Genetic yield progress in popular SNSW bread wheat cultivars from 1901-2014

James Hunt[1], Bonnie Flohr[2], Neil Fettell[3], Mike Stear[1], Tony Swan[2], Brad Rheinheimer[2], Barry Haskins[4] and John Kirkegaard[2]

[1]Department of Animal, Plant and Soil Sciences, AgriBio Centre for AgriBiosciences, 5 Ring Rd, La Trobe University, Bundoora, VIC 3086
[2] CSIRO Agriculture and Food, PO Box 1700 Canberra, ACT 2601
[3]Central West Farming Systems and University of New England, PO Box 171 Condobolin, NSW 2877
[4]Ag Grow Agronomy and Research, 7 Francine Ct, Yoogali, NSW 2680

Abstract
Yield increases achieved through wheat breeding are essential in order to increase global supply to meet future demand, and keep Australian wheat growers competitive with growers in other countries. Breeders are unable to select for yield alone, but must also maintain grain quality and disease resistance in their released cultivars. Since the late 1970s, cultivars favoured by growers in southern NSW (SNSW) have tended to be of very high grain quality, and derived from northern Australian breeding programs where quality and disease resistance are emphasised. In order to quantify the genetic gain in yield potential of cultivars favoured by growers in SNSW, we planted experiments in 15 environments across SNSW containing a set of 15 cultivars (11 from southern and 4 from northern breeding programs) widely grown in the region between 1901 and the present day. Yield potential progressed at a rate of 25 kg/ha or 0.5% per year relative to the most recent release in the southern cultivars, but no yield increase was found in the northern cultivars (P=0.571) when grown in the SNSW environment. We hypothesise that this is primarily due to emphasis on grain quality and disease resistance of northern breeding programs at the expense of yield gain.

Keywords
Grain quality, disease resistance.

Introduction
Increases in yield through wheat breeding are an important component of the production increases observed in Australia and around the world that have enabled wheat production to keep pace with global demand (Fischer et al. 2014). Consistent genetic yield increases are essential in order for Australian growers to reduce cost of production and remain competitive in a global market. However, breeders do not have the luxury of selecting for yield alone, and must also select for physical and chemical grain quality and disease resistance. Given that breeding programs have finite resources, placing emphasis on quality and disease resistance can constrain the rate of potential yield progress (Richards et al. 2014).

Previous studies have quantified genetic yield gain in WA (Perry and D'Antuono 1989) and SA (Sadras and Lawson 2011) but none have comprehensively considered cultivars adapted to the important grain producing region in the southern half of NSW (SNSW). Whilst Richards (1991) reports 'yield index' (yield adjusted for quality and expressed relative to the cultivar Federation) for cultivars popular in SNSW since 1860, he does not report absolute yield or any experimental details. A key difference between SNSW and other Australian grain growing regions is that since the late 1970s growers have favored cultivars with very high grain quality (Australian Prime Hard, APH) for the price premium this segregation attracts. These cultivars have primarily been developed by breeding programs in northern NSW and QLD, as these are the only states in which APH can be grown. Cultivars bred in southern wheat growing states (SA and VIC) tend to have lower grain quality, with either Australian Hard (AH) or Australian Premium White (APW) as their maximum classification. The aim of this study was to quantify the genetic component of yield increases observed in bread wheat cultivars widely grown in SNSW from the beginning of the 20th century until the present day.

Methods
A set of 15 spring bread wheat cultivars (Table 1) was compiled based on their historic popularity among growers in southern and central NSW (Fitzsimmons 1991; Brennan and Bialowas 2001). Seed of each line was obtained from the Australian Winter Cereals Collection, and grown in rows at Black Mountain ACT in 2013 to confirm type, purity and to bulk seed for field trials.
Field experiments using the set of historic cultivars were conducted at seven locations across SNSW from 2014 to 2016 (Table 2). Experiments at Merriwagga, Barellan, Rankins Springs and Hillston were

randomised but not replicated. All other experiments had four replicates, and were part of split-plot time of sowing x cultivar experiments with sowing time as the main plot and cultivar as the sub-plot. At these sites, the different times of sowing were considered different environments in the analysis, giving a total of 15 environments. At the Junee site and Temora site in 2015, the popular southern cultivars Mace and Corack were grown in neighbouring experiments with identical block structure and management and a cultivar in common to both experiments (Sunstate – 2.2 t/ha vs 2.3 t/ha at Junee in 2014 and 3.1 t/ha vs 3.3 t/ha at Temora in 2015), and these were included in the analysis. In experiments from 2015 onward, Suntop was replaced with Condo as it overtook Suntop as the highest yielding AH wheat in SNSW in National Variety Trials (NVT). At Temora in 2015, Suntop was grown in a neighbouring experiment with identical block structure, management and cultivars in common (Gregory 3.9 t/ha vs 3.8 t/ha) and was included in the analysis.

Table 1. Cultivars selected for the trial, their year of release, stature, state of origin and grouping of breeding program (S southern, N northern).

Cultivar	Year of release	Stature	Breeding program
Federation	1901	Tall	NSW Department of Agriculture, Tharwa (S)
Ranee	1924	Tall	VIC Department of Agriculture, Werribee (S)
Bencubbin	1929	Tall	WA Department of Agriculture, Merredin (S)
Gabo	1942	Tall	NSW University of Sydney, Sydney (S)
Insignia	1946	Tall	VIC Department of Agriculture, Werribee (S)
Olympic	1956	Tall	VIC Longerenong Agricultural College, Dooen (S)
Heron	1959	Tall	NSW Department of Agriculture Wagga Wagga (S)
Condor	1973	Semi-dwarf	NSW Department of Agriculture Wagga Wagga (S)
Banks	1979	Semi-dwarf	QLD Department of Agriculture, Toowoomba (N)
Janz	1989	Semi-dwarf	QLD Department of Agriculture, Toowoomba (N)
Gregory	2004	Semi-dwarf	QLD EGA, Toowoomba (N)
Mace	2008	Semi-dwarf	SA AGT, Roseworthy (S)
Corack	2011	Semi-dwarf	VIC AGT, Horsham (S)
Suntop	2012	Semi-dwarf	NSW AGT, Narrabri (N)
Condo	2014	Semi-dwarf	VIC AGT, Horsham (S)

Table 2. Experiment sites, years, times of sowing, summer fallow and growing season rainfall and estimated water supply of the 15 environments used in the study.

Cultivar	Year	Time of sowing	Summer fallow rainfall (mm)	Growing season rainfall (mm)	Estimated water supply (mm)
Junee	2014	21 May	138	259	293
Hillston†	2014	15 May	127	152	493
Merriwagga	2014	29 May	135	160	193
Rankins Springs*	2014	22 May	143	199	310
Barellan	2014	9 May	254	215	278
Condobolin	2014	23 April, 13 May	208	167	219
Condobolin	2015	30 April, 20 May	202	164	314
Temora	2015	27 April, 7 May, 15 May	169	276	318
Temora	2016	26 April, 6 May, 16 May	194	591	639

†experiment irrigated *experiment conducted on long fallow

In all experiments, weeds, insect pests and diseases were controlled with pesticides such that they did not affect yield. Adequate P fertiliser (MAP) was applied at sowing and N as urea top-dressed during stem-elongation to ensure that neither of these nutrients limited yield. Yield was measured by machine harvest with the exception of Temora in 2016 which was measured by hand-harvesting and threshing 2.0 m² (two 0.83 x 1.2 m quadrats taken from the middle four rows of six row plots), and Condobolin in 2015 which was measured by hand-harvesting and threshing 0.99 m² (three 0.3 x 1.0 m quadrats taken from middle rows of plots).

Yield data at field moisture content (n=587) was analysed using linear mixed models in the Genstat (v. 18.1) user interface with year of release as a fixed effect and environment (incorporating site, year and time of sowing) as a random effect. Predicted mean yields were plotted against year of release, and a simple linear model was fitted separately to cultivars from northern (QLD and NNSW) and southern (SNSW, VIC, SA and WA) breeding programs. The slope of the fitted line was assumed to be rate of genetic yield increase where it was found to be significant (P<0.05).

Results

Potential yield of southern cultivars released between 1901 and 2014 progressed at a rate of 25 kg/ha/year or 0.50% per year relative to Condo, the most recent cultivar in the set (Figure 1). There was no significant (P=0.575) genetic yield gain detected in the northern cultivars released from 1979 to 2012.

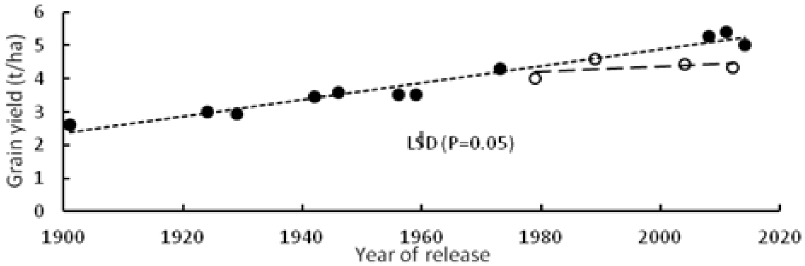

Figure 1. Predicted mean grain yield for southern (●) and northern (○) cultivars released between 1901 and 2014. The linear function fitted to the southern cultivars (- - -) is of the form y = 0.025x - 45.613 (P<0.001, R=95% SE of slope = 0.0018), the function fitted to the northern cultivars (– –) is of the form y = 0.0071x - 9.846 (P=0.571, SE of slope =0.0106).

Discussion

The yield progress (25 kg/ha/year) observed in southern cultivars is identical to that found by Sadras and Lawson (2011) for SA cultivars, and similar to those in international studies (Fischer et al. 2014). A period of stalled yield gain such as that observed in the northern cultivars has not previously been reported in Australian studies, but has been reported for a similar period in the Yaqui valley of Mexico (Fischer et al. 2014). The possible reasons for this prolonged period of yield stagnation warrant further examination. The southern cultivars are derived from breeding programs either in NSW (Federation, Gabo, Heron, Condor) or VIC (Ranee, Insignia, Olympic), with the exception of Bencubbin (WA). The northern cultivars Banks, Janz and Gregory came from the QLD state breeding program, and Suntop came from the old Sydney University program in Narrabri, which was acquired by AGT when wheat breeding was privatised. Whilst the level of resourcing, geography and selection environments of the different programs relative to SNSW may have played a role in stalled yield gain, the different breeding objectives of the northern vs. southern programs is probably of greater importance. Both the QLD and Narrabri breeding programs have historically placed more emphasis on grain quality and foliar disease resistance than their southern counterparts. Banks, Janz, Gregory and Suntop are all of APH quality, and at their time of release carried high levels of host-plant resistance to the three major rusts of wheat (Table 3).

Table 3. Maximum quality classifications and current resistance to the three major rusts of wheat (R=resistant, M=moderately, S=susceptible, V=very) of semi-dwarves derived from northern (QLD and NNSW) breeding programs vs those derived from southern (VIC and SA) breeding programs (Matthews et al. 2016).

Cultivar	State of origin	Maximum quality classification	Leaf rust	Stem rust	Stripe rust (YR17-YR27)
Banks	QLD	APH	-	-	-
Janz	QLD	APH	MR–MS	R–MR	MS
Gregory	QLD	APH	MR	MR	MR
Suntop	NNSW	APH	MR–MS	MR	MR–MS
Mace	SA	AH	MS–S	MR	S–VS
Corack	VIC	APW	S–VS	MR	MS
Condo	VIC	AH	S	R–MR	MS–S

We hypothesise that in the northern breeding programs emphasis on grain quality and disease resistance has come at the cost of genetic yield gain. This hypothesis is supported by the relatively higher yields of the recently released SA and VIC cultivars Mace, Corack and Condo (Figure 1). The programs that developed these cultivars placed less emphasis on foliar disease resistance, particularly stripe and leaf rust, and their maximum grain quality classifications are inferior to those of the northern cultivars (Table 3). Consequently, their breeders were less constrained in their ability to select for high yield. Wheat breeding in Australia was historically funded by governments and levy bodies, but since privatisation has been paid for exclusively by wheat growers through collection of end-point royalties (EPR). Given this recent change, careful attention needs to be paid to ensure that breeding focusses on the needs of growers rather than other beneficiaries or stakeholders such as exporters, millers or state pathologists. Yield is a key driver of profit on grain farms and most growers in SNSW would expect the genetic yield potential of cultivars they adopt to increase over time in line with other regions nationally and internationally. The APH grain quality emphasised by the northern programs does give growers a competitive advantage in the global market (particularly SE Asia), which is currently of benefit given the global oversupply of low quality grain. However, as the minimum protein requirement of APH (13%) is above that at which yield is maximised (~10.5%, Holford et al. 1992), substantial amounts of N fertiliser are required to achieve this grade with associated cost and production risk. Return on investment in N fertiliser is often maximised when yield is maximised i.e. at AH and APW protein levels (10.5 and 11.5% respectively). Host plant resistance to the three rusts of wheat was important to growers prior to the advent of cheap and effective foliar fungicides. However, in current times the agrochemical industry has effectively outcompeted plant breeders for control of these pathogens. For example, the cost of the EPR required for a grower to obtain the host plant resistance of Suntop to stripe rust (which has the same APH quality and yield as Janz, a cultivar with no EPR) is $ 3.25/t, costing $14/ha at the average yield achieved by Suntop in these experiments (4.3 t/ha). The fungicide required to protect Janz from rusts to a similar level as that provided by the genetics of Suntop (two 62 g/ha applications of tebuconazole) costs approximately $4/ha. In other states, growers have keenly embraced the increases in yield that reduced emphasis on disease resistance has allowed. Perhaps the best example of this is the cultivar Mace, which was released in 2008 with virtually no resistance to stripe rust. It was rapidly adopted by growers in SA, WA and VIC for its high yield and stable grain quality, and based on total production it is probably the most successful cultivar in Australian history.

Conclusion

When grown in SNSW, cultivars from southern breeding programs favoured by growers in the region have demonstrated clear genetic yield gain. However, there is no evidence of genetic yield gain in the northern cultivars that have been favoured since the late 1970s. We propose that this stagnation is due to the emphasis placed on grain quality and disease resistance by the northern breeding programs that produced the recently favoured cultivars.

Acknowledgements

This research was funded by GRDC Project No CSP00178 and a GRDC Grains Research Scholarship (Temora, Junee and Condobolin sites) and Ag Grow Agronomy and Research (Rankins Springs, Merriwagga, Hillston, Barellan).

References

Brennan JP and Bialowas A (2001). Changes in Characteristics of NSW Wheat Varieties, 1965-1997: Economic Research Report No. 8. NSW Agriculture, Wagga Wagga.

Fischer RA, Byerlee D and Edmeades GO (2014). Crop yields and global food security: will yield increase continue to feed the world? ACIAR Monograph No. 158. Australian Centre for International Agricultural Research, Canberra ACT.

Fitzsimmons RW (1991). Wheat Variety Statistics NSW 1925-1990 Areas of All Wheat Varieties Planted - NSW by Local Government Areas. Australian Institute of Agricultural Science, Wahroonga, NSW.

Holford I, Doyle A and Leckie C (1992). Nitrogen response characteristics of wheat protein in relation to yield responses and their interactions with phosphorus. Aust. Journal of Agricultural Research 43, 969-986.

Matthews P, McCaffery D and Jenkins L (2016). Winter crop variety sowing guide 2016. NSW DPI, Orange, NSW.

Perry M and D'Antuono M (1989). Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. Aust. Journal of Agricultural Research 40, 457-472.

Richards RA (1991). Crop improvement for temperate Australia: Future opportunities. Field Crops Research 26, 141-169.

Richards RA, Hunt., JR, Kirkegaard JA and Passioura JB (2014). Yield improvement and adaptation of wheat to water-limited environments in Australia - a case study. Crop and Pasture Science 65, 676-689.

Sadras VO and Lawson C (2011). Genetic gain in yield and associated changes in phenotype, trait plasticity and competitive ability of South Australian wheat varieties released between 1958 and 2007. Crop and Pasture Science 62, 533-549.