Improvement of triazine tolerant canola hybrids in Australia

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ABSTRACT

Canola breeding began in Australia in 1970 with the primary goals of improving yield and blackleg resistance of imported Canadian and European spring rapeseed varieties, primarily Zephyr (low eruric acid) and Bronowski (low glucosinolates). These were crossed with Japanese varieties Chisaya, Mutu, Chikuzen and Haya which were earlier and showed moderate blackleg resistance. A triazine tolerant (TT) version of Tower was also used in crossing, and together these seven varieties accounted for 75% of the composition of pedigrees of Australian canola varieties released between 1995 and 2002. Canola was potentially an excellent rotational crop with wheat, except that broadleaf weeds made it impossible to grow canola in the majority of the main cropping zone. The first TT variety Siren was released in Australia in 1993, quickly followed by Karoo in 1995. These TT canola varieties were the primary reason for the rapid expansion in the area of Australian canola from 0.4 to 1.9 M ha between 1996 and 1999, despite the intrinsic yield penalty associated with the mutation that provided triazine tolerance. The first TT hybrid canola variety was released in 2009 and was based on the male sterile Lembke (MSL) hybrid system. This was quickly followed by TT hybrids based on the Ogura system. Following the release of Roundup Ready® canola in 2009, it was expected that TT canola would reduce dramatically in Australia, but the area remains at about 50% of Australian canola production in 2016. Since 2009, there has been a major improvement in the yield, blackleg resistance and quality of TT canola varieties, and in 2016 new TT hybrids out-yielded open-pollinated TT canola by 20% in national variety trials and were similar in yield to nearby Roundup Ready® and Clearfield® hybrids. These high-yielding TT hybrids were assigned to a new blackleg resistance group "BF", which means canola growers have new options for rotating canola varieties for blackleg disease risk management. Australian grain growers also rotate the major herbicide groups including triazine, glyphosate and imidazolinone herbicides in order to reduce herbicide tolerance in weeds, and to improve the control of grass weeds in wheat. High yielding TT hybrids are profitable in their own right, plus they help to control grass weeds in the following wheat crop. Recently, canola hybrids with both triazine and glyphosate tolerance have found a market niche in Australia for the control of herbicide tolerant weeds.

KEY WORDS: canola, rapeseed, hybrids, triazine tolerance, glyphosate tolerance, imidazolinone tolerance

INTRODUCTION

The breeding of double-low or canola-quality rapeseed (*Brassica napus*) began in Australia in about 1970 with the arrival of various sources of new low erucic acid and low glucosinolate spring canola varieties from the northern hemisphere. The introduced varieties were late flowering and extremely susceptible to Phoma (blackleg) disease under Australian conditions, and breeding focussed on genetic improvement in earliness and moderate blackleg resistance sourced from Japanese varieties of *B. napus* (Buzza 2007; Salisbury and Wratten 1999). Weed control was paramount for successful production of canola in Australia, and triazine tolerant (TT) varieties from Canada were an important source of herbicide tolerance for canola in Australia. The varieties Zephyr (low eruric acid) and Bronowski (low glucosinolates), Japanese varieties Chisaya, Mutu, Chikuzen and Haya and a TT version of Tower accounted for 75% of the composition of pedigrees of Australian canola varieties released between 1995 and 2002 (Cowling 2007). With the arrival of Roundup Ready® canola in 2009, it was expected that TT canola would diminish in importance. However, in 2017, TT canola occupies the largest area of canola production, followed by Roundup Ready® (RR) or glyphosate tolerant and Clearfield® (CL) or imidazolinone tolerant canola.

The two main hybrid breeding systems in Australia are Ogura and MSL. The MSL system was introduced to Australia from NPZ Lembke in Germany in the mid-2000s. This paper explores the genetic improvement of TT canola and recent advances in performance of TT, CL and RR hybrid canola in Australia.

MATERIALS AND METHODS

Data on yield and seed quality of canola varieties in the Australian national variety trial (NVT) system were available from the NVT-Online website (http://www.nvtonline.com.au/). A new analysis method of NVT data was introduced in 2016, based on factor analytic modelling across years, which results in "Production Values" (PV-PLUS) for yield (t/ha) for varieties at each site, relative to the mean of all varieties in the analysis (Smith et al. 2015). Yield of all NVT trials from 2012 to 2016 was analysed by this method recently, and PV-PLUS values (t/ha) were published for commercial varieties (Daniel Tolhurst, University of Wollongong, *personal communication*). PV-PLUS values are expressed relative to the mean of all trials across all years, including all TT, RR, CL and conventional herbicide tolerance trials.

PV-PLUS values are empirical best linear unbiased predictions (EBLUPs) of common variety by environment (CVE) effects, which are considered to be random. They are expressed as deviations (t/ha) from the mean of the each environment, where environments are considered to be fixed effects. Given prevailing knowledge of a yield penalty associated with TT canola, we expected TT canola to have lower PV-PLUS values than the other herbicide tolerance groups.

For each herbicide tolerance group, a suite of environments (trial sites) and varieties were assembled so that most varieties were present at all environments within 2012 or 2016. An attempt was made to use the same trial sites in 2012 and 2016, although this was not always possible. At least two varieties were chosen because they were present in both 2012 and 2016, and the highest yielding varieties in each year were also chosen, for comparison of PV-PLUS values across a range of sites in 2012 and 2016.

Oil and other seed quality data were not analysed as indicated above, but simple arithmetic averages were made across the same sites as used in the comparison of PV-PLUS values for yield.

NPZ Australia Pty Ltd out-licenses MSL TT hybrids in Australia, including SF Ignite TT, SF Turbine TT, and InVigor T 4510, which are discussed in this paper.

RESULTS

The PV-PLUS values for yield of commercial open-pollinated (OP) TT variety ATR-Bonito and hybrid TT variety Hyola 559TT in 2012 were just above the long-term trial average for all varieties tested in NVT over the period 2012 - 2016 (Fig. 1), and well above the OP variety ATR-Snapper (average PV-PLUS -0.22 t/ha) which was released in 2011.

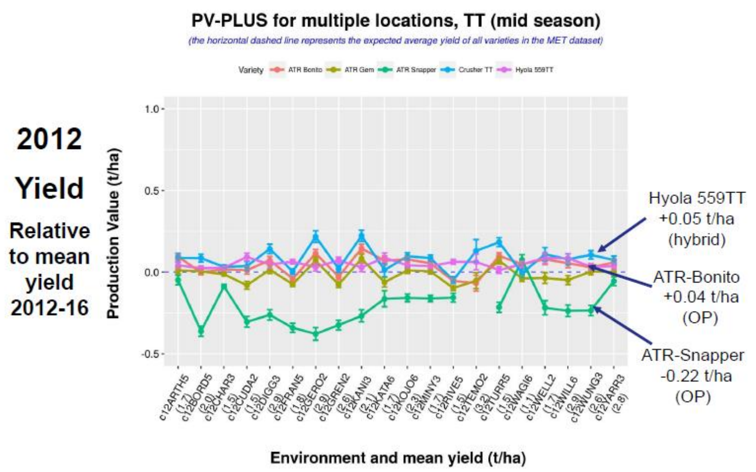

Fig. 1. PV-PLUS values for TT canola varieties tested in NVT in 2012.

In 2016, the TT varieties ATR-Bonito and Hyola 559TT had similar PV-PLUS values across the same sites in 2012 and 2016, but new TT hybrids in 2016 had significantly higher PV-PLUS values (Fig. 2). The average PV-PLUS in the new hybrid SF Ignite TT was 0.55 t/ha, equivalent to 20% increase in yield over ATR-Bonito. In 2016, the yield of TT hybrid SF Ignite TT (average 3.31 t/ha) was 20% above the yield of ATR-Bonito (average 2.76 t/ha), and equivalent to 20% “commercial heterosis” valued at $280/ha of grain yield.

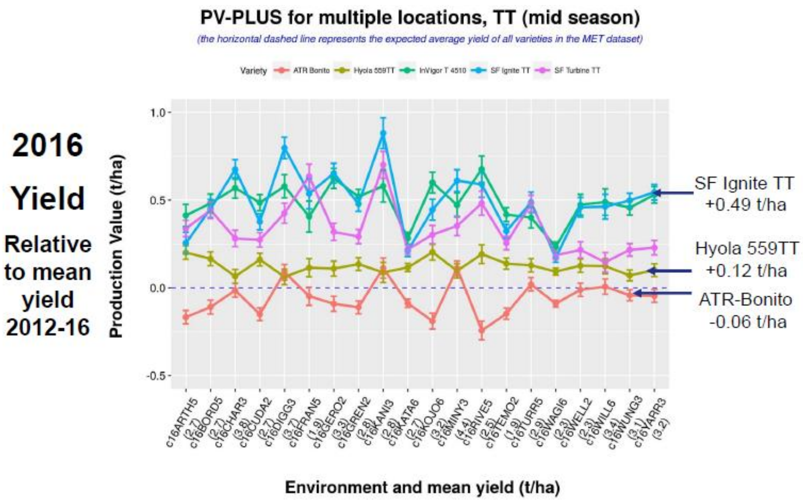

Fig. 2. PV-PLUS values for TT canola varieties tested in NVT in 2016.

There was no apparent relationship between environment mean yield and PV-PLUS values (Figs. 1, 2). In fact, most of the genetic correlations across sites in 2016 were very high (>0.7), which indicates nearly constant ranking of genotypes across sites and low impact of genotype x environment interaction (Fig. 3).

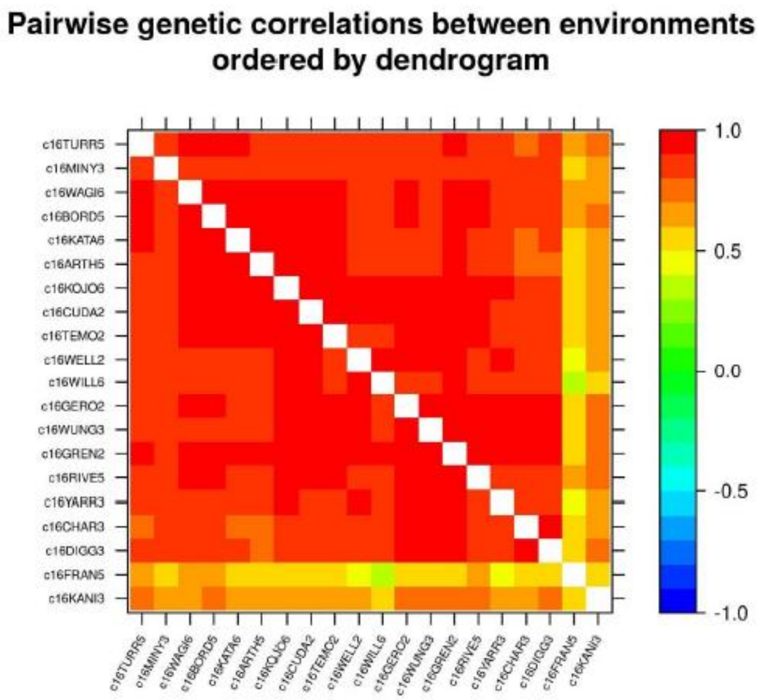

Fig. 3. Pairwise genetic correlations across sites used for PV-PLUS predictions in 2016.

The average oil content of SF Ignite TT was 44.5% across the same sites in 2016, whereas the average oil content of ATR-Bonito was 46.1% and Hyola 559TT 45.6%.

A similar process was used to compare the yield of RR varieties tested in 2012 and 2016. In 2012, the newly released RR hybrid GT-50 was 12% higher yielding on average than the OP variety GT-Cobra.

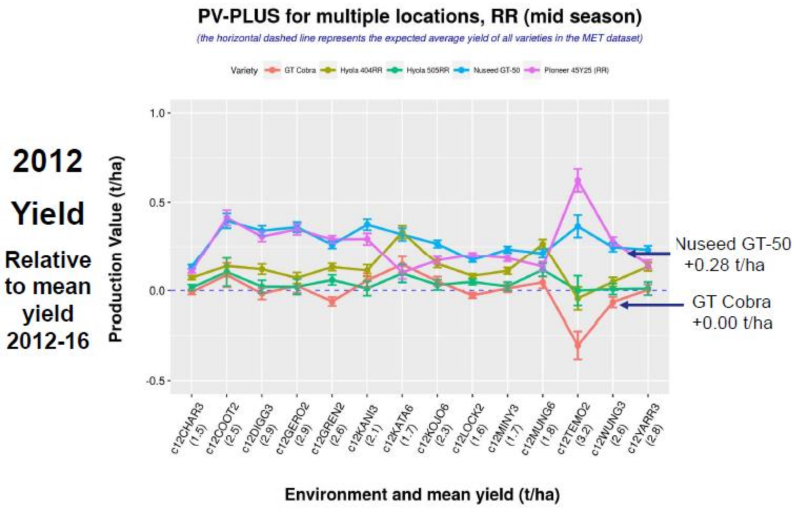

Fig. 4. PV-PLUS values for RR canola varieties tested in NVT in 2012.

RR canola hybrids continued to improve, and in 2016 the PV-PLUS of variety 45Y25RR was 0.59 t/ha (Fig. 5), which was 0.10 t/ha higher than SF Ignite TT (Fig. 2), and higher than GT-50 and GT-Cobra at a similar range of sites in 2012 and 2016. OP RR canola varieties were discontinued in 2012.

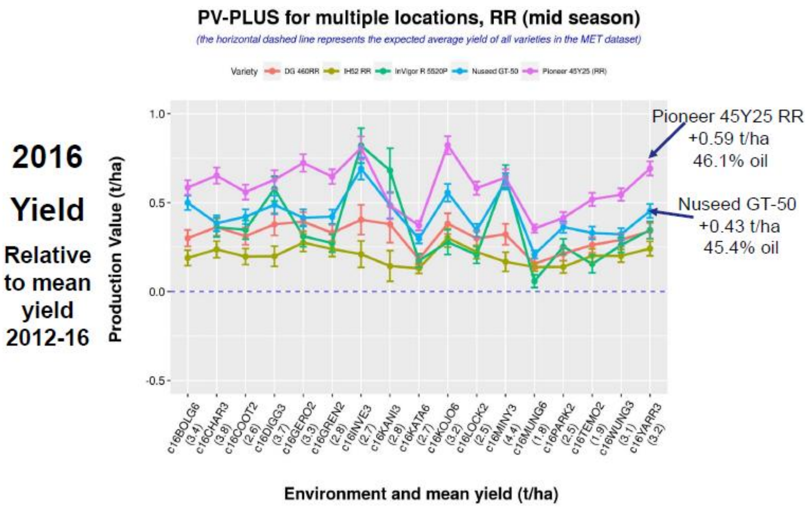

Fig. 5. PV-PLUS values for RR canola varieties tested in NVT in 2016.

CL hybrid varieties in 2012 (Fig. 6) were similar in yield to TT canola varieties evaluated in 2012 (Fig. 1), and around the long-term trial yield average.

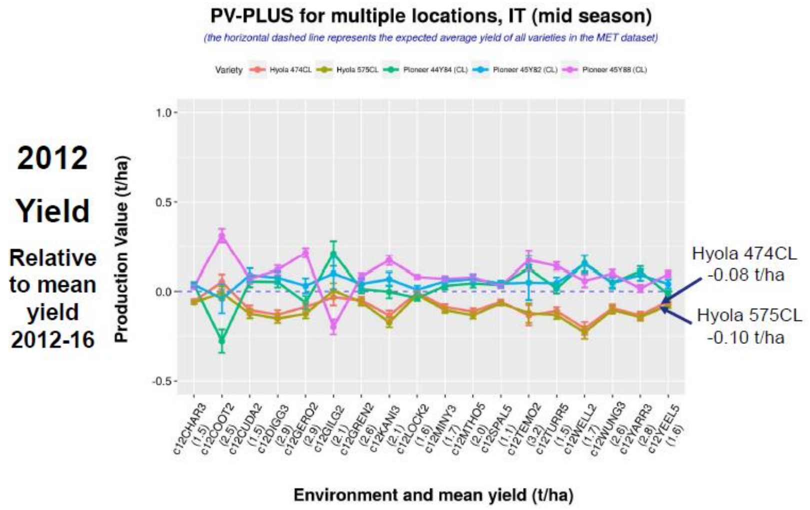

Fig. 6. PV-PLUS values for CL canola varieties (imidazolinone tolerant, IT) tested in NVT in 2012.

However, there was a dramatic increase in yield of CL hybrids in 2016 (Fig. 7), with PV-PLUS equal to 0.67 t/ha in the highest yielding CL hybrid 44Y90CL.

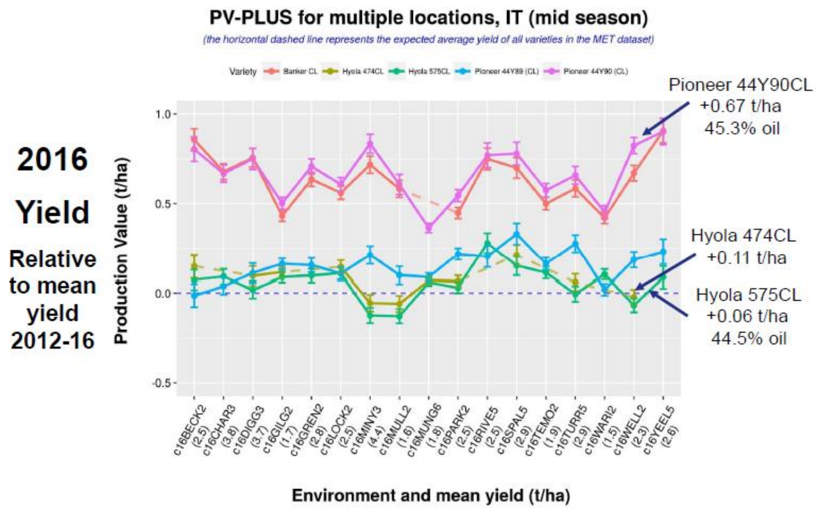

Fig. 7. PV-PLUS values for CL canola varieties (imidazolinone tolerant, IT) tested in NVT in 2016.

There was a similar range of oil content in CL and RR varieties (Figs. 5, 7) as there was in TT varieties (range 44.5% to 46.1%).

Blackleg (Phoma) resistance in new high-yielding TT hybrids SF Ignite TT, SF Turbine TT and InVigor T 4510 was MR or MR-MS, which increases to "R" or "R-MR" when sown with fungicide seed dressing, based on the national blackleg resistance publication (Fig. 8). This suggests the absence of effective major R genes for blackleg resistance in these varieties in Australia. The blackleg resistance group of these varieties is "BF", which is unique in TT canola (Fig. 8).

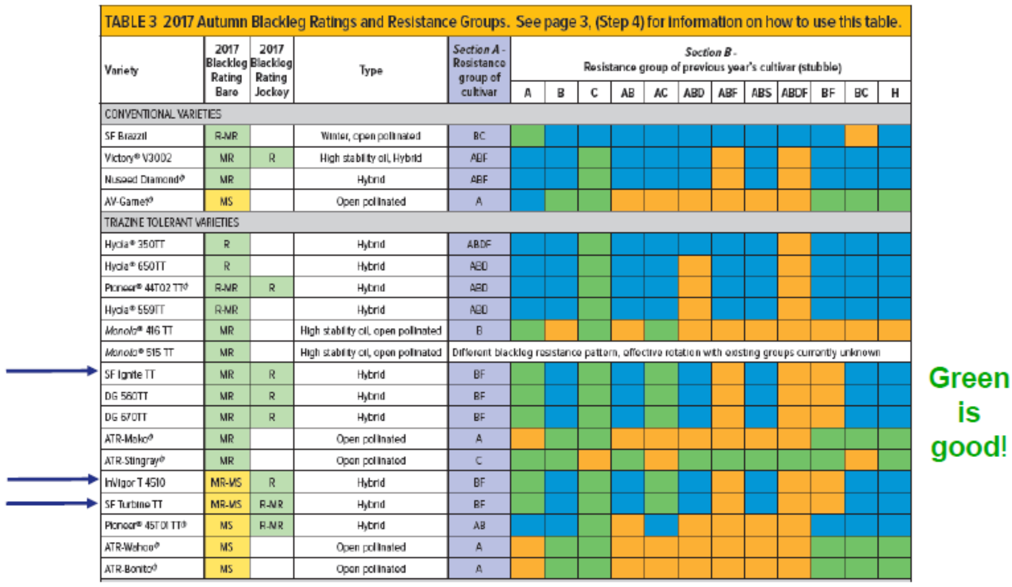

TABLE 3 2017 Autumn Blackleg Ratings and Resistance Groups. See page 3, (Step 4) for information on how to use this table.

Variety	2017 Blackleg Rating Bare	2017 Blackleg Rating Jockey	Type	Section A - Resistance group of cultivar	Section B - Resistance group of previous year's cultivar (stubble)											
					A	B	C	AB	AC	ABD	ABF	ABS	ABDF	BF	BC	H
CONVENTIONAL VARIETIES																
SF Brazzil	R-MR		Winter, open pollinated	BC												
Victory® V3002	MR	R	High stability oil, Hybrid	ABF												
Nuseed Diamond®	MR		Hybrid	ABF												
AV-Garnet®	MS		Open pollinated	A												
TRIAZINE TOLERANT VARIETIES																
Hyola® 350TT	R		Hybrid	ABDF												
Hyola® 650TT	R		Hybrid	ABD												
Pioneer® 44T02 TT®	R-MR	R	Hybrid	ABD												
Hyola® 559TT	R-MR		Hybrid	ABD												
Monola® 416 TT	MR		High stability oil, open pollinated	B												
Monola® 515 TT	MR		High stability oil, open pollinated	Different blackleg resistance pattern, effective rotation with existing groups currently unknown												
SF Ignite TT	MR	R	Hybrid	BF												
DG 560TT	MR	R	Hybrid	BF												
DG 670TT	MR	R	Hybrid	BF												
ATR-Mako®	MR		Open pollinated	A												
ATR-Stingray®	MR		Open pollinated	C												
InVigor T 4510	MR-MS	R	Hybrid	BF												
SF Turbine TT	MR-MS	R-MR	Hybrid	BF												
Pioneer® 45T01 TT®	MS	R-MR	Hybrid	AB												
ATR-Wahoo®	MS		Open pollinated	A												
ATR-Bonito®	MS		Open pollinated	A												

Fig. 8. Blackleg resistance ratings and resistance groups of high-yielding TT hybrids based on evaluation in 2016 (data courtesy of 2017 GRDC Blackleg Management Guide)

DISCUSSION

This analysis, based on PV-PLUS values of commercial varieties, indicates that the predicted yield of canola hybrids has increased rapidly in Australia from 2012 to 2016 in all herbicide groups, especially in TT and CL groups where the increase was 20% over five years, or 4% per year. In 2016, the yield of TT hybrid SF Ignite TT (average 3.31 t/ha) was 20% above the yield of ATR-Bonito (average 2.76 t/ha), and equivalent to 20% "commercial heterosis" valued at $280/ha of grain yield. The oil content of the new high-yielding TT hybrid was 1% lower than ATR-Bonito, but similar to RR and CL hybrids. Superior yield of the new hybrids was consistently expressed across all environments (low to high yield), and the PV-PLUS of SF Ignite TT (+0.49 t/ha) was achieved at low and high yields.

The increase in yield of TT hybrids in 2016 has reduced the apparent "yield penalty" of TT canola compared with the other herbicide groups: the PV-PLUS of the highest-yielding TT canola hybrid was just 0.10 t/ha less than the highest-yielding RR hybrid and 0.18 t/ha less than the best CL hybrid. There was no "oil penalty" in TT canola, which showed the same range of oil as other herbicide groups.

The highest yielding TT hybrids in 2016 had intermediate blackleg resistance, either "MR" or "MR-MS", which increase to "R" when sown with fungicide seed dressing. These varieties do not have effective major R genes in Australia, and belong to the "BF" blackleg group. This means this group can be safely sown in rotation with "A", "C", "D", or "AC" groups (e.g. rotate with ATR-Bonito which is "A" group). This recommendation is based on several other risk-minimising strategies, for example, use of fungicide seed dressing, and never growing canola immediately following canola. It is recommended to grow next year's canola at least 500 m from last year's crop (2017 GRDC Blackleg Management Guide). This is difficult to achieve in many canola growing regions of southern Australia, so blackleg resistance groups should be rotated in next year's crop to avoid the same resistance group being less than 500 m from this year's crop.

Triazine herbicide tolerance in canola is important in Australia for the control of weeds in cropping systems, and is especially useful for the control of grass weeds which would otherwise infest the following wheat crop. Atrazine is relatively safe to use on sandy acidic soils in Australia, where it is highly fixed and not mobile, and the half-life is relatively short. The best strategy for weed control involves rotation of herbicides, that is, rotating TT, CL, and RR canola varieties for long-term efficacy of these chemicals. Dual herbicide tolerance (TT-RR) canola hybrids are now available for special situations.

Hybrid seed supply in Australia was insufficient to meet demand in 2017. This suggests more investment is required in hybrid seed production. Hybrids are clear "winners" in 2016 NVT data, and no new OP canola lines are being tested in NVT in 2017. Given that ATR-Bonito has failed in some environments due to breakdown of resistance to Phoma (blackleg), the use of new hybrids with "BF" grouping is useful for blackleg gene rotation and disease management.

It is also true that low rainfall farmers may not find it attractive to invest in hybrid canola seed, and it is challenging to promote hybrids in low yield potential situations. However, the yield benefits of hybrid canola are realised across the full range of sites evaluated in this study. There is, in effect, higher percentage heterosis in low-yielding environments than in high-yielding environments, with 20% heterosis at "average" sites.

CONCLUSION

Triazine tolerant (TT) canola has remained an important component of the cropping system in southern Australia, and this is likely to continue with the release of high yielding hybrids in 2016. New TT hybrids have a 20% yield advantage over the nearest open-pollinated variety (OP) in an analysis of national variety trial data from 2012 to 2016. The yield penalty that occurs in TT canola is less obvious in hybrids than in OP varieties, and national variety trial data suggest that yield is only slightly behind in TT hybrids compared with Roundup Ready® (RR) and Clearfield® (CL) hybrids. There is no obvious TT penalty for oil content in seeds. The main reason for the popularity of TT canola is due to the value of triazine herbicides for sustainable control of weeds in Australian cropping systems, in particular grass weeds which must be controlled in canola for the benefit of the following wheat crop. A major breeding effort over several years in NPZ Australia Pty Ltd has led to the out-licensing of high-yielding TT hybrids in 2016, under the names SF Ignite TT, SF Turbine TT, and InVigor T 4510. The moderate blackleg resistance in new TT canola hybrids, and their unique "BF" blackleg resistance group, increases their value in relation to RR and CL types.

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