Do barley varieties differ in their response to increasing nitrogen and increasing plant density?

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Key messages

- Barley varieties do differ in how they respond to the management inputs of applied nitrogen (N) and seed rate (plant density).
- The relative performance of varieties was not constant as their responses changed as the environment changed.
- Knowledge of how a variety responded to increasing N was not helpful in understanding how the same variety responded to increasing plant density.
- Studies with a narrow matrix of treatments can help define the variety specific management principles that should apply when growing a new malt variety, whilst studies with a wider range of management treatments define the weaknesses and strengths of varieties.
- Knowing the strengths and weaknesses of each malt variety is critical in outlining the management practices that best suit the variety to optimise its grain yield, grain quality, harvestability and return per ha.

Aims

There has been a rapid release and uptake of Barley Australia (barleyaustralia.com.au) accredited malting barley varieties in the last five years. Each newly released malt variety has a different phenotype, potentially resulting in differing responses to management inputs. In this study we looked at the influence of nitrogen (N) fertiliser at different seed rates (plant densities) on grain yield and grain quality parameters in a range of the new ‘malt’ barley varieties. The aim of the study was to assess varieties for their responsiveness to management and determine if a different management practice might be required to maximise productivity when growing each variety. This paper builds on the data presented at the 17th Australian Barley Technical Symposium which covered only those trials conducted between 2012-2014 (Paynter *et al*. 2015a) but did not include research from northern New South Wales in that period.

Method

This study was a collaboration between the western (DAW00190 and DAW00224), southern (DAN00173) and northern (DAN00167) Grains Research and Development Corporation (GRDC) co-funded barley agronomy projects over a seven year period (2010-2016). A total of 52 trials were harvested comprising 23 in Western Australia (2010-2016), five in South Australia (2012-2016), three in Victoria (2012-2013 and 2016) and 21 in New South Wales (2012-20160. In each trial, eight (sometimes 10) barley varieties were evaluated for their response to three rates of applied N (0, 20 and 80 kg N/ha in 2010-2011 or 0, 30 and 90 kg N/ha in 2012-2016) at three different plant densities (target establishment of 75, 150 and 300 plants/m^2) over three replicates. Trials were designed with either a one-way block structure of rep/(variety.N applied.plant density) (13 trials) or a two-way block structure of (rep+colrep)/(variety.N applied)/plant density (39 trials) and a treatment structure of variety x N applied x plant density.

A total of 24 different barley varieties were assessed (predominantly varieties with a malt end use or being targeted at a malt end use). The most common varieties were Buloke (51 trials), Bass and La Trobe (47 trials), Commander and Granger (44 trials), Compass (34 trials), Wimmera (31 trials), Flinders (26 trials), Skipper (25 trials), Navigator (13 trials) and Spartacus CL (11 trials). Data for Hindmarsh (4 trials) has been merged into the La Trobe data set and data for Scope CL (4 trials) merged into the Buloke data set due to the consistent similarities in phenotype exhibited by those pairs of varieties.

Trials were established (mostly into canola or wheat stubble and sometimes fallow) and harvested with small plot research equipment. N (as urea) was top-dressed by hand after seeding. The seed rate (kg/ha) to establish the target densities of 75, 150 or 300 plants/m^2 varied for each variety and year and was adjusted based on their kernel weight and germination per cent. Results are graphed against the measured establishment (determined two to four weeks after seeding) rather than against the target densities. Common measurements at each trial included plant establishment (plants/m^2), grain yield (t/ha), kernel weight (mg, db), test weight (kg/hL), screenings (% < 2.5 mm and % < 2.2 mm), grain protein concentration (%, db) and grain protein yield (kg/ha). Plant height, lodging scores and grain brightness (Minolta ‘L*’) was also measured on trials conducted in WA but excluded from the analysis in this paper.

For each location, an ANOVA was undertaken in Genstat (VSN International 2015) using the varieties sown in that trial and the blocking factors for the relevant experimental design.

Table 1. Trial details for the 52 national barley agronomy variety by N applied by plant density trials.

Year	State	Location	Sown (date)	Apr-Oct rainfall (mm)	Location mean yield (t/ha)	Previous crop	Soil type (local name)
2010	WA	Yerecoin	28 May	168	2.22	canola	yellow sandy earth
	WA	Muresk	27 May	188	3.11	fallow	red loamy earth
	WA	Wittenoom Hills	14 May	261	3.25	canola	alkaline grey shallow sandy duplex
	WA	Grass Patch	02 Jun	228	2.70	wheat	alkaline grey loamy duplex
2011	WA	Yerecoin	31 May	342	3.36	canola	grey shallow sandy duplex
	WA	Muresk	26 May	338	4.82	canola	red loamy earth
	WA	Wittenoom Hills	25 May	281	1.71	canola	alkaline grey shallow sandy duplex
	WA	Grass Patch	25 May	238	1.81	wheat	alkaline grey loamy duplex
2012	WA	Walebing	19 Jun	224	4.18	canola	brown shallow loamy duplex
	WA	Katanning	28 Jun	289	3.35	canola	ironstone gravel
	WA	Gibson	23 May	310	4.97	canola	shallow grey sandy duplex
	SA	Turretfield	31 May	288	4.58	pasture	red-brown loam
	Vic	Birchip	14 Jun	146	2.13	wheat	clay loam
	NSW	Condobolin	30 May	177	2.38	wheat	red-brown chromosol
	NSW	Parkes	30 May	236	4.58	canola	red dermosol
	NSW	Gurley	31 May	219	3.56	sorghum	grey vertisol
	NSW	Spring Ridge	15 Jun	210	6.02	cotton	black vertisol
2013	WA	Walebing	15 May	230	4.62	canola	brown shallow sandy duplex
	WA	Kendenup	06 Jun	401	5.27	canola	brown duplex sandy gravel
	WA	Gibson	15 May	429	4.92	canola	grey deep sandy duplex
	SA	Turretfield	13 Jun	397	4.71	fallow	red clay loam
	Vic	Watchupga	16 May	221	2.14	wheat	sandy clay loam
	NSW	Condobolin	21 Jun	254	1.82	wheat	red-brown chromosol
	NSW	Parkes	31 May	356	4.28	canola	red dermosol
	NSW	Garah	01 May	108	3.26	chickpeas	black vertisol
	NSW	Pine Ridge	06 Jun	171	5.41	sorghum	black vertisol
2014	WA	Walebing	14 May	277	2.92	canola	grey shallow loamy duplex
	WA	Kojonup-West	30 May	380	3.79	canola	reddish brown deep sandy duplex
	WA	Gibson	02 Jun	445	4.45	canola	pale sandy earth
	SA	Turretfield	27 May	347	5.07	fallow	red clay loam
	NSW	Condobolin	21 Jun	167	2.06	wheat	red-brown chromosol
	NSW	Parkes	31 May	258	4.07	canola	red dermosol
	NSW	Garah	03 May	100	1.62	chickpea	black vertisol
	NSW	Spring Ridge	22 May	174	3.90	canola	black vertisol
	NSW	Terry Hie Hie	29 May	215	3.86	fallow	black vertisol
2015	WA	Walebing	21 May	305	3.94	canola	red deep sandy duplex
	WA	Kojonup-West	21 May	309	3.91	canola	dark grey deep sandy duplex
	WA	Wittenoom Hills	12 May	301	4.69	canola	alkaline grey shallow sandy duplex
	SA	Turretfield	27 May	262	1.86	pasture	grey-brown sandy loam
	NSW	Condobolin	25 May	498	0.66	wheat	red-brown chromosol
	NSW	Parkes	14 May	560	5.29	canola	red-clay loam
	NSW	Terry Hie Hie	07 Jun	307	3.67	wheat	brown vertisol
	NSW	Tulloona	07 May	304	5.38	fallow	black vertisol
	NSW	Trangie	18 May	314	4.07	wheat	red chromosol
2016	WA	Muresk	04 May	318	4.25	canola	brown loamy earth
	WA	Kojonup-West	13 May	458	2.86	canola	dark brown deep sandy gravel
	WA	Wittenoom Hills	14 May	321	4.82	canola	alkaline grey shallow loamy duplex
	SA	Turretfield	01 Jun	498	6.06	pasture	grey brown loamy earth
	Vic	Manangatang	27 Apr	263	4.65	wheat	sandy loam
	NSW	Condobolin	18 May	498	5.46	wheat	red-brown chromosol
	NSW	Parkes	21 May	605	4.43	canola	red dermosol
	NSW	Terry Hie Hie	02 May	460	5.45	linseed	grey vertisol

A combined MET analysis was conducted on the 52 trial dataset to predict the performance of a core set of eight varieties – Bass, Buloke (includes Scope CL), Commander, Compass, Flinders, Granger, La Trobe (includes Hindmarsh) and Spartacus CL. Skipper, Navigator and Wimmera were not included in the MET analysis due to their lack of commercial production. In only six of the 52 trials were all eight varieties sown together. On average, six of the eight core varieties were common in each trial, but the variety mixture varied across locations and years. The combined 52 trial data set was analysed spatially with an autoregressive correlation matrix in ASReml3 for R (Gilmour *et al*. 2009) in R 3.4.0 (R Core Team 2017) where possible. Within the spatial model fixed terms were location, variety, N applied, plant density and their interaction, while random terms were replicate and blocking factors within each of the experimental designs. The data for the measured traits of grain protein, 2.5mm and 2.2mm screenings were not normally distributed and a square root transformation was undertaken for grain protein and an arcsine transformation was undertaken for 2.5mm and 2.2mm screenings to normalise residual distribution and improve model fit. The data for grain protein, 2.5mm and 2.2mm screenings presented in this paper is the back transformed data.

The performance of the core varieties (predicted from the MET analysis) relative to the location mean was assessed within GenStat using a polynomial regression model combined with a Student's ttest (two tailed, paired). Grain protein deviation based on the relationship between grain yield and grain protein concentration was calculated with GenStat as per Paynter and van Burgel (2014).

Results

Location and variety

Growing season rainfall (April-October) ranged between 100 mm and 605 mm, with an average rainfall of 301 ± 16 mm (Table 1). The location mean grain yield ranged from 0.66 t/ha (Condobolin 2015) to 6.06 t/ha (Turretfield 2016), with an average yield of 3.81 ± 0.18 t/ha. Grain quality was assessed against the both the GTA and GIWA Barley receival specifications. Against the GTA receival specifications over 80% of samples met test weight (≥65 kg/hL), over 75% met screenings (≤7% thru 2.2 mm) and at least 70% met retention (≥70% above 2.5 mm) targets for receival as Malt1, but just over 40% of samples met grain protein concentration (9-12%) targets. Against the GIWA receival specifications over 80% of samples met test weight (≥64 kg/hL) and 70% met screenings (≤20% below a 2.5 mm) targets for receival as Malt1, with nearly 40% of samples meeting grain protein concentration (9.5-12.5%) targets (data not presented).

Table 2. Varietal differences in grain yield and grain quality based on the MET analysis when averaged across locations. Significance: *** = p<0.001, ** = p<0.01, * = p<0.05 and n.s. = not significant.

Trait Variety	Grain yield (t/ha)	Kernel weight (mg, db)	Test weight (kg/hL)	Screenings (%<2.5mm)	Screenings (%<2.2mm)	Grain protein (%, db)	Grain protein yield (kg/ha)
Bass	3.67	41.0	71.1	13.9	3.2	11.9	441
Buloke	3.69	43.1	69.8	22.8	4.7	11.4	421
Commander	3.89	39.9	69.3	16.2	4.5	10.8	425
Compass	4.17	42.7	68.8	13.2	3.1	10.3	446
Flinders	3.62	37.5	69.6	16.9	3.9	11.8	428
Granger	3.78	40.2	70.1	17.5	4.0	11.5	436
La Trobe	4.04	39.0	70.9	18.7	4.4	11.0	447
Spartacus CL	3.90	38.6	70.9	15.5	2.4	11.7	456
Significance	***	***	***	***	***	***	***
LSD (p=0.05)	0.09	0.4	0.2	<0.1	<0.1	<0.1	13

Varieties differed in their grain yield and physical grain characteristics (Tables 2, 3 and 4; Figures 1 and 2).

Of the eight core varieties assessed in the MET analysis, Compass was the highest yielding variety, out-yielding the national variety Buloke (and now Scope CL) by 0.48 t/ha when averaged across locations (a 12% difference). This difference is consistent with results observed in barley NVT nationally (nvtonline.com.au/). The ranking of varieties varied with yield potential with Compass being the highest yielding variety at locations with a yield potential between 1 and 5 t/ha. Above 5t/ha, Compass, La Trobe and Spartacus CL were the highest yielding varieties, with Granger becoming competitive above 6 t/ha. Flinders was the lowest yielding variety being slightly lower than Bass between 2 and 4 t/ha, with Buloke being the lowest yielding variety when trials yields exceeded 5 t/ha.

Buloke and Compass had higher average kernel weights than Commander, Flinders, La Trobe and Spartacus CL.

Bass, La Trobe and Spartacus CL had the highest average test weight and Compass the lowest. The test weight of Bass, La Trobe and Spartacus CL was more stable than the other five varieties evaluated, with the difference between the two groups largest around the Malt 1 receival limit of 64 kg/hL. At locations where La Trobe was at the GIWA Malt1 lower limit for test weight (64 kg/hL), the test weight of Buloke, Commander, Compass, Flinders and Granger was between 1-3 kg/hL lower than La Trobe, with Bass, La Trobe and Spartacus CL like each other. The ranking of Buloke, Commander, Flinders and Granger varied as test weight varied.

On the 2.2mm sieve, Spartacus CL had the lowest average screenings with Buloke, Commander and La Trobe the highest. Bass and Compass had the lowest average screenings below a 2.5mm sieve and Buloke the highest. The ranking for plumpness (based on 2.5mm screenings) did not change much as screenings increased. At locations where La Trobe was at the GIWA Malt1 limit for 2.5mm screenings (maximum of 20%), screenings of Compass was 7% lower than La Trobe, Bass around 5% lower, Commander and Spartacus CL around 3% lower, Flinders the same as La Trobe, Granger 1% higher and Buloke 8% higher than La Trobe.

Bass and Flinders had the highest average grain protein concentration across all rates of applied N and Compass the lowest followed by Commander. The difference in their grain protein concentration was around 1.5% when differences in their grain yield were accounted for, thereby reducing (but not eliminating) any yield dilution effect that may have occurred due to the extra yield of Compass. The grain protein deviation of Bass and Commander is consistent with the analysis of barley NVT trials in SA (Porker and Wheeler 2013) and in WA (Paynter and van Burgel 2014).

Granger was the only variety whose grain protein deviation did not deviate from zero at any rate of applied N. Compass and Commander were low protein at all rates of applied N, Buloke and La Trobe were low protein varieties at high N, Spartacus CL was a high protein variety at high rates of N and Bass was a high protein variety at all rates of applied N. These observations for Buloke, La Trobe, Granger and Bass were similar to that observed by Paynter *et al*. (2016) when analysing the national agronomy trials from WA conducted between 2012 and 2014.

Buloke and Compass had the lowest average grain protein yield, whilst Spartacus CL had the highest.

Table 3. MET analysis of variance for main effects (location, variety, N applied and plant density) and their interactions. Significance: *** = p<0.001, ** = p<0.01, * = p<0.05 and n.s. = not significant.

Trait Source	Grain yield (t/ha)	Kernel weight (mg, db)	Test weight (kg/hL)	Screenings (%<2.5mm)	Screenings (%<2.2mm)	Grain protein (%, db)	Grain protein yield (kg/ha)
Location (L)	***	***	***	***	***	***	***
Variety (V)	***	***	***	***	***	***	***
N applied (N)	***	***	***	***	***	***	***
Plant density (PD)	***	***	***	***	***	***	***
L x V	***	***	***	***	***	***	***
L x N	***	***	***	***	***	***	***
V x N	***	***	***	***	***	***	***
L x PD	***	***	***	***	***	***	***
V x PD	***	***	***	***	***	***	***
N x PD	***	***	**	***	***	***	n.s.
L x V x N	***	***	***	***	***	***	***
L x V x PD	***	***	***	***	***	***	***
L x N x PD	***	***	***	***	***	***	***
V x N x PD	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
L x V x N x PD	n.s.	n.s.	***	***	***	**	n.s.

Table 4. Likelihood of the main effects (variety, N applied and plant density) and their interactions being significant (p<0.05) in single location analyses. Significance: rarely = significant in ≤20% trials, occasionally = 20-40% trials, 50% chance = 40-60% trials, often = 60-80% trials and consistently = ≥80% trials significant.

Trait Source	Grain yield (t/ha)	Kernel weight (mg, db)	Test weight (kg/hL)	Screenings (%<2.5mm)	Screenings (%<2.2mm)	Grain protein (%, db)	Grain protein yield (kg/ha)
Variety (V)	consistently	consistently	consistently	consistently	consistently	consistently	consistently
N applied (N)	consistently	consistently	often	consistently	consistently	consistently	consistently
Plant density (PD)	consistently	consistently	often	consistently	consistently	often	consistently
V x N	occasionally	occasionally	50% chance	50% chance	50% chance	occasionally	occasionally
V x PD	50% chance	often	often	often	often	occasionally	occasionally
N x PD	50% chance	occasionally	rarely	50% chance	50% chance	rarely	occasionally
V x N x PD	rarely	rarely	rarely	rarely	occasionally	rarely	rarely

Nitrogen and plant density

N and plant density both influenced yield and quality (Tables 2, 3 and 5; Figure 2).

N influenced grain yield at 87% of locations, with a positive impact in two thirds of trials (average response +0.68 t/ha) and a negative impact in one quarter of trials (-0.28 t/ha) (Table 5). Across locations, grain yield responded all the way to the highest N treatment. Negative impacts on test weight and positive effects on 2.5mm screenings were more common than no effect or the reverse, whereas N always increased grain protein concentration.

Plant density influenced grain yield at 90% of locations, with an increase in grain yield in three quarters of locations (+0.34 t/ha) and a decrease in about one in every seven trials (-0.17 t/ha). Across locations, grain yield plateaued between the target establishment treatments of 150 and 300 plants/m^2. Increasing plant density decreased test weight, increased 2.5mm screenings and deceased grain protein concentration in two thirds of trials or more and only improved those quality traits in one in every ten trials. The average negative impact on test weight and grain protein was larger than the average positive response, whilst the opposite was true for 2.5mm screenings.

Across locations, the absolute effect (and direction of change) of increasing N from 0 to 80-90 kg N/ha was higher than increasing the plant density from 75 to 300 plants/m^2 for grain yield (+0.44 vs +0.25 t/ha), 2.5mm screenings (+6.4% vs +3.2%), 2.2mm screenings (+1.7 vs +1.1%), and grain protein yield (+123 vs +18 kg/ha). N had a smaller effect on kernel weight (-1.3 vs -2.3 mg) and test weight (-0.1 vs -0.5 kg/hL) than plant density.

The change in yield and quality, however, varied with location. On average, locations in WA were more yield responsive to applied N (116% vs 107%) and to increasing plant density (109% vs 104%). Grain quality responses in the west and east were not consistently different across traits or treatments.

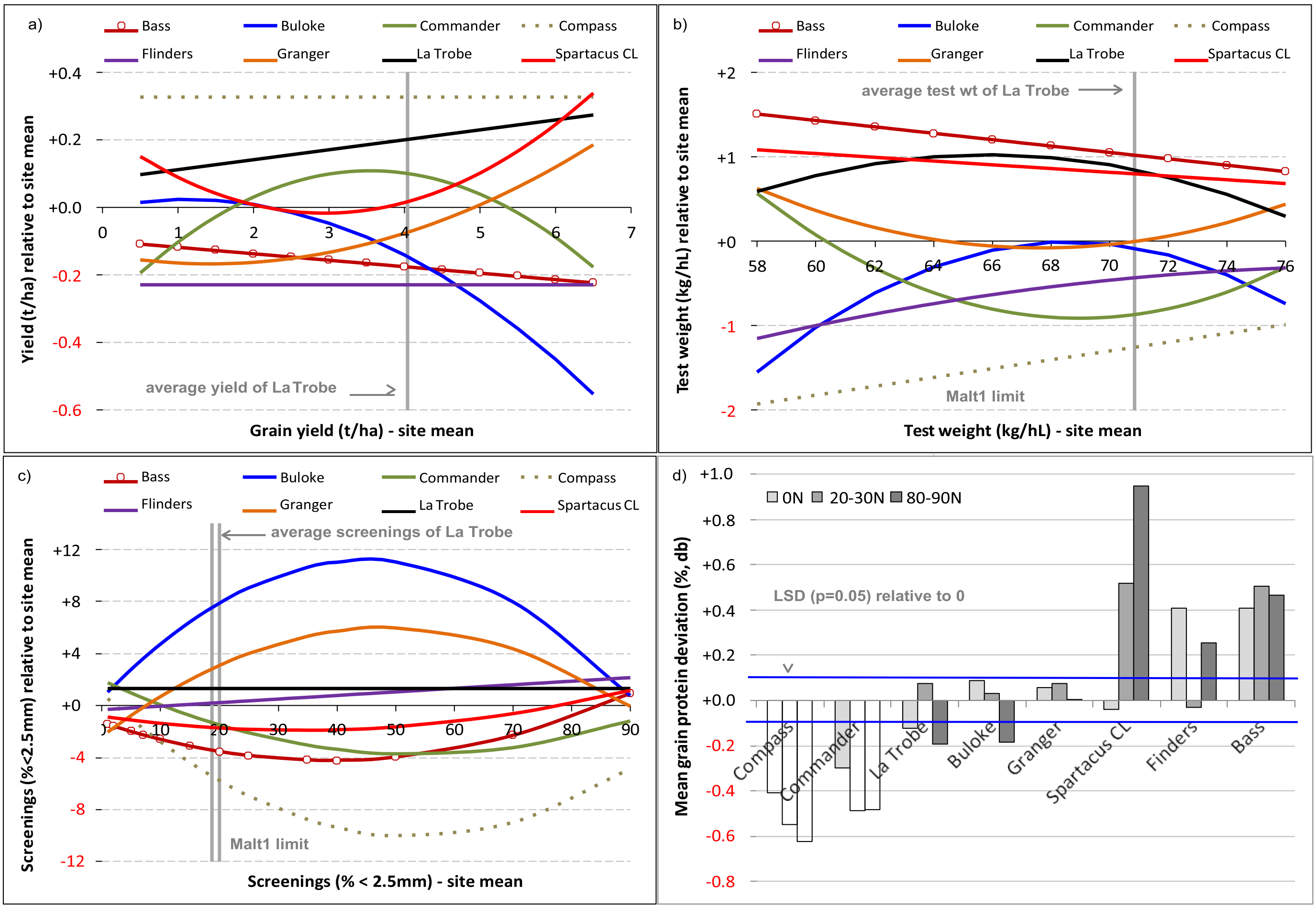


Figure 1. a) relative grain yield (t/ha) of Bass, Buloke, Commander, Compass, Flinders, Granger, La Trobe and Spartacus CL at different site mean grain yields achieved;
b) relative test weight (kg/hL) of Bass, Buloke, Commander, Compass, Flinders, Granger, La Trobe and Spartacus CL at different site mean test weights achieved;
c) relative screenings (%<2.5mm) of Bass, Buloke, Commander, Compass, Flinders, Granger, La Trobe and Spartacus CL at different site mean screenings achieved; and
d) mean grain protein deviation of Bass, Buloke, Commander, Commander, Flinders, Granger, La Trobe and Spartacus CL when the influence of differences in their grain yield is removed. For varieties whose bars are outside the LSD (p=0.05), their grain protein concentration deviates significantly from zero at that level of N applied.

Table 5. Direction (decrease, no change and increase, p<0.05) and size of influence (difference between lowest and highest treatments) of increasing N and plant density on grain yield, test weight, 2.5mm screenings and grain protein concentration over all 52 locations.

	Response to N applied (% trials)			Response to plant density (% trials)		
Trait	decrease	no change	increase	decrease	no change	increase
Grain yield (t/ha)	23%	13%	64%	15%	10%	75%
Test weight (kg/hL)	49%	27%	24%	64%	24%	12%
Screenings (%<2.5mm)	2%	11%	87%	10%	10%	80%
Grain protein (%, db)	0%	0%	100%	62%	29%	10%
	Absolute effect due to N applied			Absolute effect due to plant density		
Trait	decrease	no change	increase	decrease	no change	increase
Grain yield (t/ha)	-0.28	-	+0.68	-0.17	-	+0.34
Test weight (kg/hL)	-0.9	-	+1.4	-0.9	-	+0.3
Screenings (%<2.5mm)	-0.9	-	+8.0	-0.9	-	+4.8
Grain protein (%, db)	-	-	+2.4	-0.4	-	+0.2

Table 6. Responsiveness of varieties to increasing N applied or increasing plant density when averaged across locations for grain yield and grain quality based on MET analysis.

Management treatment	N applied		Seeding rate	
Trait	Smallest change	Largest change	Smallest change	Largest change
Grain yield	Flinders Granger	Compass La Trobe Spartacus CL	Buloke Commander	Compass Spartacus CL

Kernel weight	Flinders Spartacus CL	La Trobe	Spartacus CL	Compass Granger
Test weight	Commander Compass Granger	Buloke Flinders Spartacus CL	-	Flinders Granger
Screenings (%<2.5mm)	Commander	Buloke La Trobe	Commander Flinders	Granger
Screenings (%<2.2mm)	Commander Compass Spartacus CL	Buloke La Trobe Flinders	-	Granger Spartacus CL
Grain protein	-	Spartacus CL	Buloke Compass	Flinders Spartacus CL
Grain protein yield	Buloke Commander Compass Flinders	Spartacus CL	Buloke Compass	Commander

Varietal interactions with nitrogen or plant density

Varieties responded differently to each other with increasing N applied and to increasing plant density (Tables 2, 3 and 6; Figures 2-4). This response was also influenced by location (Table 3). Varietal interactions with N or plant density were only observed in two in every five trials for grain yield. Varietal interactions with plant density were more common than with applied N for kernel weight (68% vs 28%), test weight (61% v 41%), 2.5mm screenings (75% vs 58%) and 2.2mm screenings (78% vs 50%) and similar for grain protein concentration (37% vs 31%) and grain protein yield (29% vs 29%).

Compass, La Trobe and Spartacus CL tended to be more responsive to applied N than Flinders and Granger, adding an additional 0.2 t/ha when a high rate of N was applied. The shape of the response curve to N for Spartacus CL was different to that of observed for Compass and La Trobe.

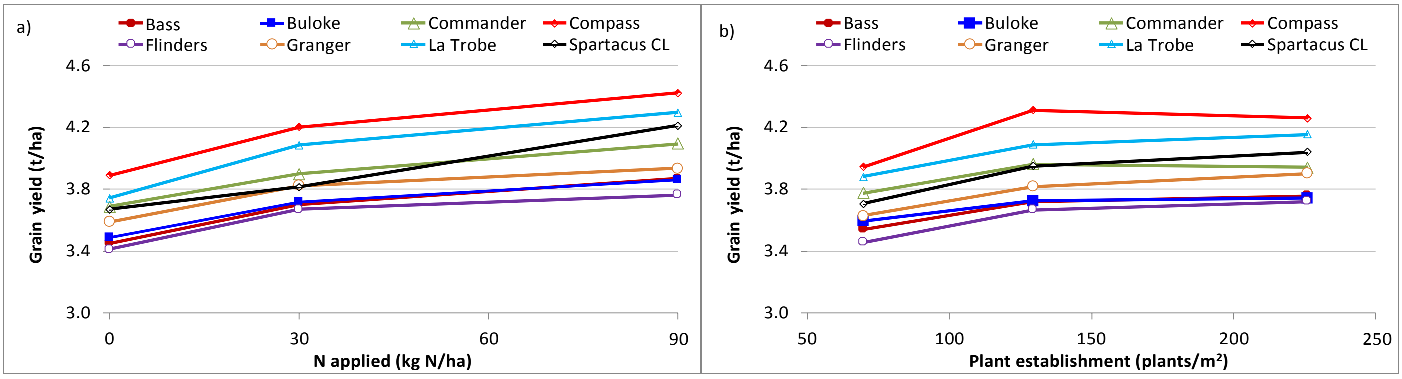
For plant density, Compass and Spartacus CL were the most yield responsive varieties to increasing density, with an overall yield response double that of Buloke and Commander (+0.32 vs +0.16 t/ha).

With both N and plant density only having a small overall effect on test weight, varietal differences in response to applied N or plant density were relatively small. For applied N, the difference between the most responsive group and least responsive group was only 0.3 kg/hL. For plant density, the decline in test weight of Flinders and Granger was double that of the other six varieties (-1.0 vs <-0.5 kg/hL).

For the important receival trait 2.5mm screenings, Commander had lowest change in screenings due to applied N, increasing by only 2% compared to 10% for Buloke and La Trobe. 2.5mm screenings of Commander and Flinders were the least affected by increasing plant density, increasing by only 1-2% compared to Granger by 6%.

Spartacus CL had the highest change in grain protein concentration with applied N, increasing by 1% more than the other seven varieties (+3.29 vs 2.27 %). The change in grain protein due to plant density was the lowest in Buloke and Compass (decrease of around 0.1%) and the highest in Flinders and Spartacus CL (decrease of close to 0.5%).

The response of a variety to applied N was not a good indicator of how the same variety might respond to increasing plant density for both yield and quality traits (Table 6). For example, in terms of 2.5mm screenings, Buloke and La Trobe were the most sensitive varieties (biggest screenings increase) to increasing N, whereas Granger was the most sensitive variety to increasing plant density.



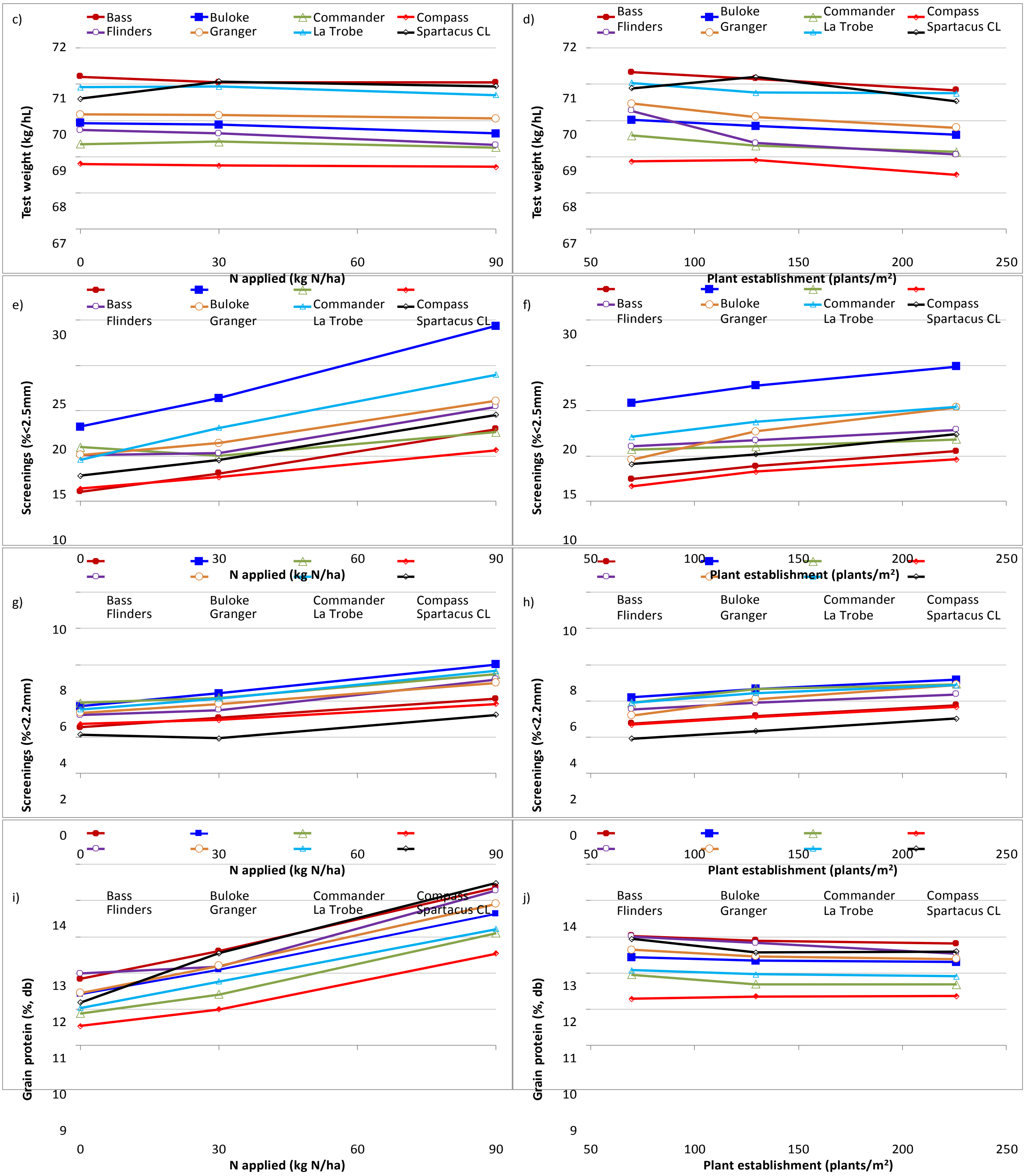


Figure 2. Grain yield and receival grain quality responses of eight barley varieties to increasing N applied or increasing plant density (plotted against established plant number) when averaged across locations.

Nitrogen and plant density interactions

In the MET analysis, N and plant density interacted to influence grain yield and grain quality (Table 3). However, at individual locations, there was only a 50% chance of an N by plant density interaction for grain yield, 2.5mm and 2.2mm screenings and a lower probability (<40%) for the other grain quality traits (Table 4).

Across all locations, the highest grain yield and highest grain protein yield were achieved with the highest inputs, being 20% higher yielding than the lowest input treatment with 40% more protein yield (Tables 7 and 8). The highest kernel weight and lowest 2.5mm and 2.2mm screenings was achieved at the lowest inputs, being 3.8 mg heavier, with 10% lower 2.5mm screenings and 3% lower 2.2mm screenings than the high input treatment. The highest grain protein was achieved at the lowest density but highest rate of applied N. Difference in grain protein between combinations of N and plant density treatments was up to 2.65%. The highest test weight was achieved at the lowest density, irrespective of the rate of applied N.

Table 7. Grain quality for each N applied and plant density treatment averaged across locations and varieties. Maximum values highlighted in bold.

	Kernel weight (mg, db)			Test weight (kg/hL)			Screenings (%<2.5mm)		
Treatment	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2
0 N	**42.1**	40.8	39.8	**70.3**	70.1	69.8	**13.2**	14.3	15.5
20-30 N	41.4	40.3	39.3	**70.3**	70.1	69.9	14.5	15.6	17.4
80-90 N	40.7	39.6	38.3	**70.3**	70.0	69.6	18.4	20.8	23.0
	Screenings (%<2.2mm)			Grain protein (%, db)			Grain protein yield (kg/ha)		
Treatment	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2
0 N	2.8	3.2	3.5	10.40	10.27	10.21	369	385	388
20-30 N	3.1	3.5	4.0	11.08	10.97	10.87	413	438	432
80-90 N	4.0	4.8	**5.7**	**12.86**	12.62	12.59	495	506	**511**

Table 8. Grain yield, per cent of samples meeting GIWA Barley Malt1 receival standards and return per ha (yield by price minus costs) for each N applied and plant density treatment averaged across locations for each variety and averaged across varieties. Maximum values highlighted in bold.

		Grain yield (t/ha)			% samples meeting GIWA Barley Malt 1 standards			Return ($/ha)		
Variety	Treatment	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2	75 plants/m^2	150 plants/m^2	300 plants/m^2
Bass	0 N	3.30	3.50	3.55	42%	40%	40%	$ 517	$ 535	$ 503
	20-30 N	3.56	3.76	3.79	38%	38%	**42%**	$ 529	**$553**	$ 517
	80-90 N	3.76	3.90	**3.94**	25%	29%	29%	$ 495	$ 512	$ 480
Buloke	0 N	3.39	3.54	3.54	**40%**	37%	29%	$ 531	$ 540	$ 490
	20-30 N	3.63	3.73	3.78	38%	37%	35%	**$ 543**	**$545**	$ 509
	80-90 N	3.77	**3.90**	**3.91**	33%	19%	19%	$ 508	$ 506	$ 460
Commander	0 N	3.56	3.75	3.75	27%	29%	21%	$ 551	$ 572	$ 519
	20-30 N	3.77	3.98	3.94	31%	35%	29%	$ 563	**$591**	$ 532
	80-90 N	3.99	**4.16**	4.13	**38%**	35%	31%	$ 557	$ 569	$ 517
Compass	0 N	3.64	3.86	4.17	33%	25%	25%	$ 557	$ 574	$ 587
	20-30 N	3.99	4.46	4.16	35%	21%	23%	$ 588	**$655**	$ 552
	80-90 N	4.19	**4.62**	4.46	38%	**42%**	38%	$ 580	$ 647	$ 569
Flinders	0 N	3.27	3.48	3.49	**40%**	35%	37%	$ 499	$ 519	$ 483
	20-30 N	3.51	3.75	3.75	33%	**40%**	**40%**	$ 507	**$545**	$ 502
	80-90 N	3.59	3.77	**3.93**	17%	21%	33%	$ 449	$ 472	$ 480
Granger	0 N	3.42	3.60	3.75	31%	27%	19%	$ 524	$ 537	$ 513
	20-30 N	3.66	3.90	3.91	**35%**	31%	31%	$ 544	**$570**	$ 522
	80-90 N	3.80	3.95	**4.05**	29%	27%	25%	$ 509	$ 518	$ 493
La Trobe	0 N	3.59	3.80	3.83	37%	25%	25%	$ 565	$ 574	$ 539
	20-30 N	3.91	4.11	4.23	**46%**	42%	35%	$ 603	**$622**	$ 594
	80-90 N	4.13	4.35	**4.40**	38%	35%	31%	$ 583	$ 609	$ 572
Spartacus CL	0 N	3.53	3.80	3.68	29%	29%	29%	$ 543	$ 579	$ 512
	20-30 N	3.46	3.93	4.06	38%	38%	**40%**	$ 501	**$581**	$ 564
	80-90 N	4.14	4.11	**4.39**	21%	33%	31%	$ 558	$ 557	$ 566
Average	0 N	3.46	3.67	3.72	35%	31%	28%	$ 536	$ 554	$ 518
	20-30 N	3.69	3.95	3.95	**37%**	35%	34%	$ 547	**$583**	$ 537
	80-90 N	3.92	4.09	**4.15**	30%	30%	30%	$ 530	$ 549	$ 517

Varietal interactions with nitrogen and plant density

Varietal response to the interaction between N and plant density was strongly influenced by location for all traits except grain yield, although it rarely occurred (Tables 3 and 4). For Bass, Buloke, Flinders, Granger, La Trobe and Spartacus CL, maximum grain yield was achieved with the highest inputs. Buloke had the lowest overall yield response to inputs at 15% compared to the other five varieties between 18-24% (Table 8). Maximum grain yield in Commander and Compass was achieved at a target density of 150 plants/m^2 and the highest rate of applied N. Compass was the most responsive variety, showing a 27% overall yield response to inputs.

The management package that maximised grain yield was not the same as that which had the highest proportion of locations meeting the GIWA Barley Malt1 receival limits for test weight, 2.5mm screenings and grain protein concentration (Table 8). The strike rate for Malt1 ranged from as low as 17% (one in ten trials) to as high as 46% (nearly one in two trials) across different N and plant density combinations for each of the eight varieties. Averaged over all treatments, Bass and La Trobe had the highest per cent of samples meet GIWA Malt1 barley receival standards. Bass and La Trobe averaged 36% and 35% respectively and the other six varieties averaged similar to each other at around 31%. The success of each variety, however, varied with rate of N applied, plant density and location.

In most varieties (except Buloke, Commander and Compass), the highest strike rate as Malt1 was achieved at the mid N treatment (20-30N), but at different plant densities depending on variety. The highest strike rate for Commander and Compass was achieved at the high N input (80-90N) and lowest density, where grain protein was maximised (as they are varieties with inherently low protein). For Buloke the highest strike rate was achieved without N and at the lowest density as this minimised 2.5mm screenings (as it is a variety with lower grain plumpness). For Bass, the highest strike rate was achieved with the mid N treatment and the highest density. This was to balance its grain protein risks (as it is a higher protein variety).

Economic analysis

An economic analysis calculating return (yield by price minus costs) was done for each variety, treatment (N and plant density combination) and location, using the assumptions in Table 9 and the current GIWA Barley receival standards. GTA was used for trials conducted in eastern Australia, even though GTA, not GIWA, barley standards are used in the east. The average return ($/ha) across all 52 locations is presented in Table 8. It should be noted that these trials were not designed to determine the optimum N and plant density package for each variety. The treatments chosen were designed to facilitate the discrimination of varietal performance rather than be economic rates of N application or farmer used plant densities. Operating costs do not consider differences between varieties in disease control that may be required and the analysis assumes all varieties can be delivered to the same bin and that Malt1, Malt2 and feed grade pricing options are available for all varieties sown.

The treatment that maximised returns per hectare was not the same as that which maximised grain yield and generally not same at that that had the highest proportion of the locations meeting the GIWA Malt1 receival standards (Table 8) or the GTA Malt1 receival standards (data not shown).

Table 9. Assumptions used in the economic analysis of the 52 national barley agronomy trials. The analysis assumes all varieties can be delivered to the same bin and that Malt1, Malt2 and feed grade pricing options are available for all varieties sown.

	Indicative cash price ($/t)			EPR ($/t)	1000 seed weight (g)	Seed rate (kg/ha) to achieve		
Variety	Malt 1	Malt 2	Feed			75 plants/m^2	150 plants/m^2	300 plants/m^2
Bass	$265	$240	$230	$3.50	45	41	86	197
Buloke	$260	$240	$230	$2.00	45	41	86	197
Commander	$260	$240	$230	$3.80	42	38	80	184
Compass	$255	$240	$230	$3.80	45	41	86	197
Flinders	$260	$240	$230	$3.80	42	38	80	184
Granger	$260	$240	$230	$2.95	45	41	86	197
La Trobe	$260	$240	$230	$4.00	42	38	80	184
Spartacus CL	$260	$240	$230	$4.25	42	38	80	184
Establishment per cent						85%	80%	70%

Barley receival + BAMA	$12.50	$/t	
Freight: farm to port	$22.50	$/t	farm to bin + bin to natural port
Seed cost	$350	$/t	
Seed dressing cost	$61	$/t	
Operating costs	$150	$/ha	fuel, P fertiliser, weed control, foliar fungicides
Urea cost	$420	$/t	
Urea spreading cost	$10	$/ha	
R&D levy	1.02%	farm gate value	

For the treatments assessed, the return of all varieties was maximised with mid N (20-30 N) and sowing at a target density of 150 plants/m^2. Compass had the highest average return, being $33/ha better than the next best variety La Trobe and $110/ha better than the lowest returning varieties Buloke and Flinders.

The loss in return from sowing at a strategy that did not optimise return varied with variety. Whilst Compass had the highest return, sowing it at a target density above or below 150 plants/m^2 caused a bigger drop in its return than the other seven varieties (-103 vs -38 $/ha at higher densities and -66 vs -31 $/ha at lower densities), although it was often still equally or more profitable at those treatments than the other varieties. Buloke had the smallest drop in return when sown lighter than 150 plants/m^2 (-2 $/ha) whilst La Trobe and Spartacus CL the smallest drop in return when sown heavier than 150 plants/m^2 (-27 and -17 $/ha respectively). This suggests that Buloke has a lower optimum target density and La Trobe has a higher optimum target density than the other varieties assessed in this study and with the treatments included. This aligns with the recommendations for target plant density in Western Australia for Buloke and La Trobe, but due to the lack of N rates and plant densities in this study around the profit maximising treatments of 20-30N and 150 plants/m^2 it is difficult to be definitive in statements about whether or not the varieties tested differ in their management packages that optimises grain yield, grain quality and net return.

Conclusion

Bass, Compass, Flinders, Granger, La Trobe and Spartacus CL differed in how they responded to management relative to the established malt varieties Buloke (= Scope CL) and Commander, with the response of each variety to management (N applied and/or plant density) trait dependent and management related (Tables 3-8 and Tables 1-2).

Spartacus CL appeared to differ from La Trobe in how it responded to management inputs even though it is a BC4 variety derived from the same cross from which La Trobe but was developed with the incorporation of the ‘imi’ gene from Scope CL. It is possible that the MET results for Spartacus CL may be un-representative due to the lower number of data points for Spartacus CL in the analysis. Spartacus CL was only sown in 21% of locations compared to at least 85% for Bass, Buloke, Commander, Granger and La Trobe. Further research is therefore required to affirm if Spartacus CL does differ to La Trobe in how it responds to management. This study suggests that, compared to La Trobe, it is not a low protein variety as N supply increases but it does have a similar grain yield response to applied N combined with slightly plumper grain and a similar test weight.

Whilst Buloke rather than Scope CL was used in this study, it should be expected that Scope CL will react similarly to Buloke to applied N and plant density. This statement is based on the similarity of their performance in National Variety Trials and barley agronomy trials in Western Australia (i.e. Paynter *et al*. 2015b).

Although we could establish that the eight varieties assessed did differ in their response to the management inputs N and plant density for most traits, varietal differences were generally small (e.g. 2.2mm screenings for applied N). However, there were rare instances where varietal response to N and plant density treatments were large (e.g. 2.5mm screenings for applied N) and these may be important factors influencing the success of a variety on farm. Although the response to increasing plant density was influenced by the amount of N applied, varieties only responded consistently differently for grain yield.

Maximising the productivity of each variety is a balancing act. An ideal variety has a high hectolitre weight, low 2.5mm and 2.2mm screenings, with a moderate grain protein concentration, a high grain brightness, doesn’t hay off at high N and is not very responsive to plant density. Although none of the varieties evaluated displayed all those characteristics, each variety assessed could be successful if one managed the strengths and weaknesses for the environment they were growing in.

For example, Compass and La Trobe are two high yielding varieties with different agronomic strengths and weaknesses. Compass is a low protein variety with poor straw strength but is highly yield responsive to applied N and has plump grain (low screenings risk when N is applied). Therefore, it will be critical to use higher levels of N to maximise grain protein, whilst managing its increased lodging risk. La Trobe is a high tillering, N responsive variety with a relatively small grain size, good straw strength and a risk of low grain protein only at high N application (compared to other varieties). Therefore, it will be critical to manage N rates to maximise yield and meet grain protein specifications without falling outside 2.5mm screenings limits.

In this study, to achieve a grain protein concentration of 10.5% a total of 46 kg N/ha was required (across all locations and plant densities, Figure 2) for Compass compared to only 19 kg N/ha for La Trobe. However, at this protein target, the grain yield of Compass was at 99% of its maximum yield (or 4.34 t/ha) with a test weight of 68.8 kg/hL and 2.5mm screenings of 9.1%, compared to 93% of maximum yield for La Trobe (or 3.98 t/ha) at 70.5 kg/hL test weight and 2.5mm screenings of 16.8%. So, to achieve the same protein target of 10.5% an extra 27 kg N/ha (= $24.73/ha) was required on the Compass crop which resulted in an extra $71.90/ha in return (due to the higher grain yield) relative to La Trobe (assuming all other costs were equal). Whilst in this study, an ideal N rate was achieved in Compass that both hit protein targets and maximised yield, in scenarios with even lower background N rates (e.g. after consecutive high yielding cereal crops), very high N rates may be required in Compass just to meet the lower limit of GIWA barley receival standards for protein (compared to higher protein varieties), and this may carry with it other negatives (e.g. lodging risk with very high N).

In this study, if lodging cost 0.1t/ha in grain yield ($25.55/ha in returns) then Compass was still more profitable than La Trobe by $21.62/ha when management was altered to deliver grain at 10.5% protein. However, if harvest losses due to lodging were to double to 0.2 t/ha (therefore $51.10/ha), then Compass would be $3.93/ha worse off than growing La Trobe to deliver the same grain protein target. In these scenarios, growers will additionally have to manage lodging risk by choosing not to apply as much additional N, to apply their N later in the season and not up-front, or to apply a plant growth regulator (PGR). Applying less N will reduce benefits in grain yield and increased grain protein concentration but may reduce lodging risk with significant N rate reductions. Cutting back the rate to the same used to deliver 3.98t/ha of La Trobe at 10.5% grain protein would reduce Compass’s grain yield to 4.10 t/ha (an advantage now of only 0.12 t/ha) at a grain protein concentration of 9.8%. In this scenario, Compass would still have an advantage of $10.70/ha over La Trobe. Applying the same amount of N but at a different timing might actually increase grain protein concentration with only a small impact on lodging risk (Paynter 2017). Whilst applying a PGR at stem elongation may or may not decrease lodging risk and impact on returns, application will cost $15-25/ha in an attempt to protect the potential $71.90 advantage in return of Compass over La Trobe.

Growers need to focus on maximising returns (yield by quality) rather than focusing on maximising yield when growing malt barley. Maximum yield and maximum receival quality rarely occurred under the same management (Table 8). Similarly maximum return and maximum yield or maximum quality rarely occurred under the same management.

This paper presents a first look at a complex and large dataset and outlines the first order observations apparent when looking at 30,000 data point dataset. The next step will be to drill down further into the dataset and look for regional differences, if they exist, in how varieties respond to management inputs. For example, locations in the west were more yield responsive to both applied N and increasing plant density in this study. How likely is it that there may be regionally specific responses to management present in this dataset not yet observed?

This study looked at a broad range of varieties over its seven years against a matrix of nine management treatments. Given that this study was focused on selecting management inputs to define differences (strengths and weaknesses) between varieties in their inherent yield and quality traits it was unable to adequately define if different management packages are required. It was only able to do this by inference rather than by evidence *per se*. To determine varietal specific optimum management for profit, more rates of N and more plant densities than used in this study are needed to assist the discrimination between varieties.

Different management packages do exist however. Here in the west we have been able to establish that malt barley varieties differ in WA in their target plant density (Paynter 2016; 2018 BVSG). In this study, an observation was made suggesting that Buloke and La Trobe may differ in their target plant density, which is line with the recommendations of Paynter (2016) and BVSG (2018), but due to the limited treatment number we could not comment further on these observations or make any additional comment on the other six varieties evaluated.

Downgrading to feed due low or high grain protein was more common than due to a low test weight or high 2.5mm and 2.2mm screenings (data not shown). At least 80% of samples met GIWA Barley Malt1 limits for test weight and at least 50% (average 69%) for 2.5mm screenings (with grain brightness not assessed in eastern Australia for this study), but only 42% (range 25-56%) of variety by N by plant density samples averaged across locations were inside the Malt1 protein window of 9.5-12.5**%.** If assessed against the GTA Barley receival standards the per cent of samples inside the Malt1 protein window of 9-12% and above the test weight standard of 65 kg/hL was similar to that when assessed against the GIWA standards, but a lower per cent of samples met plumpness standards in GIWA versus GTA specifications (69% vs 79%).

This study highlights that grain protein management is one of the more critical factors in successfully growing malt barley. The protein specification for the premium malt grade (Malt1) has a minimum grain protein concentration of 9% in the GTA standard and 9.5% in the GIWA standard, with maximums of 12% and 12.5% respectively. As there is no financial incentive to deliver barley above the minimum protein target, noting that N supply in Australian paddocks more often than not limits, rather than exceeds requirements for grain protein; most growers manage their paddock selection, rotation and N inputs to ensure they just meet the grade. This often comes at a cost to yield potential and inevitably many growers drop below the minimum target and are downgraded. One of the reasons growers are reluctant to use increased N rates on malt barley crops to increase grain protein and grain yield, aside from the extra cost, is the risk of not meeting 2.5mm screenings targets. The N management strategies for varieties with a narrow kernel and therefore a higher 2.5mm screenings risk will be more tempered than for varieties with a plumper grain and a lower 2.5mm screenings risk. With international market feedback suggesting Australian malt barley is generally too low in its grain protein concentration, there is growing pressure to lift the protein concentration of the barley shipped to international customers. Continued investment in variety specific management is therefore required to ensure Australian barley growers can meet the changing needs of international customers whilst being profitable. A shift to growing barley for yield and therefore feed is growing as the price differential between malt and feed continues to remain low whilst China is a big player in the feed barley market. As the main grain quality requirement for delivery as feed barley in WA is a minimum test weight of 56 kg/hL, going for yield can easily be achieved as there is no quality disincentive. Yield when growing feed is maximised by sowing barley at higher densities and with more N than would be applied to a crop targeted at the malt market.

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Key words

Barley, nitrogen, plant density, grain yield, grain quality, return, profit

Acknowledgments

The authors acknowledge the assistance or technical support in DAW00190 and DAW00224 of Andrea Hills, Sue Cartledge, Rod Bowey, Georgia Oliver and Rachel Brunt and the DPIRD Technical Support Units at Wongan Hills, Katanning and Esperance; in DAN00173 of Nick Moody, Rohan Brill, Daryl Reardon, Warren Bartlett, Simon Craig, Simon Goss and Rob Wheeler; and in DAN00167 of Matt Gardner, Stephen Morphett and Jim Perfrement. We also acknowledge the generous support of farmers who provided non-government land for these research trials. This research was backed by the Department of Primary Industries and Regional Development (formerly the Department of Agriculture and Food Western Australia), New South Wales Department of Primary Industry, Birchip Cropping Group and South Australian Research and Development Institute with co-funding from the Grains Research and Development Corporation. This paper was reviewed by David Ferris, DPIRD.

GRDC Project Numbers: DAW00190, DAW00224, DAN00167 and DAN00173