on wild radish seed production in the absence of herbicides.



Source: UWA

Trials look to improve Sclerotinia stem rot management

By Associate Professor Sarita Bennett, Dr Pippa Michael and Ashmita Rijal Lamichhane

KEY POINTS

- Sclerotinia stem rot (SSR) severity is primarily driven by environmental conditions
- Petal testing for Sclerotinia spores is not a reliable method of determining future SSR severity to inform spray decisions
- Seasonal environmental conditions and paddock history are the best assessment method for SSR risk to determine the need to spray

Research into the impact of Sclerotinia stem rot (SSR) on canola caused by *Sclerotinia sclerotiorum* fungal infection has raised questions about the disease severity prediction method and the infection level that leads to yield loss.

Between 2017 and 2020, 25 trials were conducted across WA by the Centre for Crop and Disease Management at Curtin University with GRDC support. They investigated fungicide application efficacy on canola varieties by trial site, from Moonyoonooka (north) to Mount Barker (south) and east to Corrigin.

Commonly grown open-pollinated, hybrid and Roundup Ready® canola varieties were grown, and treatments included unsprayed plots and plots sprayed with prothioconazole + tebuconazole generally at 30 per cent flowering.

Twenty-two of the 25 locations received less than the long-term growing season rainfall and maximum daily temperatures were higher than average at all sites.

FINDINGS

The potential SSR infection source and subsequent impact on canola production was systematically investigated throughout the growing season.

Soil samples prior to sowing showed sclerotia (the hard melanised structures of Sclerotinia that remain in the soil following harvest of infected crops) were unlikely to be the main infection source within a season, as few sclerotia were found.

Disease incidence was variable when ascospore presence on petals collected at 30 per cent flowering was high (more than 75 per cent), ranging from zero to 36 per cent. A high Sclerotinia ascospore presence on petals at this stage indicated potential for higher SSR infection but did not mean there would be higher infection. Petal assays were therefore a poor indicator of later disease severity.

Disease incidence was low across all four years, with 36 per cent the highest infection level recorded in a single plot in 2018 and high variablility between plots within a site, with an average of less than 20 per cent (Figure 1). Significant differences in yield between the main treatments and interactions between management and site, and variety and site, were found, indicating SSR occurrence was primarily driven by the environment at each trial site.

Although at some sites fungicide management significantly decreased SSR, there were no significant differences in yield. At present, risk assessment for SSR infections remains most reliably determined by thorough knowledge of the seasonal environmental conditions and paddock history.

In 2021 trials, SSR percentage within a plot was simulated and yields recorded. This data is being analysed to generate a yield loss curve for SSR in canola, which will assist growers in determining the level of SSR infection resulting in yield loss and therefore economic spray thresholds. □

GRDC Code CUR1403-002BLX (CUR00023-Project C1)

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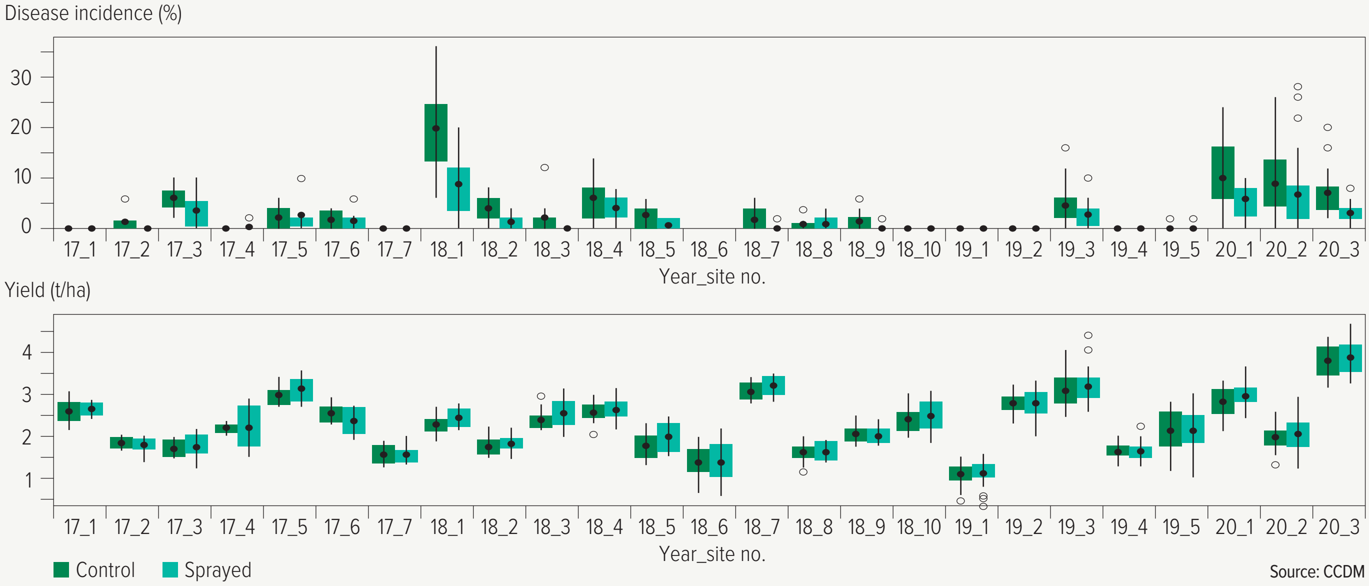
Figure 1: Average Sclerotinia stem rot disease incidence (top, percentage) and canola yield (bottom) across 25 trial sites (2017–20) from unsprayed control plots and plots treated with fungicide at 30 per cent flowering.



Source: CCDM

Vigilance system key to blackleg management

Blackleg is an ever-present and evolving risk to canola production, and it requires a national system of surveillance to detect any changes to the disease

By Associate Professor Alex Idnurm, Dr Angela Van de Wouw and Dr Steve Marcroft

Photo: University of Melbourne

Dr Steve Marcroft of Marcroft Grains Pathology and Dr Angela Van de Wouw from the University of Melbourne lead a team of researchers from CSIRO, NSW Department of Primary Industries, the WA Department of Primary Industries and Regional Development and Eyre Peninsula Ag Research to monitor changes in blackleg virulence in canola across Australia.

A severe disease risk such as blackleg of canola needs a vigilant industry-wide monitoring and warning system to keep on top of any changes in the plant-pathogen dynamics and to hone management practices.

Caused by the fungus *Leptosphaeria maculans*, blackleg is a stubble-borne disease that leads to seedling, crown canker and upper canopy infection. It is challenging to manage due to the dynamic nature of seasonal conditions together with changing farming systems and changing climate, as the fungus is able to evolve and readily adapt to these changes.

With GRDC investment, the University of Melbourne together with Marcroft Grains Pathology, CSIRO and an experienced team on the ground are monitoring changes in virulence of blackleg fungal populations nationally, alerting growers when canola varieties with specific resistance genes are at threat of high disease levels.

FIELD SURVEILLANCE

From 2011 onwards, all canola varieties and National Variety Trials (NVT) lines have been classified for their type of blackleg resistance: either major gene resistance (often referred to as seedling resistance, although it is expressed throughout the life of the plant) or quantitative resistance (often referred to as adult plant resistance and involving the combined contribution of a number of minor genes).

Seven resistance genes – A, B, C, D, F, H and S – have been identified and every canola variety is described by one or several of these letters according to what type of resistance they contain.

The level of blackleg disease for each resistance group is monitored at 34 NVT sites across Australian canola growing regions. Each season the variety responses are upgraded and recommendations released to growers.

Blackleg resistance groups AD, ABDF and H were effective at almost all sites in 2021. Conversely, resistance groups A, B, C and BF were overcome or partially ineffective at most sites.

Where Group H varieties had been grown for several years as a grain-and-graze option – such as at Hamilton, Victoria – unusually high levels of disease were observed in a Group H cultivar in 2020 and 2021. Further molecular investigation revealed that the fungal population had evolved virulence to this resistance. A warning was released for growers.

These observations emphasise the importance of constantly monitoring the level of disease on your own property as the local fungal population will greatly influence the effectiveness of the resistance genes in your cultivars.

Previous work showed upper canopy infection (UCI) can result in up to 20 per cent yield loss through infection of upper stems, branches and flowers.

With the move to earlier sowing, canola crops are flowering in late July and early August when conditions are conducive for blackleg infection and spores can land directly on the upper canopy. While UCI was detected at all sites in 2021, disease levels were less severe than previous years due to the late break to the season resulting in later sowing times.

Fungicide applications reliably reduced UCI disease symptoms; however, yield responses to fungicides were inconsistent (from zero to 50 per cent yield increase).

Environmental stress, thermal time, timing of infection and plant genetic resistance were identified as potential factors involved in determining whether UCI causes yield loss.

In 2021, experiments were conducted to try to further tease apart the contributions of these factors. Initial analysis of the data shows genetic resistance to UCI is present in some cultivars and this can be detected using glasshouse and field-based experiments. However, it is still unclear whether resistance to UCI is the same as resistance to stem canker – in other words, quantitative resistance – and further work is underway. □

GRDC Code UOM1904-004RTX

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https://grdc.com.au/GRDC-FS-BlacklegManagementGuide

https://www.agric.wa.gov.au/apps/blacklegcm-blackleg-management-app

Armoury for blackleg management strengthened

Photo: Evan Collis

Professor Jacqueline Batley from the University of Western Australia is a member of a multidisciplinary team working to bolster resources and knowledge for blackleg management in canola.

By Dr Angela Van de Wouw, Professor Jacqueline Batley and Dr Susie Sprague

KEY POINTS

- An international library of blackleg isolates has been re-established as a research resource
- A set of near-isogenic canola lines that contain major blackleg resistance genes has also been made available as a research resource
- Three new major genes for blackleg resistance have been identified
- A method is being developed to phenotype canola for quantitative blackleg resistance

■ To address the plant resistance component of blackleg management, GRDC is partnering with CSIRO, the University of Western Australia (UWA) and the University of Melbourne to take a methodical approach to understanding the disease as the causal fungus, *Leptosphaeria maculans*, constantly mutates.

This entails strengthening the armoury of resources that can be used across current and future blackleg investments, working with international experts to compile a library of blackleg variants, accessing new sources of genetic resistance and developing a disease phenotyping method to evaluate new sources of resistance.

The severity of blackleg disease has increased as the area and intensity of canola production has grown across Australia. Yield losses to blackleg infections of 50 per cent or more have been recorded in some seasons.

The fungus reproduces sexually, which makes it highly variable and enables it to overcome plant resistance and fungicides. This makes it an ongoing challenge to manage.

For these reasons, an armoury of management resources is required that incorporates knowledge of the blackleg fungus, sources of plant resistance, cultural practices and fungicides.

RESOURCE ARMOURY

Historically, a library of international blackleg isolates had been curated but this work had lapsed. In 2019, at the International Rapeseed Congress in

Berlin, Germany, a group of international blackleg researchers agreed to re-establish this resource. Since then, researchers from the University of Melbourne have received isolates from 12 contributors, representing nine countries, and isolates from a further four countries are expected. This will be the first time isolates have been collected and analysed from countries such as Iran, South Africa, Argentina and Tunisia.

Added to this international collection are 17 isolates from the original collection and 25 Australian isolates collected between 2000 and 2021 representing all growing regions of Australia. All isolates have been characterised phenotypically and genotypically and this information is curated together with 'passport' information that includes collection location, who collected it and other general information.

This worldwide collection will be used to identify isolates for targeting and characterising novel sources of resistance and to establish common benchmarks across international research groups to prevent duplication and misinterpretation of data.

In addition to the international isolate collection, access has been gained to a set of near-isogenic canola lines that contain major blackleg resistance genes. These lines represent all major resistance genes that are currently available in Australian commercial varieties, as well as three major resistance genes not at present in Australian varieties. These will be a key research resource for Australia.

These resources have been provided to other GRDC-supported blackleg research programs at CSIRO and UWA and are being used for identifying novel sources of resistance, understanding quantitative resistance and characterisation of resistance genes in commercial cultivars.

NEW RESISTANCE SOURCES

The genetic pool for blackleg resistance is being expanded through an interlinked research effort at UWA, University of Melbourne and CSIRO, examining both major and minor genes for blackleg resistance. Major gene resistance relies on a single gene to confer resistance while minor gene or 'quantitative' resistance relies on a number of minor genes that work together.

The two forms of resistance work to control blackleg infections in different ways and are important members of the resistance armoury, as blackleg is able to rapidly overcome major gene resistance in as few as three years after commercial release.

Major gene resistance limits pathogen entry into plants while quantitative resistance restricts pathogen growth after it has entered the plant.

Researchers at the University of Melbourne and UWA have discovered three new major genes (*Rlm3*, *Rlm4*, *Rlm7*) for resistance and are actively screening introgression lines, synthetic lines and wild species for novel sources of resistance.

In addition to the discovery of novel sources of resistance, the researchers are identifying and developing molecular markers that pinpoint a part of the DNA in or near the resistance gene, which allows researchers to identity if the gene is present in the canola plant for all the known resistance genes for use in breeding programs.

Quantitative resistance is complex as it involves multiple genes that act together to reduce blackleg. In addition, it is masked in varieties that have major resistance genes, which prevent blackleg from entering the plant.

Using state-of-the-art genome sequencing technologies, the team has already cloned resistance genes *Rlm4* and *Rlm7*, in collaboration with researchers from Canada, and have candidate genes for *Rlm1*, *Rlm3* and *Rlm6*.

Molecular markers have been established for *Rlm4*, *Rlm7* and the previously cloned resistance genes *Rlm2*, *Rlm9* and *LepR3*. These molecular markers have been provided to all Australian breeding companies and are being used routinely for screening for resistance genes in all Australian cultivars in another GRDC-supported project.

PHENOTYPING QUANTITATIVE RESISTANCE

Traditionally, breeders have relied on field assessments to screen for quantitative resistance based on the severity of blackleg crown canker in mature plants.

However, this approach has limitations when the aim is to understand the genetics of quantitative resistance and develop molecular markers for breeding, as it does not account for environmental variation, diversity of blackleg populations and presence of major resistance genes, which prevent invasion of the plant and therefore mask the effect of quantitative resistance.

CSIRO researchers have been focusing on the development of a method to quantify blackleg disease (phenotype) to identify quantitative resistance. To develop biologically relevant phenotyping approaches, it is crucial to gain fundamental knowledge of the mechanisms, growth stages and tissues in which quantitative resistance acts, as well as interactions with the pathogen and environment.

Quantitative resistance is complex as it involves multiple genes that act together to reduce blackleg. In addition, it is masked in varieties that have major resistance genes, which prevent blackleg from entering the plant.

As each gene involved can have a small effect on disease severity, a highly sensitive molecular technique has been developed to quantify the blackleg fungus. This method has been used to generate new knowledge on how quantitative resistance functions, crucial to the development of a biologically relevant phenotyping assay.

Novel findings are that quantitative resistance does not provide partial resistance to all isolates nor does it act only in the adult plant as previously thought. Instead, it reacts with individual blackleg isolates differently, and functions in both leaves and stems from the seedling stage through to maturity.

CSIRO researchers are now applying this new knowledge and techniques to gain further understanding of the impact of environmental conditions and blackleg populations to blackleg disease and exploring novel techniques to quantify blackleg severity using machine learning. □

GRDC Codes UOM1905-003RTX, UWA1905-006RTX, CSP1904-007RTX

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Functional design improvements for canola

Photo: Hannah Roe, NSW DPI

Dr Harsh Raman from NSW DPI is leading a team of researchers investigating the different components of plant architecture and their role in improving canola productivity. Here Dr Raman points out genetic variation for architectural traits among canola varieties released since 1978 – when the first canola variety, Wesreo, was released for commercial cultivation in Australia – to a group of canola growers and research and development advisers at the Wagga Wagga Agricultural Institute field day 2021.

Mother nature has 'designed' plants in such a way that they can survive, thrive and complete their life cycle to produce offspring for future generations. With respect to canola, the question is: can we improve on this to better match this plant to evolving farming systems and changing regional climates?

By Dr Harsh Raman

KEY POINTS

- Historical and modern canola varieties are being characterised for their 'plant architecture'
- Canola types will be dissected to determine how they have evolved and what structural components are contributing to yield

■ Plant architecture is an important agronomic trait for matching plant type not only to growing environments but also to farming systems.

The term 'plant architecture' refers to the three-dimensional arrangement of the plant's organs and structures such as shoots, leaves and pods. It could be considered its 'functional design'.

Improved knowledge of plant architecture aids our understanding of the genetic, physiological and agronomic drivers that contribute to local adaptation and crop yield.

It can be a useful tool in the toolkit to manipulate canola growth and development to reduce the impact of risks – in particular frost, heat and drought – and boost canola yield.

With co-investment from the New South Wales Department of Primary Industries (DPI) and GRDC through the Grains Agronomy and Pathology Partnership (GAPP), a team of researchers has been assembled to investigates these aspects, includes Brett McVittie (technical officer, canola genetics), Mathew Dunn (research and development agronomist) and Dr Rajneet Uppal (crop physiologist), all based at the Wagga Wagga Agricultural Institute.

LEARNING FROM HISTORY

Researchers are growing historical and contemporary canola varieties of Australian origin in order to quantify the variation in canopy architectural traits.

In 2021, NSW DPI planted 34 open-pollinated canola varieties and 10 hybrids (released since 1978) plus four 'check' accessions (from GRDC National Brassica Germplasm Improvement projects), representing conventional and different herbicide resistance groups (triazine, Roundup Ready® and Clearfield®, comprising spring and semi-winter varieties).

Evaluating historical and contemporary varieties in the same experiment allows the estimation of yield improvement associated with changes in plant architectural traits over 50 years. It also defines the yield architecture traits that drive yield potential by ensuring a balance between vegetative growth and seed yield.

In the 2021 season, NSW DPI measured several traits at the vegetative stages (seedling emergence, fractional ground cover, above-ground shoot biomass, leaf area index, leaf number, thickness and orientation, leaf angle), and reproductive stages (days to flowering, flowering duration, maturity, branch number, plant height, plant density, branch and pod orientation angle, length of the primary branch, number of pods on a primary branch, pod canopy depth, pod strength and yield and its components).

From these measurements the plant trait or attribute's overall contribution to yield will be estimated and genetic correlations between all pairs of trait measurements will be calculated.

In addition to investigating canola varietal variation for the architectural traits, the team is conducting two experiments to investigate the effect of plant density and nitrogen status on the plant architecture in an open-pollinated canola cultivar, ATR Bonito⦻.

This research is being carried out in collaboration with Colin McMaster (Orange Agricultural Institute, NSW DPI) and Danielle Malcolm (NSW DPI, Wagga Wagga). Both trials are being conducted at two sites, Canowindra and Wagga Wagga.

Commensurate with growers' experiences, the team is recording higher branch numbers when plants are spaced 45 centimetres apart, compared to when sown at densities of 15 or 30 plants per square metre. Once the trial is harvested, the relationship between different plant architectural trait components and canola yield will be investigated. □

GRDC Code DPI2108-008BLX (BLG125)

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Satellites recruited to inform canola harvests

Could satellite imagery be used to reduce the risk posed by incorrect windrowing timing?

By Mathew Dunn, Josh Hart and Dr Priyakant Sinha

Windrowing canola prior to harvest is a common practice throughout Australia. However, research has shown that mistiming windrowing can cause yield losses of up to 100 kilograms per hectare per day.

Optimum windrow timing is typically determined by walking through crops, hand sampling and subjectively measuring seed colour change. It can be difficult to pinpoint the correct timing for optimum yield due to the speed at which seed colour can change, particularly on a commercial scale across paddocks with variable soil types, aspect and topography.

Remote-sensing methods could be a feasible alternative to hand sampling and could more reliably assess optimal timing for windrowing at the field scale.

A joint investment between the New South Wales Department of Primary Industries (DPI) and GRDC under the Grains Agronomy and Pathology Partnership (GAPP) is supporting a collaborative project with the University of New England Applied Agricultural Remote Sensing Centre to study this.

The project, 'Improving canola harvest management decisions with remote sensing', is investigating the accuracy of satellite and drone-based multispectral imagery sensing for better prediction of canola maturity and, therefore, the timing for optimal windrowing (and desiccation).

The project builds on canola harvesting research findings from the GRDC-supported NSW DPI and CSIRO project 'Optimised Canola Profitability', together with the drone-based pilot research project 'Determining canola physiological maturity with remote sensing'. This project demonstrated the potential for multispectral imagery to assess physiological maturity in canola.

Further investigation using low-cost/freely available satellite imagery is now required to bring this technology closer to large-scale implementation and enable the technology to be more affordable and accessible.

Due to the highly variable nature of Australia's agricultural soils, combined with differing paddock histories and the wide range of cultivars grown, the maturity of canola crops often varies significantly between and within commercial paddocks.

The proposed remote-sensing approach has the potential to aid canola growers and advisers with optimum canola windrow timing decisions by:

- identifying which paddocks will reach optimum window timing first;
- allowing informed scheduling for paddock windrowing;
- identifying in-crop maturity variability to guide optimum windrowing timing;
- guiding manual-based crop maturity assessment to ensure representative areas are assessed; and
- allowing the centre of paddocks to be assessed for maturity, which are often inaccessible in high-biomass crops.

Two field experiments were established in the 2021 season, with several common commercial cultivars being examined across differing environments. With only a 12-month investment on this topic, this project aims to assess the potential of the technology's application and determine the requirement for further research. Results will be available by June 2022. □

Photo: NSW DPI

A collaborative project is underway to improve canola harvest management decisions. This Wagga Wagga canola field experiment site, photographed by drone on 10 September 2021, was subjected to further investigation by satellite technology to assess the feasibility of using this technology to make better canola windrowing timing decisions.

GRDC Codes DPI2108--6BLX (BLG123), DPI1909-032BLX (BLG308)

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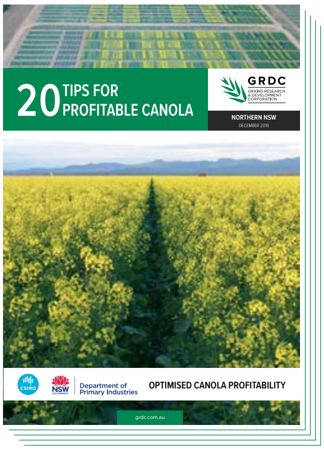
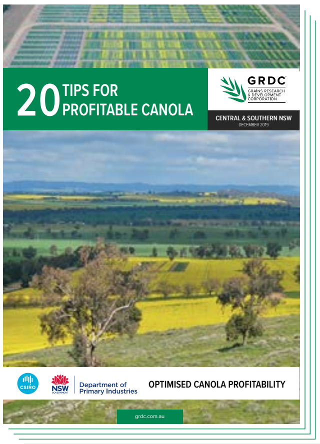
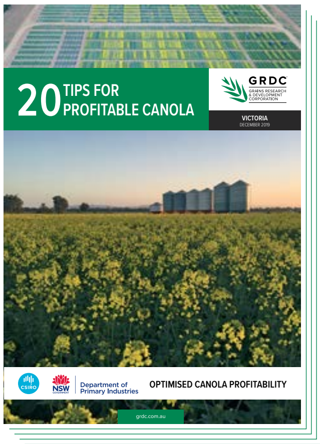
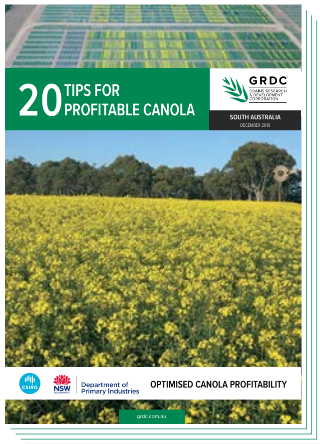
CANOLA PRODUCTION RESOURCES









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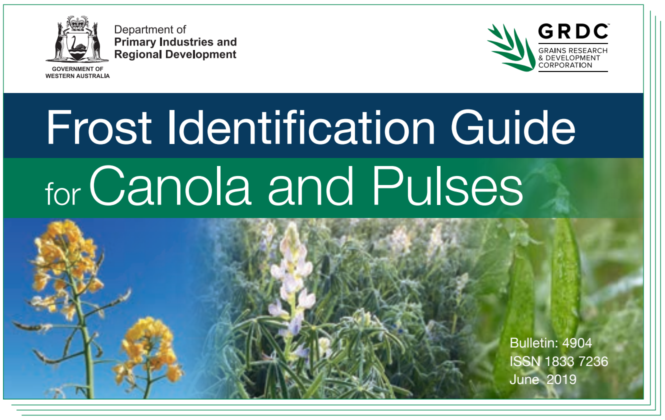

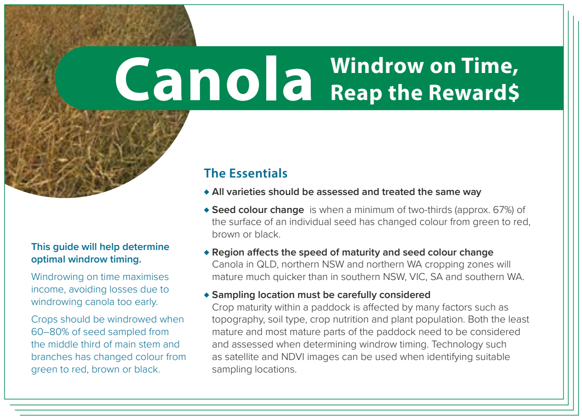

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