PROJECT 4B-103 1112: SELECTION OF
FEED WHEAT AND/OR BARLEY VARIETIES
FOR THE AUSTRALIAN PIG INDUSTRY

Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

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Executive Summary

Improving reliability and consistency in energy and protein supplies for pig diets will benefit Australian pig producers. Such benefits are likely to include: (a) reduced variation in the annual cost of pig feed, (b) reduced total cost of pig feed, (c) a wider range of feed ingredients available to more producers, and (d) a closer match of diet specifications to pig requirements. To this end, the CRC for an Internationally Competitive Pork Industry initiated an Innovative Grain Production research program. Expected outcomes of this program focused on delivering commercial quantities of cereals (and pulses) of high yield and high energy content and acceptable nutritional characteristics for pigs, with cost-effective agronomy, and appropriate marketing arrangements for grain and pig producers.

The objectives of this particular project were to determine if breeding varieties of wheat and barley specifically for the pig industry, and with enhanced yield and digestible energy (DE) content could be achieved. An additional aim was to gain a greater understanding of the nutritional characteristics of grain, in particular wheat, that affect the DE content.

This research project involved the collaborative support of Murdoch University, the Department of Agriculture and Food WA (DAFWA) and InterGrain (IG). Under the guidance of IG, breeding programs for wheat and barley lines were conducted in Southern Australia. These lines were assessed for yield as well as characteristics such as starch, protein, fibre components and DE content (using AusScan) to generate a valuable data set of wheat characteristics important to the pig industry.

This project was not able to deliver a feed wheat or barley variety that would have been commercially competitive across southern Australia. However, research findings derived from this project provided data for additional research that ultimately could be of benefit to the Australian pig and grains industries.

With regard to grain characteristics that are associated with DE content and/or DE yield and effect on variety, the following general conclusions can be made from the data analyses:

- From general analyses there was no significant correlation between yield and grain chemical characteristics;
- Faecal DE content was negatively correlated with components linked to ‘fibre’ content of grain such as arabinoxylan, ADF, and insoluble NSP;
- Site and particularly variety also had an influence on faecal DE;
- In terms of DE yield, yield contributed more than DE;
- The environment, in relation to genotype, may play a bigger role than expected and it would be useful to confirm if this is the case.

As a result of the outcomes in this study the following recommendations have been made:

1. Further research into new feed wheat and barley varieties should not be continued by the Pork CRC;
2. Current varieties that are high in DE and yield should be promoted by the pig industry;
3. Current varieties that are high in DE should be sought out by feed manufacturers;
4. Statistical analyses should be extended to provide more information on external effects such as the effect of the environment on DE.
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1. Introduction

Improving reliability and consistency in energy and protein supplies for pig diets will benefit Australian pig producers. Such benefits may include: (a) reduced variation in the annual cost of pig feed, (b) reduced total cost of pig feed, (c) a wider range of feed ingredients available to more producers, and (d) a closer match of diet specifications to pig requirements. To this end, the CRC for an Internationally Competitive Pork Industry initiated an Innovative Grain Production research program. Expected outcomes of this program focused on delivering commercial quantities of cereals (and pulses) of high yield and high energy content and acceptable nutritional characteristics for pigs, with cost-effective agronomy, and appropriate marketing arrangements for grain and pig producers.

The objectives of this particular project were to determine if breeding varieties of wheat and barley specifically for the pig industry, and with enhanced yield and digestible energy (DE) content could be achieved. An additional aim was to gain a greater understanding of the nutritional characteristics of grain, in particular wheat, that affect the DE content.

2. Methodology

2.1. Breeding high energy wheat and barley varieties

This research project involved the collaborative support of Murdoch University, the Department of Agriculture and Food WA (DAFWA) and InterGrain (IG). Under the guidance of IG, breeding programs for wheat and barley lines were conducted in Southern Australia. These lines were assessed for yield as well as characteristics such as starch, protein, fibre components and DE content (using AusScan) to generate a valuable data set of wheat characteristics important to the pig industry. Specific methodology associated with this program is presented in Appendix 1.

2.2. Statistical analyses

For digestible energy and grain yield, empirical best linear unbiased predictors (EBLUPs) for lines in a cluster were computed by Simon Diffey with the report presented in Appendix 2.

2.3. Digestible energy analyses

Grain samples, obtained from experiments outlined in Appendix 1, and conducted at the Eastern States trial sites, were sent to the NSW Department of Primary Industries, Wagga Wagga Agriculture Institute laboratory, for AusScan testing. The Western Australian samples were sent to the Department of Agriculture and Food, Grain Products Laboratory for the same NIRS analyses.

Analyses of the data included: statistical quantitative evaluation of the relative contribution of environment and genotype to variation in DE content (MJ/kg) and DE yield (GJ/ha), and identification of best varieties for DE content and yield across environments (see Appendix 3 for more information).
2.4. Identification of relevant grain characteristics

NIRS was used to assess attributes of a subset of wheat varieties/lines grown in Western Australia in the 2011/12 season including grain hardness, colour, starch composition, degree of water absorption and protein. As there are differences in grain composition depending on where and how the crops are grown, six sites in WA - Esperance, Dandaragan, Katanning, Merredin, Scaddan and Wongan Hills - were chosen to evaluate genotype by environment interactions. The environmental component was removed statistically from the analyses to give a truer indication of digestibility differences between varieties and this data was then used for analysis of grain traits. Multivariate mixed-model analyses of the Near Infared spectroscopy (NIRS) spectra from each grain sample were also completed in this experiment. Specific methodology concerning these analyses is outlined in Appendix 4.

3. Outcomes

This project was not able to deliver a feed wheat or barley variety that would have been commercially competitive across southern Australia. However, research findings derived from this project provided data for additional research that ultimately could be of benefit to the Australian pig and grains industries.

Analyses of data from this research indicated that there is an interaction between site and DE indicating that environmental factors contribute to the level of DE in grain. However, there is evidence to suggest that varying levels of DE in grain may be determined more by a variety effect than a site effect.

Moreover, the findings from this research support the NIRS testing of grain varieties destined for pig feed. In addition, analyzing the NIRS spectrum, indicated that environmental conditions at a site can have an impact on the grain quality.

4. Application of Research

4.1. Application of the research findings in the commercial world

Results suggested that DE in grain is determined by genotype and environment and hence it would be rational for pig producers to consider high DE wheat, barley and triticale varieties, subject to assessment with AusScan, when making grain purchasing decisions. By knowing the DE of varieties, producers can make better decisions about what grain to purchase and the effect on DE of mixing different varieties. This information would be relatively simple and inexpensive to obtain and could result in significant cost reductions for producers. In terms of improving NIRS calibrations methods, the results supported removing the environmental differences to enable a more accurate prediction of grain-traits than that currently available.

4.2. Opportunities uncovered by the research

To further this research a funding application has been submitted to the GRDC. The concept proposed is that more value can be obtained from NIRS fingerprints based on a focus on specific regions of the spectra and allowing for environmental variability.
Further, a project (Project 1A-111) completed in 2011 resulted in findings associated with reasons why grain growers choose to grow certain varieties and types of cereals (varieties and feed versus food), the subsequent implications for the feed grains supply chain and adoption of new feed grains within the supply chain. The outcomes from 1A-111, in association with lessons learned from 1A-109/4B-103, subsequently led to the development and consequent funding of a project in the CRC for HIAP with triticale, that will attempt to establish marketing and pricing arrangements for triticale based on its higher DE content and yield.

4.3. Adoption strategies

The main strategy to arise from this research is continued support of NIRS analyses. Results suggested that there is variation in DE in grain and by using AusScan, pig producers could better select their inputs and hence achieve a more cost effective output. With on-going development of the AusScan technology it could be expected that its associated cost will decrease and therefore accessibility should increase.

4.4. Research papers associated with this project


5. Conclusion

While the project objective of releasing up to three feed grain varieties was not fulfilled, data obtained from the trials enabled several analyses to be conducted on the grain.

With regard to grain characteristics that are associated with DE content and/or DE yield and effect on variety, the following general conclusions can be made from the data analyses:

- From general analyses there was no significant correlation between yield and grain chemical characteristics;
- Faecal DE content was negatively correlated with components linked to ‘fibre’ content of grain such as arabinoxylan, ADF, and insoluble NSP;
- Site and particularly variety also had an influence on faecal DE;
- In terms of DE yield, yield contributed more than DE;
- The environment, in relation to genotype, may play a bigger role than expected and it would be useful to confirm if this is the case.

6. Limitations/Risks

Due to time limitations, preliminary data analyses were conducted as part of this research. As there is a large data set available, additional research should be considered so as to further exploit this data. For example, across sites and seasons, why did a variety such as Cascade have the highest DE whilst relative to other varieties, its yield varied from being low to being at least comparable? This project did not provide as in depth an analysis of EGA Bonnie
Rock but it may be worth exploring this variety further? Answering such questions could provide pig producers with general information about particular varieties that would be of greater value to them in terms of DE and also importantly provide grain growers with knowledge about where best to grow such varieties.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Further research into new feed wheat and barley varieties should not be continued by the Pork CRC;
2. Current varieties that are high in DE and yield should be promoted by the pig industry;
3. Current varieties that are high in DE should be sought out by feed manufacturers;
4. Statistical analyses should be extended to provide more information on external effects such as the effect of the environment on DE.

Appendices

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Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

APPENDIX 1: PLANT BREEDING

By

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October 2012

1 This project was transferred from The CRC for an Internationally Competitive Pork Industry
Executive Summary

The CRC for an Internationally Competitive Pork Industry identified feed grains and pulses as a research priority (Program 1). In particular, research was directed towards breeding varieties of grains and pulses that could be grown in major pig production areas with the aim of securing more reliable and consistent energy (and protein) supplies for the formulation and manufacturing of pig diets. The expected outcomes of the research were a reduced variation in the annual cost of pig feed; a reduced total cost of pig feed; a wider range of feed ingredients available to more producers; and a closer match of diet specifications to pig requirements. To that end, a number of plant breeding projects were commissioned for the generation of new wheat, barley, triticale, and (or) pea varieties that contained favourable characteristics for the pig industry, such as a higher DE content.

The overall aim of this project was to explore whether new high yielding, high DE wheat and barley varieties could be found specifically for the medium to low rainfall areas of southern Australia, with the corollary objective (if successful) of delivering, in time, commercial quantities of wheat and barley of high yield and high energy content, and acceptable nutritional characteristics for pigs. Further, the research program was expected to generate outcomes that were cost-effective in terms of production with appropriate marketing arrangements for grain and pig producers. Specifically, the objectives of the project were to: identify high yielding wheat and barley lines that are not suitable for milling (i.e., the human food market), but may be better suited to livestock feeding particularly if they have a higher DE content as well as high yields; assess these lines of wheat and barley in plot trials to identify lines that may be subsequently commercialized and; identify specific lines of wheat and barley for commercial release with accompanying agronomic packages.

This project was not able to deliver a feed wheat or barley variety that would have been commercially competitive across southern Australia. However, research findings derived from this project will increase knowledge associated with feed grains and ultimately be of benefit to the Australian pig and grains industries. These findings are discussed in Appendices 2 and 3 of this report.

Results from initial trials indicated that there was a distinct possibility that an economically viable feed wheat and/or barley variety would emerge from these trials. While grain growers may consider switching milling/malting varieties that have good agronomic benefits with a minimum 3% yield advantage, they would expect for feed varieties a yield advantage of around 15-20%. However, further trials indicated that such improvements in yield, over current varieties, were not consistently achievable over the three years of this project. In addition, the increases in yield that were being achieved in the feed-only lines were being at least matched in the dual purpose lines. Again this outcome would hinder adoption of the feed only varieties.

In terms of DE, and overall, analyses suggested that there was very little variation in DE between grain varieties grown in Australia. It would also seem that there is already high DE present in the current germplasm and that differences may be caused by an environmental effect. This notion is further explored in the other appendices of this report.

While the project objective of releasing up to three feed grain varieties was not fulfilled, data obtained from the trials will provide valuable information about grain characteristics that are important for the pig and grains industries.

As commercial grain varieties were not discovered in this project there are no direct applications. However, as a result of the outcomes in this study the following recommendations have been made:

1. Further research into new feed wheat and barley varieties should not be continued by the Pork CRC
2. Current varieties that are high in DE and yield should be promoted by the pig industry.
3. Current varieties that are high in DE should be sought out by feed manufacturers.
4. Statistical analyses should be extended to provide more information on external effects on DE
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1. Introduction

The CRC for an Internationally Competitive Pork Industry identified feed grains and pulses as a research priority (Program 1). In particular, research was directed towards breeding varieties of grains and pulses that could be grown in major pig production areas with the aim of securing more reliable and consistent energy (and protein) supplies for the formulation and manufacturing of pig diets. The expected outcomes of the research were a reduced variation in the annual cost of pig feed; a reduced total cost of pig feed; a wider range of feed ingredients available to more producers; and a closer match of diet specifications to pig requirements. To that end, a number of plant breeding projects were commissioned for the generation of new wheat, barley, triticale, and (or) pea varieties that contained favourable characteristics for the pig industry, such as a higher DE content.

The overall aim of this project was to explore whether new high yielding, high DE wheat and barley varieties could be found specifically for the medium to low rainfall areas of southern Australia, with the corollary objective (if successful) of delivering, in time, commercial quantities of wheat and barley of high yield and high energy content, and acceptable nutritional characteristics for pigs. Further, the research program was expected to generate outcomes that were cost-effective in terms of production with appropriate marketing arrangements for grain and pig producers. Specifically, the objectives of the project were to: identify high yielding wheat and barley lines that are not suitable for milling (i.e., the human food market), but may be better suited to livestock feeding particularly if they have a higher DE content as well as high yields; assess these lines of wheat and barley in plot trials to identify lines that may be subsequently commercialized and; identify specific lines of wheat and barley for commercial release with accompanying agronomic packages.

2. Methodology

This project was an integrated study involving research specialists from different fields. Research trials were conducted across Australia with a maximum time limit of three years imposed upon the study.

2.1. The Project participants

This collaborative research program directly involved Murdoch University, the Department of Agriculture and Food WA (DAFWA) and InterGrain (IG). IG is a crop breeding company established as a joint venture between the Government of Western Australia, the Grains Research and Development Corporation (GRDC) and the Monsanto Company, with the aim of providing a cereal crop breeding service to the Australian grains industry. It has an Australian-wide focus with breeding sites in Western Australia (WA), South Australia (SA), Victoria (VIC), New South Wales (NSW) and Queensland (QLD), with two operational nodes, in Perth, WA, and newly established facilities in Horsham, Victoria.

2.2. Trial Site Locations

During the 2009/10 growing season and at the discretion of IG, selected wheat and barley lines (from existing genetic resources owned by IG) were allocated to trial sites across the wheatbelt of WA, and to sites in low to medium rainfall zones of SA, Victoria and NSW. Six...
trial sites were planted in south western WA, four in south eastern SA, four in south western Victoria and five in southern NSW (Figure 1).

Figure 1 The pig producing areas of Australia (shaded) and the crop trial sites for the 2009/10 season (map from Geoscience Australia, 2005; shaded area based on APL, 2005).

Key

To fit with the overall IG crop breeding program, in the following season the trial locations were slightly different although the broad geographic regions were the same. There were 19 trial sites in WA, nine sites in each of SA and Victoria, 11 trial sites in NSW and one in Tasmania (Figure 2).
Figure 2 The pig producing areas of Australia (shaded) and the trial sites for the 2010/11 season (map from Geoscience Australia, 2005; shaded area based on APL, 2005).

Key
WA:  1. Northampton; Eradu; 2. Buntine; Arrino; 3. Dandaragan; Wongan Hills; Kalannie; 4. Meckering; Bullaring; Wilgoyne; Merredin; 5. Williams; Wagin 6.: Mount Barker; Frankland; 7. Kukerin; Varley; 8. Coomalbidgup; Wittenoom Hills
SA:  9. Cummins; Rudall; 10. Jamestown; Paskeville; Urania; Balaklava; Roseworthy; 11. Geranium; Loxton
Vic:  12. Murrayville; Swan Hill; 13. Jeparit; Warracknabeal; Elmore; 14. Dahlen; Wonwondah; Lake Bolac; 15. Rutherglen
NSW:  16. Brocklesby; Lockhart; Yerong Creek; Henty; 17. Wagga Wagga; Beckom; Temora; Harden; Junee; 18. Condobolin; 19. Grenfell
Tas:  20. Campbell Town

For the 2011/12 season the trial locations were again slightly altered to fit with the overall IG crop breeding program (Figure 3).
Figure 3 The pig producing areas of Australia (shaded) and the trial sites for the 2011/12 season (map from Geoscience Australia, 2005; shaded area based on APL, 2005).

Key
SA: 9. Cummins; Lock; Rudall; 10. Paskeville; Urania; Balaklava; Spalding; 11. Geranium; Wunkar
Vic: 12. Murrayville; 13. Jeparit; Warracknabeal; Dahlen; Wonwondah; 14. Elmore; Swan Hill; 15. Streatham;

2.3. Variety Selection

There was a quota set for the number of varieties that could be selected by IG for advancement. Variety selection was based firstly on yield followed by quality (e.g. characteristics such as disease) and digestible energy (DE) content. AusScan calibrations were used to estimate starch, protein, amino acids, fat and fibre components, and the DE content of the grains. Samples from the Eastern States sites were sent to the NSW Department of Primary Industries, Wagga Wagga Agriculture Institute laboratory for testing and the WA samples were sent to the Department of Agriculture and Food, Grain Products Laboratory. At the end of each season any superior lines were identified for trialing in the following season. In this report IG barley lines are referred to as VBxxx and wheat lines as VWxxx.
2.3.1. The 2009/10 Season: Year 1

IG selected and planted 132, stage 3/4 lines of wheat (both soft and hard). With regard to barley, 25 stage 3/4 lines were planted in WA and 24 stage 3/4 lines were planted interstate. All wheat and barley lines planted were chosen based on both their high yielding potential and their unsuitability for human grain production. Two replicates were sown at each site. The CRC’s triticale variety (Berkshire), the CRC’s barley varieties (Shepherd and Grout), and commonly grown commercial wheat varieties (Magenta and Wyalkatchem) were incorporated into the field trial program.

The purpose of these trials was to find varieties that, according to agronomic (yield performance with lines equal to, or out yielding current varieties and minimum disease standards) and nutritional selection criteria, would be suitable for further investigation in the 2010/11 growing season.

2.3.2. The 2010/11 Season: Year 2

It was recommended that the project continue beyond June 2010 as suitable lines that were superior to the benchmark varieties were identified from the Year 1 trials. To improve agronomic management and increase the amount of data, the trial sites were established differently from the previous season so that barley and wheat were not necessarily located on the same sites. This meant that for instance in WA, there were 14 sites instead of 6. The total number of trials sites increased from around 20 to 42 with 11 wheat lines at 40 sites and 9 barley lines at 26 sites. Berkshire triticale (JRCT74), triticale (JRCT101) and Shepherd barley (instead of Grout) were added as controls. At least 9 new barley varieties and 10 wheat varieties were selected for additional trials.

2.3.3. The 2011/12 Season: Year 3

It was recommended that the project continue into the third year. Wheat lines were selected for trial, while barley was removed from the project because no lines that outperformed the commercial variety Hindmarsh were discovered. To avoid plot contamination, triticale was not grown. For the 2011/12 season there are 16 trial sites in WA, 9 sites in SA, 8 in each of Victoria and NSW, and none in Tasmania.

Following Diffey’s findings (see Appendix 2) data was considered in clusters so as to gain a better understanding of the results.

3. Outcomes

3.1. The 2009/10 Season

ABARE (2009) reported that despite southern NSW recording average winter rainfall, it was later than ideal for winter crops and the subsequent late sowing of crops on marginal moisture affected yield potential. Little rains, combined with hot and windy conditions in mid-September, resulted in crops suffering moisture stress in the critical spring growth phase and hence detrimentally affecting yields. Generally, November continued the dry spring conditions experienced across most of the NSW grains-belt (DPI 2009a). Rainfall patterns were generally patchy with no major falls recorded in the southern regions during spring (DPI 2009a). Late rain in the Lower Western and Riverina (15-60 mm) was too late to benefit winter crops and caused some delay with harvest (DPI 2009a)
The majority of the Mallee region (including Murrayville) received average rainfall throughout June and July, but below average rainfall in August (ABARE 2009). Winter crops in the Wimmera and Western District received above average rainfall throughout July and August (ABARE 2009). DPI (2009b) reported that Ouyen and Longerenong had average May and June temperatures, with a slightly warmer July and August. Further, Hamilton had an average May, June and July, with August being slightly warmer. In the Mallee region (incorporating Murrayville, Sea Lake and Birchip) in November temperatures were above average and the majority of the wheat escaped rain damage. In the Wimmera (incorporating Dahlen and Warracknabeal) in November the high temperatures and rainfall significantly reduced seed quality barley and delayed harvest (DPI 2009c).

ABARE (2009) reported that despite below average August rainfall, winter crops in SA were in a good position leading into spring and warmer temperatures had assisted crop growth. For the Lower Eyre Peninsula (incorporating Cummins) spring conditions were ideal for grain fill with warm northerlies, average rainfall and no serious disease or pest issues (Rural Solutions SA 2009). Rainfall was variable with average to above average falls recorded, although hail caused crop losses of up to 90% in some parts. Yield and quality of barley was variable. Balaklava in the Mid North region experienced mild conditions with above average rainfall recorded during late September. In the western part of the district, grain was of good quality. The Yorke Peninsula, incorporating Paskeville in the north, recorded several warm to hot days in the first half of September followed by cool to mild conditions, with warm to hot weather returning later in October. There were a few isolated, light frosts during September and early October with thunderstorm activity in September bringing gale force winds and scattered hail showers. Nevertheless, yields for early barley crops ranged from 2 to 5 t/ha (Rural Solutions SA 2009).

In the southern grains-belt of WA, conditions over winter were highly variable with crops in many areas showing signs of moisture stress (ABARE 2009). However, according to DAFWA (2009a), average to slightly above average rainfall over much of the WA wheatbelt in September generally increased the crop yield rankings. Further, frost events during September were not widespread (DAFWA 2009a). Yields were average to above average ranging from 2 to 3 t/ha in western areas of the Northern Agricultural Region (DAFWA 2009b). However, protein in wheat was variable and the late rainfall resulted in a slight reduction in grain quality with sprouting damage reported in the Dandaragan area (DAFWA 2009b). Barley yields were generally poor, with more than half making feed grade due to low protein and screenings (DAFWA 2009b). In the central Agricultural region (incorporating Ballaying, Bullaring and Meckering), showers and thunderstorm activity in November resulted in above average rainfall for the region but caused crop losses. Barley screenings were high across most of the region. Small seed resulted in many growers missing Malt Grade 1. The Southern Agricultural Region (incorporating Darkan and Katanning) experienced erratic temperatures with hot days and associated thunderstorms, followed by wet, cool conditions resulting in average to slightly above average rainfall across the region. High screenings and low weights in barley were reported. These, and the other quality issues, were a result of the delayed start to the season, compounded by the prevailing dry and unstable conditions during November and December (DAFWA 2009b).

Due in part to a dry spring, yields of trials located in WA, NSW and Victoria were mostly below average. Frosts, particularly at Darkan and Katanning in WA, and stripe rust in the Eastern States, also caused problems at trial sites. Hence decision making associated with variety selection was difficult because later maturing varieties were disadvantaged. In WA the difference in yield between sites was large, e.g. at Dandaragan, barley yielded 4.9 t/ha and wheat 5.5 t/ha, while at Meckering, barley yielded 1.62 t/ha and wheat 1.65 t/ha. The average yield for South Australia was around 3 t/ha while for Victoria and New South Wales it was less than 2 t/ha.
The mean yields (using meta analyses) and the faecal DE values (using NIRS analyses; AusScan) for each of the varieties are presented in Figure 4 for barley and Figure 5 for wheat. For comparison, Grout barley and Magenta and Wyalkatchem wheats are presented in the relevant figures.

**Figure 4** Average barley yields (t/ha) and corresponding faecal DE values (MJ DE/kg): Varieties were grown during the 2009/10 season at trial sites in WA ( ), SA ( ), Victoria ( ) and NSW ( ).

**Figure 5** Average wheat yields (t/ha) and corresponding faecal DE values (MJ DE/kg): Wheat varieties grown during the 2009/10 season at trial sites in WA ( ), SA ( ), Victoria ( ) and NSW ( ).
Overall the IG lines out-yielded Grout barley and Magenta and Wyalkatchem wheats. However, it is evident that seasonal conditions had a large effect on the results with yields in SA being significantly greater than the other States. Furthermore, it is good practice not to judge the performance of a variety/line from only one year of data. For example, a newly submitted variety may far out-yield an established variety (e.g. Wyalkatchem) in its first and/or second year, only to fail badly in its third. Hence it is important to consider annual results from plant breeding trials within the context of the whole plant breeding program.

In terms of faecal DE, all barley varieties in Figure 4 had a value between 12.5 and 13.3 MJ DE/kg and the values for wheat in Figure 5 were between 13.5 and 14.3 MJ DE/kg. Generally faecal DE values were higher in NSW where yields were the lowest of the four States. The faecal DE values for all new lines were generally greater than for Grout barley in all States except for Victoria. Conversely, the DE values for Magenta and Wyalkatchem wheats were greater or at least comparable to the new lines.

The resulting high coefficient of variation associated with some of the yield data was taken into consideration when interpreting the data. However, the data was considered sufficient and in accord with that required to make decisions regarding line selection. Based on the 2009/10 results five new barley lines, and 10 wheat lines were selected for additional trials in the 2010/11 season.

### 3.2. The 2010/11 Season

According to To et al. (2010a), the majority of the Eastern States winter cropping regions received average to above average autumn rainfall. The majority of winter crops in NSW were sown during the optimal planting window and into either a reasonable or a full moisture profile and in addition, there was widespread early spring rainfall (To et al. 2010b). Between 50 and 150 mm of rain recorded in August and early September across nearly all parts of Victoria resulted in one of the best starts to the winter cropping season in many years (To et al. 2010b). However further rainfall in November and early December in major cropping regions affected crop quality (reduce wheat protein levels and downgrading barley to feed quality) (To et al. 2010c). Rainfall was below average in most of Tasmania (Bureau of Rural Sciences 2010).

Autumn rainfall was average to above average across the majority of SA’s cropping regions, with timely rainfall in late May helping to replenish subsoil moisture profiles (To et al., 2010a). Rainfall in July was below average in most of the SA cropping areas, while August rainfall was mostly above average and there was good follow up rainfall in early September (To et al. 2010b). Average rainfall results were recorded for October (To et al. 2010c).

In WA, below average autumn rainfall following a dry summer resulted in winter crop prospects being less positive (To et al., 2010a). To et al. (2010c) reported that after a dry autumn and start to winter, parts of the Geraldton region received above average rainfall in August with below average rainfall in spring. In the central wheatbelt, rainfall was mostly below average throughout the growing season and rainfall in the Albany zone was generally average in the coastal areas but below average further inland. The Esperance zone had above average rainfall in May, followed by average to below average monthly rainfall until November.

Despite harsh growing and/or harvesting conditions over much of Australia during the 2010/11 season, only seven trials sites were not harvested. Stem rust, stripe rust and locusts may have caused yield reductions at some sites. In NSW there were some record wheat yields but crop quality was affected by heavy rainfall with widespread flooding resulting in crops being lost or suitable for stock feed purposes only. Five sites in NSW were classified as being good to excellent with five other sites negatively affected by the climatic conditions.
Damage caused by sprouting was visually evident at some locations, e.g., Grenfell. Above average rainfall during the barley growing season produced a mean expected yield of 2.9 t/ha, (above the 10-year average of 1.6 t/ha), however, rainfall at harvest time resulted in more feed grade barley being produced than in previous seasons (To et al. 2010c). Seven project sites in Victoria were classified as being good to excellent with an acceptable quality. There were issues with the yield at Dahlen and the site at Rutherglen was not harvested due to waterlogging problems. The barley site at Campbell Town in Tasmania was lost due to contractor error. All nine project sites in SA were deemed good to excellent. Wheat yields were expected to average 2.5 t/ha (although protein levels were expected to be down) and average barley yields were forecast to be a record 2.6 t/ha, double the five-year average of 1.64 t/ha (To et al. 2010c). In general, it was very dry in WA, with some project sites not harvested because of this e.g. Varley. In WA six project sites were classified as good to excellent. Yield was compromised at four sites due to adverse climatic conditions and five sites were not harvested because of the drought. Berkshire triticale was expected to out-yield wheat and barley at some sites as it has more resistance to dry conditions.

Based on trial results none of the barley varieties examined in 2010/11 were consistently better yielding than existing varieties, especially Hindmarsh (Figure 6). Further, DE content, for the new barley lines varieties considered in this project, was not significantly different from current varieties (Figure 7).

**Figure 6** Average yields (t/ha) for barley varieties grown during the 2010/11 season: Trial sites in WA ( ), SA ( ), Victoria ( ), and NSW ( ).
Figure 7 Average yields (t/ha), as a percentage of Hindmarsh, for barley varieties grown during the 2010/11 season:
Trial sites situated in WA ( ), SA ( ), Victoria ( ) and NSW ( ).

Overall, the new wheat lines did well with VW112, VW113 and VW114 lines having a yield advantage of around 15% over current varieties (see Figures 8, 9 and 10). As a note, Berkshire triticale was comparable in yield to the Yitpi and Wyalkatchem wheat varieties.

Figure 8 Average yields (t/ha), as a percentage of Wyalkatchem, for wheat varieties:
Grown during the 2010/11 season at trial sites in WA ( ), SA ( ) and Victoria ( ).
**Figure 9** Average yields (t/ha), as a percentage of *Yitpi*, for wheat varieties:
Grown during the 2010/11 season at trial sites in WA (●), SA (■) and Victoria (○).

**Figure 10** The average yields (t/ha), as a percentage of *Ventura*, for wheat varieties grown during the 2010/11 season at trial sites in NSW.

Using the WA trials as an example, when compared to *Yitpi* and *Wyalkatchem*, the results suggested that the new wheat lines did not have an advantage in DE (Figure 11).
By achieving a 15% yield increase for a potential feed variety it was deemed that there was reason to continue investigating that variety. In addition, varieties due for release (especially dual purpose and those in the NVT) should be monitored and existing varieties that are particularly suited to the pig industry should be promoted. It was also recommended not to continue with any barley line for the 2011/12 season and instead reallocate funding to priority areas for wheat.

3.3. The 2011/12 Season

There was a good start to the 2011/12 winter cropping season in the Eastern States and much of WA with rainfall received over summer and autumn having replenished soil moisture profiles and provided a good foundation for crop establishment and early growth (Agbenyegah et al. 2011a).

In NSW, most winter crops were sown into excellent subsoil moisture during the optimal planting window. Late winter rainfall across southern and central NSW significantly improved prospective yields, particularly in the Riverina and across the southern slopes (Agbenyegah et al. 2011b). Spring rainfall in the majority of the winter cropping regions improved yield prospects, particularly in the central cropping areas (Fell et al. 2011).

Growing conditions over winter and early spring were generally favourable for most of Victoria. August rainfall in the major cropping regions was average to above average (Agbenyegah et al. 2011b), while that falling in September was generally below average. However rainfall increased to average to above average in October and November, the period when grain filling occurs (Fell et al. 2011). According to Fell et al. (2011), the outlook for crop yields was expected to be favourable in most regions although wheat protein levels may be lower than normal.

Due to good early rainfall, the majority of winter crops in SA were sown during the optimal planting window (Agbenyegah et al. 2011b). Whilst most of SA’s major cropping regions
received below average rainfall in September, rainfall in October ensured good growing conditions with high yield potential for most crops (Fell et al. 2011). No major disease outbreaks were reported in wheat crops but protein levels were generally down on normal (Fell et al. 2011).

Winter rainfall across the WA grain belt was generally average but enough to boost the relatively low soil moisture profiles in most areas; subsequently, crop growth was favourable in many regions (Agbenyegah et al. 2011b). Most major cropping regions in WA received above average spring rainfall with the heaviest falls being recorded in the Geraldton and Kwinana regions (Fell et al. 2011). Due to late rains the quality of some mature crops was down with lower starch content and sprouting (Fell et al. 2011). In contrast the rain was beneficial for less mature crops in the Kwinana and Albany growing regions and particularly timely in the Esperance region, where conditions were drier than average during winter and early spring (Fell et al. 2011).

Overall and in terms of yield, it was a good year for experimental data across all trial sites. Late rains resulted in some sprouting. Two varieties in the feed wheat family showed potential as high yielding, high DE lines across a range of data collected from the 2009/10, 2010/11 and 2011/12 seasons. Results indicated that VW111 and VW114 had a consistent yield advantage over most currently released varieties (Figure 12).

![Figure 12](image)

**Figure 12** The yield of various varieties for different clusters:

Current varieties, Cascades (●), EGA Bonnie Rock (●), Wyalkatchem (●) and Yipi (●), did not have a general yield advantage over new lines VW111 (●) and VW114 (●) for each of 7 clusters: 1, predominantly poor WA sites from 2010 and 2011, mixture of ES sites; 2, poor WA sites across all years; 3, low yield, 2009 ES drought year; 4, 2009 and 2010 NSW sites; 5, high yield, mixture of ES sites; 6, high yield, 2011, mixture of ES sites; 7, predominantly 2011 high yielding WA sites.

VW114 performed better in WA and SA, while VW111 performed best in Victoria and NSW. Figure 13 illustrates the yield advantage of VW114 and VW111 over popular varieties from the NVT MET dataset (Appendix 1). The NVT data indicated a maximum 6% yield advantage of the lines over released varieties. The InterGrain data indicated more favourable yield advantages, especially in Victoria, but it should be noted that the dataset is from a restricted number of years (3 compared to 7). For the purposes of marketing, the NVT dataset should be used.
Figure 13 Yield advantage of new lines:
Yield advantage for lines VW111 (△) and VW114 (○) is calculated: from NVT MET data (2005–2011) (△) as the difference between the line and the maximum value from selected varieties; from InterGrain MET data (2009–2011) (○) as the difference between the line and the maximum value from control varieties used in the trial series.

Even so, these lines did not end up consistently showing enough potential as feed wheat varieties to compete in the market place. In addition, an established variety, Cascade, was found to have a higher DE than these two varieties (Figure 14).

Figure 14 The digestible energy of various varieties for different clusters:
Current varieties, Cascades (○), EGA Bonnie Rock (△), Wyalkatchem (△) and Yitpi (△) generally had a DE advantage over IG new lines VW111 (□) and VW114 (○) for each of 6 clusters: 1, Poor yielding WA sites, mainly from 2010 (drought year); 2, SA 2011, WA 2011, mixture of 2009 sites; 3, Higher yielding VIC 2010 sites (plus 2 northern WA 2011 sites); 4, High yielding 2010 sites from NSW (plus 2 from VIC); 5, Good yield, mainly VIC 2011 sites, with 3 2009 SA and 2 WA 2011 sites; 6, Good yield, predominantly NSW and WA 2011 sites.
4. Application of Research

This project was not able to deliver a feed wheat or barley variety that would have been commercially competitive across southern Australia. However, research findings derived from this project will increase knowledge associated with feed grains and ultimately be of benefit to the Australian pig and grains industries. These findings are discussed in Appendices 2 and 3 of this report.

5. Conclusion

Results from initial trials indicated that there was a distinct possibility that an economically viable feed wheat and/or barley variety would emerge from these trials. While grain growers may consider switching milling/malting varieties that have good agronomic benefits with a minimum 3% yield advantage, they would expect for feed varieties a yield advantage of around 15-20%. However, further trials indicated that such improvements in yield, over current varieties, were not consistently achievable over the three years of this project. In addition, the increases in yield that were being achieved in the feed-only lines were being at least matched in the dual purpose lines. Again this outcome would hinder adoption of the feed only varieties.

In terms of DE, analyses suggested that there was very little variation in DE between new lines grown in Australia. That is, it would also seem that there is already high DE present in the current germplasm and that differences may be caused by an environmental effect. This notion is further explored in the other appendices of this report.

While the project objective of releasing up to three feed grain varieties was not fulfilled, data obtained from the trials will provide valuable information about grain characteristics that are important for the pig and grains industries.

6. Limitations/Risks

As commercial grain varieties were not discovered in this project there are no direct applications.

7. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Further research into new feed wheat and barley varieties should not be continued by the Pork CRC;
2. Current varieties that are high in DE and yield should be promoted by the pig industry;
3. Current varieties that are high in DE should be sought out by feed manufacturers;
4. Statistical analyses should be extended to provide more information on external effects on DE.
8. References


http://www.dpi.vic.gov.au


http://www.abares.gov.au


Appendices

Appendix 1a:

Table A 1  NVT MET results 2005–2011 for a selection of popular varieties across regions. Highlighting indicates site mean yields above 110%.

| Region | N/E | N/W | S/E | S/W | Lower EP | Mid North | Murray Mallee | South East | Upper EP | Yorke P | Mallee | North Central | North East | Wimmera | Agzone1 | Agzone2 | Agzone3 | Agzone4 | Agzone5 | Agzone6 |
|--------|-----|-----|-----|-----|---------|-----------|--------------|------------|----------|---------|--------|-------------|-----------|----------|---------|---------|---------|---------|---------|---------|---------|
| NSW    | 99  | 98  | 96  | 96  | 106     | 107       | 112          | 105       | 108     | 105    | 105   | 107         | 102       | 109     | 105    | 108    | 105    | 110    | 105    | 105    |
| VIC    | 106 | 101 | 107 | 104 | 106     | 103       | 108          | 103       | 107     | 104    | 107   | 100         | 102       | 108     | 107    | 105    | 108    | 106    | 108    | 105    |
| WA     | 108 | 104 | 104 | 103 | 107     | 106       | 112          | 103       | 108     | 106    | 106   | 104         | 102       | 108     | 103    | 108    | 103    | 105    | 104    | 108    | 105    |
PROJECT 4B-103 1112: SELECTION OF FEED WHEAT AND/OR BARLEY VARIETIES FOR THE AUSTRALIAN PIG INDUSTRY

Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

APPENDIX 2: STATISTICAL CONSULTING REPORT

By

Simon Diffey

October 2012
Selection of feed wheat and barley varieties for the Australian pig industry

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August 14, 2012
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1 Introduction

This report has been compiled for Dr Dan Mullan (Wheat Breeder, InterGrain Pty Ltd). The data arises from a Pork CRC project where the aim was to select lines within an existing breeding programme that had higher levels of digestible energy (DE). DE values were obtained by applying near infrared (NIR) technology to grain samples and their unit of measurement is a megajoule (MJ).

Besides digestible energy another trait of interest is digestible energy yield (DE Yield). DE Yield is calculated as the product of digestible energy and grain yield, where grain yield has been measured in tonnes per hectare (t/ha). The unit of measurement for DE Yield is gigajoules per hectare (GJ/ha).

A defining feature of the data is the sampling scheme used to obtain grain samples for the measurement of DE. This and other features of the data are discussed next.
2 Experimental design

The data consists of three years of trials with a different sampling scheme in each year for obtaining grain samples used to measure DE. The sampling scheme is summarised below for each year.

- 2009 - all trials comprised 2 replicates of multiple lines of wheat and barley, and a single line of triticale named Berkshire. Grain yield was measured on all plots. DE was obtained for every line by measuring a grain sample that was a composite of the two plots for that line.

- 2010 - all trials comprised 4 replicates of multiple wheat lines and the triticale line Berkshire. Grain yield was measured on all plots. DE was measured on all plots of a selection of wheat lines and the triticale line Berkshire.

- 2011 - trials comprised wheat lines only. Grain yield and DE was measured on all plots in replicate 1 only.

Table 2.1 provides the number of trials, species, and the number of lines of each species that make up the data for digestible energy. In 2009 all lines measured for DE appear in all trials. In 2010 the least number of trials a breeding line appears in is 7 and most appear in 17 or more trials. In 2011 the least number of trials a breeding line appears in is 8 and most appear in at least 16 trials. The number of breeding line concurrences between the three years for digestible energy is provided in Table 2.2.
Table 2.1: Digestible energy data summarised by the number of trials, species, and the number of lines of each species. Note that the summary for grain yield is the same with the exception that in 2010 there was data on 60 lines of wheat compared to 25 for digestible energy.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of trials</th>
<th>Species (and number of lines)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>19</td>
<td>Barley (31), Wheat (28), Triticale (1)</td>
</tr>
<tr>
<td>2010</td>
<td>26</td>
<td>Wheat (25), Triticale (1)</td>
</tr>
<tr>
<td>2011</td>
<td>41</td>
<td>Wheat (90)</td>
</tr>
</tbody>
</table>

Table 2.2: Number of breeding line concurrences between three years for digestible energy. For grain yield the number of lines increases from 26 to 61 in 2010 and the number of concurrences between 2010 and 2011 changes from 13 to 33.

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>15</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>6</td>
<td>13</td>
<td>90</td>
</tr>
</tbody>
</table>
3 Statistical Methods

The digestible energy and grain yield data can generally be described as multi-environment trial (MET) data. It consists of 86 environments (comprising site by year combinations) and a total of 148 and 163 lines for digestible energy and grain yield respectively. We have used the mixed model approach described by Smith et al. (2001) where the line by environment effects are modelled using factor analysis. A series of factor analytic models of order $k$ (FA-$k$) were fitted to the digestible energy and grain yield data.

The REML log-likelihood associated with each of the models fitted to the digestible energy data is presented in Table 3.1. Based on a residual maximum likelihood ratio test the factor analytic model of order 4 (FA-4) was selected as providing the most parsimonious fit to the data. This model explained approximately 80% of the genetic variation. The REML log-likelihood associated with each of the models fitted to the grain yield data is presented in Table 3.2. Based on a residual maximum likelihood ratio test the factor analytic model of order 6 (FA-6) was selected as providing the most parsimonious fit to the data. This model explained approximately 89% of the genetic variation.

The package asreml (Butler et al., 2007) for the statistical computing software R (R Development Core Team, 2011) was used to fit all models. The R call to asreml for the factor analytic models of order 4 and 6 fitted to the digestible energy data and grain yield data respectively is provided in the appendix.
Table 3.1: REML log-likelihood (RLL) associated with a series of factor analytic models of order \( k \) (FA-\( k \)) fitted to the digestible energy data. Also provided is the \( p \)-value associated with a residual maximum likelihood ratio test (REMLRT) of FA-(\( k+1 \)) versus FA-\( k \) and the amount of genetic variation explained by the factor analytic model.

<table>
<thead>
<tr>
<th>FA-( k )</th>
<th>RLL</th>
<th>REMLRT ( p )-value</th>
<th>% genetic var. expl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA-1</td>
<td>8944.93</td>
<td>&lt;0.001</td>
<td>66</td>
</tr>
<tr>
<td>FA-2</td>
<td>9092.83</td>
<td>&lt;0.001</td>
<td>74</td>
</tr>
<tr>
<td>FA-3</td>
<td>9179.86</td>
<td>&lt;0.001</td>
<td>77</td>
</tr>
<tr>
<td>FA-4</td>
<td>9201.53</td>
<td>&lt;0.001</td>
<td>80</td>
</tr>
<tr>
<td>FA-5</td>
<td>fail</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

Table 3.2: REML log-likelihood (RLL) associated with a series of factor analytic models of order \( k \) (FA-\( k \)) fitted to the grain yield data. Also provided is the \( p \)-value associated with a residual maximum likelihood ratio test (REMLRT) of FA-(\( k+1 \)) versus FA-\( k \) and the amount of genetic variation explained by the factor analytic model.

<table>
<thead>
<tr>
<th>FA-( k )</th>
<th>RLL</th>
<th>REMLRT ( p )-value</th>
<th>% genetic var. expl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA-1</td>
<td>7140.82</td>
<td>&lt;0.001</td>
<td>39</td>
</tr>
<tr>
<td>FA-2</td>
<td>7521.27</td>
<td>&lt;0.001</td>
<td>55</td>
</tr>
<tr>
<td>FA-3</td>
<td>7726.90</td>
<td>&lt;0.001</td>
<td>72</td>
</tr>
<tr>
<td>FA-4</td>
<td>7833.26</td>
<td>&lt;0.001</td>
<td>78</td>
</tr>
<tr>
<td>FA-5</td>
<td>7982.82</td>
<td>&lt;0.001</td>
<td>83</td>
</tr>
<tr>
<td>FA-6</td>
<td>8121.93</td>
<td>&lt;0.001</td>
<td>89</td>
</tr>
<tr>
<td>FA-7</td>
<td>fail</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>
The tools described in Cullis et al. (2010), i.e., the dendrogram and heatmap, can be used to explore the estimated genetic correlations for digestible energy and grain yield. The function `agnes()` from the R package `cluster` (Maechler et al., 2012) was used to form the dendrogram (Figure 4.1 and Figure 4.3) and to order environments in the heatmap of genetic correlations (Figure 4.2 and Figure 4.4). For each trait these graphs should be investigated to determine if environments can be grouped into biologically sensible clusters. Determining meaningful clusters is a key step as an empirical best linear unbiased predictor (EBLUP) for a line in a cluster can be computed to assess line performance.
4 Results

4.1 Digestible Energy (MJ)

The dendrogram and heatmap based on the estimated genetic correlations from the FA-4 model for digestible energy are provided in Figure 4.1 and Figure 4.2 respectively.
Figure 4.1: Dendrogram of the dissimilarity matrix for estimated genetic correlations based on the FA-4 model for digestible energy.
Figure 4.2: Heatmap of estimated genetic correlations based on the FA-4 model for digestible energy. The dendrogram in Figure 4.1 has been used to determine the order of environments in the heatmap.
4.2 Grain yield (t/ha)

The dendrogram and heatmap based on the estimated genetic correlations from the FA-6 model for grain yield are provided in Figure 4.3 and Figure 4.4 respectively.

Figure 4.3: Dendrogram of the dissimilarity matrix for estimated genetic correlations based on the FA-6 model for grain yield data.
Figure 4.4: Heatmap of estimated genetic correlations based on the FA-6 model for grain yield. The dendrogram in Figure 4.3 has been used to determine the order of environments in the heatmap.
Based on the heatmaps and dendrograms presented in Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4 Dr Dan Mullan has grouped environments into clusters (mega-environments) for both digestible energy and grain yield. These clusters are presented in Table A.1 in the Appendix. Clusters are labelled numerically, however their biological interpretation is provided in Table 4.1. Although digestible energy and grain yield clusters don’t align exactly it is the view of Dr Dan Mullan that there is sufficient similarities for a lines DE Yield to be calculated as the product of that lines EBLUP for digestible energy in a particular cluster and the grain yield EBLUP in a similar cluster.

Table 4.1: Description of digestible energy and grain yield clusters (mega-environments). Note that the abbreviation ES stands for eastern states.

<table>
<thead>
<tr>
<th>cluster</th>
<th>grain yield</th>
<th>digestible energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>mainly poor WA 2010, 2011 sites and some ES states</td>
<td>poor yielding WA sites, mainly from 2010</td>
</tr>
<tr>
<td>2</td>
<td>1 site only</td>
<td>SA 2011, WA 2011, mix of 2009 sites</td>
</tr>
<tr>
<td>3</td>
<td>poor WA sites over all years</td>
<td>high yielding VIC 2010 sites plus 2 WA 2011 sites</td>
</tr>
<tr>
<td>4</td>
<td>low yielding 2009 ES sites</td>
<td>high yielding NSW 2010 sites plus 2 VIC sites</td>
</tr>
<tr>
<td>5</td>
<td>2009, 2010 NSW sites</td>
<td>good yield, VIC 2011 sites plus 3 SA 2009 and 2 WA 2011 sites</td>
</tr>
<tr>
<td>6</td>
<td>high yield, mix of ES sites</td>
<td>good yield, mainly NSW and WA 2011 sites</td>
</tr>
<tr>
<td>7</td>
<td>high yield, 2011, mix of ES sites</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1 site only</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>mainly 2011 high yielding WA sites</td>
<td></td>
</tr>
</tbody>
</table>

For digestible energy and grain yield empirical best linear unbiased predictors (EBLUPs) for lines in a cluster have been computed. These have been provided in the files `de_wheat_clusters_pred.csv` and `yld_wheat_clusters_pred.csv` for digestible energy and grain yield respectively.
Bibliography


A Appendix

FA-4 model for digestible energy

```r
> de.fs4.asr <- asreml(FEE ~ 1 + Env + Species +
+   Env:Species + at(Env2010, c("ARR2010", "TND2010"),
+   "KAT2010", "TEM2010")) 1:2010, random = "fa(Env,
+   4):Name + at(Env2010):Rep + at(Env2010, "GRF2010")::idv(Row):ari(Column) +
+ at(Env2010_lessGRF):Row:Column, family = asreml.gaussian(dispersion = 1e-04),
+ na.method.X = "include", data = all, control = asreml.control(maxiter = 25,
+   stepsizes = 1e-06), R.param = "C:/simon/SAPI/mullan/eweave/allFA4iv.csv",
+ C.param = "C:/simon/SAPI/mullan/eweave/allFA4iv.csv"
>
for (i in 1:25) {
  cat("\nUPDATE", i, \n"
  de.fs4.asr <- update.asreml(de.fs4.asr)
+ if (de.fs4.asr$converge == TRUE)
+   break
+ }
```

FA-6 model for grain yield

```r
> yld.fs6.asr <- asreml(Yield ~ 1 + Env + Species +
+   Env:Species + at(Env, ir.ali):ir + at(Env,
+   ir.ali):ir, random = "fa(Env, 6):Name + at(Env):Rep,
+   rcoy = "at(Env, spatial.ali):ari(Column):ari(Row),
+   data = yld.ali, na.method.X = "include", control = asreml.control(maxiter = 100,
+     stepsizes = 1e-14, workspace = 5:12e+06),
+   R.param = "C:/simon/SAPI/mullan/eweave/yldallFA6iv.csv",
+   C.param = "C:/simon/SAPI/mullan/eweave/yldallFA6iv.csv"
```
Clusters (mega-environments) for digestible energy and grain yield

Table A.1. Clusters (mega-environments) for digestible energy and grain yield

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PROJECT 4B-103 1112: SELECTION OF FEED WHEAT AND/OR BARLEY VARIETIES FOR THE AUSTRALIAN PIG INDUSTRY

Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

APPENDIX 3: DIGESTIBLE ENERGY

By

Jae Kim, Jo Pluske, and John Pluske.

October 2012
Executive Summary

Factors, such as climate, growing locality, wheat variety, post-harvest storage, exogenous enzyme supplementation, grain processing and carbohydrate characteristics may contribute to variation in wheat DE content (van Barneveld, 1997). A review by Kim et al. (2005) found that the chemical composition of wheat was influenced by the variety and the growing environment, e.g., soil types, agronomic practices, precipitation level and the growing season. The extent of variation in chemical composition of wheat can then be an indicator of the nutritive value of wheat, such as the DE content (Kim et al. 2005). Van Barneveld (1999) suggested that variation in DE content can be up to 3.7 MJ/kg DM. Such wide variation in wheat energy value is of importance to the feed manufacturing industry because precise formulation and optimal utilisation of feed ingredients are the key factors in terms of the efficient conversion of feed to meat (Kim et al. 2005).

The objective of this part of the project was to use the extensive data set accumulated from the Plant Breeding Trials (as outline in Appendix 1) to further explore the relationship of DE with other characteristics associated with the grain and those external to it.

Analyses of data from this research indicated that there is an interaction between site and DE indicating that environmental factors contribute to the level of DE in grain. However, there is evidence to suggest that varying levels of DE in grain may be determined more by a variety effect than a site effect. If this is the case then it would be rational for pig producers to consider high DE wheat, barley and triticale varieties when making grain purchasing decisions. Further, experiments conducted within PGLP (see Appendix 3a) suggested that the energy content of sprouted grains for animals is not decreased and in some circumstances may be increased when compared with non-sprouted grain.

The findings from this research support the NIRS testing of grain varieties destined for pig feed. If the DE of varieties is known then producers can make better decisions about what grain to purchase and the effect on DE of mixing different varieties. This information would be relatively simple and inexpensive to obtain and could result in significant cost reductions for producers.

With regard to grain characteristics that are associated with DE content and/or DE yield and effect on variety, the following general conclusions can be made from the data analyses:

- There was no significant correlation between yield and grain chemical characteristics.
- Faecal DE content was negatively correlated with components linked to the ‘fibre’ content of grain such as arabinoxylan, ADF, and insoluble NSP.
- Site and particularly variety also had an influence on faecal DE.
- In terms of DE yield per hectare, yield contributed more than DE.
- The environment, in relation to genotype, may play a bigger role than expected and it would be useful to confirm if this is the case.

Findings from this research clearly demonstrate the need for further research in this area with the focus directed towards relevant analyses of varieties commonly grown by grain producers.
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1. Introduction

Factors, such as climate, growing locality, wheat variety, post-harvest storage, exogenous enzyme supplementation, grain processing and carbohydrate characteristics may contribute to variation in wheat DE content (van Barneveld, 1997). A review by Kim et al. (2005) found that the chemical composition of wheat was influenced by the variety and the growing environment, e.g., soil types, agronomic practices, precipitation level and the growing season. The extent of variation in chemical composition of wheat can then be an indicator of the nutritive value of wheat, such as the DE content (Kim et al. 2005). Van Barneveld (1999) suggested that variation in DE content can be up to 3.7 MJ/kg DM. Such wide variation in wheat energy value is of importance to the feed manufacturing industry because precise formulation and optimal utilisation of feed ingredients are the key factors in terms of the efficient conversion of feed to meat (Kim et al. 2005).

The objective of this part of the project was to use the extensive data set accumulated from the Plant Breeding Trials (as outline in Appendix 1) to further explore the relationship of DE with other characteristics associated with the grain and those external to it.

2. Methodology

Grain samples, obtained from experiments outlined in Appendix 1, and conducted at the Eastern States trial sites, were sent to the NSW Department of Primary Industries, Wagga Wagga Agriculture Institute laboratory, for AusScan testing. The Western Australian samples were sent to the Department of Agriculture and Food, Grain Products Laboratory for the same NIRS analyses.

Given Diffey’s findings (see Appendix 2), some of the data collected during the plant breeding experiment (see Appendix 1) were considered in clusters.

The final two InterGrain lines of most interest (derived from Appendix 1) are referred to in this report as VW111 and VW114.

Analyses of the data included: statistical quantitative evaluation of the relative contribution of environment and genotype to variation in DE content (MJ/kg) and DE yield (GJ/ha), and identification of best varieties for DE content and yield across environments.

3. Outcomes

3.1. Relationships between DE and other characteristics in grain

Results from the 2009/10 season indicated that the yield of wheat, barley and triticale was not associated with DE or NDF (Figures 1 to 2) but DE was negatively related to the various definitions of fibre in grains (Figures 3 to 7).
**Figure 1** Relationship between yield and faecal DE: 2009/10 season ($r = -0.2224$)

**Figure 2** Relationship between faecal DE and NDF content: 2009/10 season ($r = -0.82$)
Figure 3 Relationship between faecal DE and soluble NSP content: 2009/10 season (r = -0.80)

Figure 4 Relationship between faecal DE and Beta-glucans content: 2009/10 season (r = -0.79)
Figure 5 Relationship between faecal DE and crude fibre content: 2009/10 season
(r = -0.76)

Figure 6 Relationship between faecal DE acid detergent fibre content: 2009/10 season
(r = -0.76)
Figure 7 Relationship between faecal DE and insoluble NSP content: 2009/10 season
\( r = -0.73 \)

Analyses on data collected from the 2010/11 season again suggested that DE content of wheat was not associated with yield (Figure 8) and CP content was positively related to the DE content of wheat (Figure 9).

Figure 8 The relationship between faecal DE content and wheat yield: 2010/11 season.
Figure 9 The relationship between faecal DE content and crude protein: 2010/11 season

These findings were further substantiated by analyses completed on wheat data collected from the 2011/12 season. Faecal DE content was negatively correlated with arabinoxylan, ADF, and insoluble NSP (Figures 10 to 12). However, it was positively correlated with total protein content (Figure 13).

Figure 10 Relationship between faecal DE (MJ/kg) content of wheat and arabinoxylan content: 2011/12 season (y = 14.626 - 0.122 *X, R^2= 0.5, P<0.001).
Figure 11 Relationship between Faecal DE (MJ/kg) content of wheat and ADF content: 2011/12 season (y = 14.593 - 0.189 * X, R^2= 0.202, P<0.001).

Figure 12 Relationship between Faecal DE (MJ/kg) content of wheat and total insoluble NSP content: 2011/12 season (y = 14.724 - 0.087 * X, R^2= 0.351, P<0.001).
To investigate DE further, 2010/11 and 2011/12 seasonal data were combined and analysed. Again the faecal DE content was negatively correlated with arabinoxylan, and insoluble NSP (Figures 14 to 15).

**Figure 13** Relationship between Faecal DE (MJ/kg) content of wheat and NIR grain protein content: 2011/12 season ($y = 13.03 - 0.088 \times X$, $R^2= 0.47$, $P<0.001$).

**Figure 14** Relationship between Faecal DE (MJ/kg) content of wheat and arabinoxylan content: 2010/11 and 2011/12 seasonal data ($y = 14.70 - 0.15$, $R^2= 0.47$, $P<0.001$) (with 95% confidence limits).
Figure 15 Relationship between Faecal DE (MJ/kg) content of wheat and insoluble NSP content: 2010/11 and 2011/12 seasonal data
(y = 14.7 - 0.09, R^2= 0.39, P<0.001) (with 95% confidence limits).

3.2. The relationship between trial site, variety and DE

NIRS analyses indicated that for the combined 2010/11 and 2011/12 seasonal data, yield and faecal DE were negatively correlated (r = -0.310). This result was supported by further analyses of a range of data sets for wheat data collected from the 2009/10, 2010/11 and 2011/12 seasons, demonstrating the relationship between yield and the DE content of wheat across sites in WA, NSW and Victoria (Figure 16). In addition, results suggested that factors associated with site may have influenced DE content (Figure 16).
Figure 16  The relationship between yield (■ columns) and the DE content (■ dots) of wheat across a range of sites (DND, MKR in WA; GRF, WWG, BEC, LKH in NSW; MVL, DHN in Vic) based on data collected from the 2009/10, 2010/11 and 2011/12 seasons.

Cluster analyses of a range of data sets for wheat indicated that the effect of variety appeared to influence DE content more than the site effect (Figure 17). For example, despite the site and environmental conditions, the variety Cascade had the highest DE for any cluster (Figure 17).
Figure 17 The DE content of various varieties for different clusters: Current varieties, Cascades (■), EGA Bonnie Rock (□), Wyalkatchem (▲) and Yitpi (●); new lines, VW111 (●) and VW114 (■) for each of 6 clusters: 1, Poor yielding WA sites, mainly from 2010 (drought year); 2, SA 2011, WA 2011, mixture of 2009 sites; 3, Higher yielding VIC 2010 sites (plus 2 northern WA 2011 sites); 4, High yielding 2010 sites from NSW (plus 2 from VIC); 5, Good yield, mainly VIC 2011 sites, with 3 2009 SA and 2 WA 2011 sites; 6, Good yield, predominantly NSW and WA 2011 sites.

When considering the DE x yield interaction (MJ per hectare) in cluster analyses of a range of data sets for wheat, it is evident that yield had a greater influence on the level of DE/ha than did DE (Figure 18).

Figure 18 The DE Yield per hectare of various varieties for different clusters: Current varieties, Cascades (■), EGA Bonnie Rock (□), Wyalkatchem (▲) and Yitpi (●); new lines VW111 (●) and VW114 (■) for each of 4 clusters: 1, DE from poor yielding WA sites, mainly from 2010 (drought year), Yield from predominantly poor WA sites from 2010 and 2011, mixture of ES sites; 2, DE from higher yielding VIC 2010 sites (plus 2 northern WA 2011 sites), Yield from high yield, 2011, mixture of ES sites; 3, DE from high yielding 2010 sites from NSW (plus 2 from VIC), Yield from high yield, 2011, mixture of ES sites; 4, DE from good yield, mainly VIC 2011 sites, with 3 2009 SA and 2 WA 2011 sites, Yield from high yield, 2011, mixture of ES sites.
4. Application of Research

Analyses of data from this research indicated that there is an interaction between site and DE indicating that environmental factors contribute to the level of DE in grain. However, there is evidence to suggest that varying levels of DE in grain may be determined more by a variety effect than a site effect. If this is the case then it would be rational for pig producers to consider high DE wheat, barley and triticale varieties, subject to assessment with AusScan, when making grain purchasing decisions. Further, experiments conducted within PGLP (see Appendix 3a) suggested that the energy content of sprouted grains for animals is not decreased and in some circumstances may be increased when compared with non-sprouted grain.

The findings from this research support the NIRS testing of grain varieties destined for pig feed. If the DE of varieties is known then producers can make better decisions about what grain to purchase and the effect on DE of mixing different varieties. This information would be relatively simple and inexpensive to obtain and could result in significant cost reductions for producers.

5. Conclusion

With regard to grain characteristics that are associated with DE content and/or DE yield and effect on variety, the following general conclusions can be made from the data analyses:

- There was no significant correlation between yield and grain chemical characteristics.
- Faecal DE content was negatively correlated with components linked to the ‘fibre’ content of grain such as arabinoxylan, ADF, and insoluble NSP.
- Site and particularly variety also had an influence on faecal DE.
- In terms of DE yield, yield contributed more than DE.
- The environment, in relation to genotype, may play a bigger role than expected and it would be useful to confirm if this is the case.

6. Limitations/Risks

Due to time limitations preliminary data analyses were conducted as part of this research. As there is a large data set available additional research should be considered so as to further exploit this data.

7. Recommendations

Given the variation in DE caused by the environment and genotype, if pig producers are to source maximum value grains, results reinforce testing of varieties commonly grown by grain producers.
8. References


Appendices

Appendix 3a:

Results obtained from PGLP on the nutritional value of sprouted cereal grains. Premium Grains for Livestock: Extract from GRDC Final Report – September 2008 (Project JLB2: Coordination). John Black: Program Coordinator

Experimentally sprouted grains: Two cultivars each of wheat and barley and three cultivars of sorghum were germinated for periods from 16 to 48 hours and germination ceased by drying. Germination for these periods did not alter the starch content of the grains, but reduced significantly the Falling Numbers values (Table 16). The disappearance of starch using in vitro enzyme digestion tended to increase with germination, but the trend was significant only for barley (P<0.001). Germination did not affect the microbial fermentation of starch. However, the rate of starch digestion appeared to be increased with a significant increase in total acid and lactic acid production with all grain species (P<0.005). These results indicate that germination increases the accessibility of both rumen microbial and animal digestive enzymes to starch and increases the rate of starch digestion for all cereal species examined.

Table 16. In Vitro measurement of starch digestibility and fermentability in sprouted wheat, and barley cultivars.

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<td>44.0</td>
<td>26.1</td>
<td>8.0</td>
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<td>28.5</td>
<td>8.6</td>
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<td>9.2</td>
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<td>415.0</td>
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<td>Gilbert</td>
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<td>44.0</td>
<td>49.2</td>
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<td>Gilbert</td>
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<td>44.9</td>
<td>254.7</td>
<td>45.9</td>
<td>52.0</td>
<td>6.2</td>
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<tr>
<td>Gilbert</td>
<td>48</td>
<td>46.0</td>
<td>62.0</td>
<td>50.5</td>
<td>51.9</td>
<td>15.7</td>
</tr>
</tbody>
</table>

In summary, the experiments conducted within PGLP suggest that the energy content of sprouted grains for animals is not decreased and in some circumstances may be increased when compared with non-sprouted grain. However, the effects of storage on the possible deterioration of sprouted grain or of mycotoxins that may develop needs to be examined.
PROJECT 4B-103 1112: SELECTION OF FEED WHEAT AND/OR BARLEY VARIETIES FOR THE AUSTRALIAN PIG INDUSTRY

APPENDIX 4: GRAIN CHARACTERISTICS OF SELECTED WESTERN AUSTRALIAN WHEATS GROWN IN THE 2011/12 SEASON

Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

By
Rudi Appels, Dean Diepeveen, Jo Pluske and John Pluske

October 2012
Executive Summary

Grain varieties that have yield superiority are generally preferred by grain growers. If pig producers want to differentiate between varieties to identify valuable feed characteristics then NIRS analyses may be important. Moreover, an understanding of the parameters produced in the analyses in terms of feed quality will be important for modelling the relative value of diets containing feed grains. For example, the total NSP and xylose contents have been reported as being more accurate predictors for the DE content in wheat than the content of NDF, although more data is required to confirm these findings (Kim et al. 2005).

The objective of this research was to conduct statistical evaluations of the relative contribution of environment and genotype to variation in DE content, yield and DE yield for a subset of wheat varieties grown in Western Australia during the 2011/12 season. Moreover, investigating aspects of other grain characteristics by testing the seeds of wheat varieties/lines with varying levels of DE will provide a deeper understanding of DE content. Seeds with cell walls that fracture more easily are expected to have a higher DE than those that don’t.

Cluster analyses indicated that there was a variety effect on yield and DE with Cascade being a relatively lower yielding variety but with a relatively high DE. Chemical analyses confirmed these results but also indicated that even if the season and/or site improved, the yield of Cascade still had a relatively high DE. Correlations of attributes supported this result.

When location was considered the yield and grain hardness for the Merredin site were significantly lower than for the other sites, whilst the faecal DE and protein were generally significantly higher for all sites. This finding, together with that from analyzing the NIRS spectrum, indicated that the environmental conditions at that site had an impact on the grain quality.

Findings from this research indicated that for some characteristics there is a difference between the data adjusted for the environment and that which is not. This finding should be considered in future data analyses.
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1. Introduction

Wheat varieties that have yield superiority are generally preferred by grain growers. If pig producers want to differentiate between varieties to identify valuable feed characteristics then NIRS analyses may be important. Moreover, an understanding of the parameters produced in the analyses in terms of feed quality will be important for modelling the relative value of diets containing wheat. For example, the total NSP and xylose contents have been reported as being more accurate predictors for the DE content in wheat than the content of NDF, although more data is required to confirm these findings (Kim et al. 2005).

The objective of this research was to conduct statistical evaluations of the relative contribution of environment and genotype to variation in DE content, yield and DE yield for a subset of wheat varieties grown in Western Australia during the 2011/12 season. Moreover, investigating aspects of other grain characteristics by testing wheat varieties/lines with varying levels of DE will provide a deeper understanding of DE content. For example, wheat seeds with cell walls that fracture more easily might have a higher DE than those that are harder to fracture.

2. Methodology

Following Diffey’s findings (see Appendix 2), data collected during the plant breeding experiment (see Appendix 1) was considered in clusters. The varieties Cascades, Westonia, and the InterGrain lines, referred to in this report as VW111 and VW114, could then be compared in terms of yield and DE.

In addition, Professor Rudi Appels and Dr. Dean Diepeveen, cereal chemists from Murdoch University and DAFWA respectively, used NIRS to assess attributes of these wheat varieties/lines including grain hardness, colour, starch composition, degree of water absorption and protein. As there are differences in grain composition depending on where and how the crops are grown, six sites in WA - Esperance, Dandaragan, Katanning, Merredin, Scaddan and Wongan Hills - were chosen to evaluate genotype by environment interactions. The environmental component was removed statistically from the analyses to give a truer indication of digestibility differences between varieties and this data was then used for analysis of grain traits.

A total of 24 (4 varieties x 6 sites) samples from the 2011/12 season were scanned using a FOSS XDS NIR instrument using DAFWA/InterGrain calibrations. Analyses on selected samples also included traits for: Yield per plot, Yield kg/ha, DE x Yield, Protein, ADF DM, ARA-XYL DM, CF DM, NDF DM, Faecal DE, HYD CAP, Ileal DE, Total Starch DM, TOT INS NSP DM, TOT SOL NSP DM. The R statistical package (www.r-project.org) with R statistical libraries (pls, aov, asreml) was used for the analyses.

Multivariate mixed-model analyses of the Near Infared spectroscopy (NIRS) spectra from each grain sample were also completed in this experiment. The grain-traits were measured by NIRS with calibrations under licence by DAFWA/InterGrain.
3. Outcomes

3.1. Cluster analyses

Results based on cluster analyses (outlined in Appendix 2) of various sites indicated that VW111 and VW114 had a yield advantage over Cascade but had similar yields to Westonia (Figure 1).

![Figure 1](image1.png)

**Figure 1** The yield of various varieties for different clusters:
Current varieties, Cascades (■) and Westonia (■) did not have a general yield advantage over new lines VW111 (■) and VW114 (■) for each of 5 clusters: 1, predominantly poor WA sites from 2010 and 2011, mixture of ES sites; 2, poor WA sites across all years; 3, high yield, mixture of ES sites; 4, high yield, 2011, mixture of ES sites; 5, predominantly 2011 high yielding WA sites.

Cascade was found to have a higher DE than Westonia which in turn tended to have a slightly higher or similar DE when compared to the IG varieties, VW114 and VW111 (Figure 2).

![Figure 2](image2.png)

**Figure 2** The DE content of various varieties for different clusters:
Current varieties, Cascades (■), Westonia (■), generally had a DE advantage over IG new lines VW111 (■) and VW114 (■) for each of 5 clusters: 1, Poor yielding WA sites, mainly from 2010 (drought year); 2, SA 2011, WA 2011, mixture of 2009 sites; 3, Higher yielding VIC 2010 sites (plus 2 northern WA 2011 sites); 4, Good yield, mainly VIC 2011 sites, with 3 2009 SA and 2 WA 2011 sites; 5, Good yield, predominantly NSW and WA 2011 sites.
3.2. **Grain chemical analyses: Variety**

When just the 2011/12 grain growing season and sites at Dandaragan, Esperance, Katanning, Merredin, Scaddan and Wongan Hills were considered for these same varieties, Cascade generally had the lowest yield except at the Esperance site. High protein levels generally trended with low yield levels. Conversely to grain yield, the DE content was highest for Cascade at all sites. However, Westonia generally had the softer grain (see bold figures in Table 1).

**Table 1** Data for predicted wheat traits, grain hardness by SKCS (SPSI), faecal DE, wheat protein and yield from six Western Australian sites for the 2011/12 season.

<table>
<thead>
<tr>
<th>Site</th>
<th>Attributes</th>
<th>Cascades</th>
<th>Variety</th>
<th>Westonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dandaragan</td>
<td>Grain hardness (PSI)</td>
<td>19.49</td>
<td>23.85</td>
<td>24.40</td>
</tr>
<tr>
<td></td>
<td>DE (MJ/kg DM)</td>
<td>14.31</td>
<td>13.94</td>
<td>13.89</td>
</tr>
<tr>
<td></td>
<td>Protein (%)</td>
<td>11.12</td>
<td>11.16</td>
<td>10.28</td>
</tr>
<tr>
<td></td>
<td>Yield (t/ha)</td>
<td>3.46</td>
<td>3.52</td>
<td>4.01</td>
</tr>
<tr>
<td>Esperance</td>
<td>Grain hardness (PSI)</td>
<td>18.32</td>
<td>17.69</td>
<td>18.89</td>
</tr>
<tr>
<td></td>
<td>DE (MJ/kg DM)</td>
<td>14.51</td>
<td>14.46</td>
<td>14.20</td>
</tr>
<tr>
<td></td>
<td>Protein (%)</td>
<td>10.82</td>
<td><strong>11.94</strong></td>
<td>11.18</td>
</tr>
<tr>
<td></td>
<td>Yield (t/ha)</td>
<td>4.00</td>
<td>2.94</td>
<td>3.57</td>
</tr>
<tr>
<td>Katanning</td>
<td>Grain hardness (PSI)</td>
<td>23.25</td>
<td>24.33</td>
<td>25.49</td>
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<tr>
<td></td>
<td>Protein (%)</td>
<td>11.64</td>
<td>8.74</td>
<td>9.46</td>
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<td></td>
<td>Yield (t/ha)</td>
<td>2.59</td>
<td>6.01</td>
<td>4.98</td>
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<td>DE (MJ/kg DM)</td>
<td>14.84</td>
<td>14.68</td>
<td>14.57</td>
</tr>
<tr>
<td></td>
<td>Protein (%)</td>
<td>15.36</td>
<td><strong>15.92</strong></td>
<td>13.74</td>
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<tr>
<td></td>
<td>Yield (t/ha)</td>
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<td><strong>1.31</strong></td>
<td>2.27</td>
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<td>DE (MJ/kg DM)</td>
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<td>14.38</td>
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<tr>
<td></td>
<td>Protein (%)</td>
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<td>11.70</td>
<td>10.61</td>
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<tr>
<td></td>
<td>Yield (t/ha)</td>
<td>2.98</td>
<td>3.41</td>
<td>4.73</td>
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<td>Wongan Hills</td>
<td>Grain hardness (PSI)</td>
<td>23.06</td>
<td>20.99</td>
<td>24.19</td>
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<td></td>
<td>DE (MJ/kg DM)</td>
<td>14.17</td>
<td>13.92</td>
<td>13.90</td>
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<tr>
<td></td>
<td>Protein (%)</td>
<td>10.01</td>
<td>9.11</td>
<td>9.44</td>
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<tr>
<td></td>
<td>Yield (t/ha)</td>
<td>2.58</td>
<td>2.93</td>
<td>3.14</td>
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</table>
To understand how specific traits were related, analyses were adjusted for the environment and location (as described previously). When considering grain hardness, the only strong correlation indicated that the lower the water absorption the harder the grain (Table 2). Faecal DE was positively correlated with wheat protein and water absorption but negatively correlated with yield and most of the other traits. The results indicated that wheat protein was correlated to the traits in a similar fashion to DE. Conversely, yield was correlated to the selected traits in an opposite pattern to that for protein and DE (Table 2). Further, the analyses presented in Appendix 3 suggested a weakly negative to no correlation between yield and faecal DE, whilst these analyses suggested there was a relatively strong correlation between these two variables. For some of the traits there were significant differences between the adjusted and unadjusted data, in particular that associated with grain hardness. For example the unadjusted data indicated that there was a strongly negative correlation between grain hardness and faecal DE and wheat protein, whilst the adjusted data suggested that this correlation was relatively weak (Table 2).

### Table 2 Correlations when adjusted for environment/location for various wheat traits from six Western Australian sites for the 2011/12 season (unadjusted data is presented in brackets).

<table>
<thead>
<tr>
<th></th>
<th>Grain Hardness</th>
<th>Faecal DE</th>
<th>Protein</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain Hardness</td>
<td>1.00 (1.00)</td>
<td>-0.33 (-0.77)</td>
<td>-0.23 (-0.71)</td>
<td>0.30 (0.49)</td>
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<tr>
<td>Faecal DE</td>
<td>-0.33 (-0.77)</td>
<td>1.00 (1.00)</td>
<td>0.79 (0.83)</td>
<td>-0.84 (-0.60)</td>
</tr>
<tr>
<td>Protein</td>
<td>-0.18 (-0.69)</td>
<td>0.81 (0.84)</td>
<td>1.00 (1.00)</td>
<td>-0.83 (-0.73)</td>
</tr>
<tr>
<td>Yield (kg/ha)</td>
<td>0.30 (0.49)</td>
<td>-0.84 (-0.60)</td>
<td>-0.85 (-0.73)</td>
<td>1.00 (1.00)</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>-0.65 (-0.91)</td>
<td>0.79 (0.89)</td>
<td>0.68 (0.83)</td>
<td>-0.70 (-0.46)</td>
</tr>
<tr>
<td>DE x Yield</td>
<td>0.30 (0.46)</td>
<td>-0.81 (-0.55)</td>
<td>-0.85 (-0.70)</td>
<td>1.00 (1.00)</td>
</tr>
<tr>
<td>Flour colour</td>
<td>-0.56 (-0.71)</td>
<td>0.51 (0.58)</td>
<td>0.45 (0.50)</td>
<td>-0.34 (-0.54)</td>
</tr>
<tr>
<td>ARA.XYL.DM</td>
<td>0.22 (0.63)</td>
<td>-0.90 (-0.89)</td>
<td>-0.72 (-0.63)</td>
<td>0.82 (0.49)</td>
</tr>
<tr>
<td>CF.DM</td>
<td>-0.32 (-0.31)</td>
<td>0.12 (0.33)</td>
<td>0.32 (0.69)</td>
<td>-0.18 (-0.48)</td>
</tr>
<tr>
<td>ADF.DM</td>
<td>-0.26 (-0.02)</td>
<td>-0.45 (-0.15)</td>
<td>-0.16 (0.31)</td>
<td>0.38 (-0.17)</td>
</tr>
<tr>
<td>NDF.DM</td>
<td>0.29 (0.61)</td>
<td>-0.84 (-0.80)</td>
<td>-0.53 (-0.50)</td>
<td>0.70 (0.12)</td>
</tr>
<tr>
<td>Ileal DE</td>
<td>-0.32 (-0.69)</td>
<td>0.86 (0.90)</td>
<td>0.57 (0.65)</td>
<td>-0.78 (-0.32)</td>
</tr>
<tr>
<td>Total Starch.DM</td>
<td>0.29 (0.34)</td>
<td>-0.07 (-0.35)</td>
<td>-0.24 (-0.68)</td>
<td>0.12 (0.48)</td>
</tr>
<tr>
<td>TOT.INS.NSP.DM</td>
<td>-0.12 (0.47)</td>
<td>-0.50 (-0.64)</td>
<td>-0.67 (-0.60)</td>
<td>0.52 (0.55)</td>
</tr>
<tr>
<td>TOT.SOL.NSP.DM</td>
<td>0.22 (0.59)</td>
<td>-0.79 (-0.83)</td>
<td>-0.64 (-0.68)</td>
<td>0.73 (0.26)</td>
</tr>
</tbody>
</table>

### 3.3. Grain chemical analyses: Site

Data for predicted wheat traits, grain hardness by SKCS (SPSI), faecal DE, wheat protein and yield indicated that across the sites there were differences in grain quality impacting on the composition of the grain (refer back to Table 1). Grain growing conditions at Merredin for the 2011/12 season resulted in low yields and produced a softer, higher protein, higher DE grain than what was expected as normal, that is, from grain grown at Dandaragan,
Katanning and Wongan Hills. Data from Esperance and Scaddan indicated that they were intermediate sites with less impact of “weathering” from the environment at plant/grain maturity (Table 1).

For the 2011/12 season, the yield for the Merredin site was lower than that of other sites (Figure 3). When location was considered in an Analysis of Variance, the yield for the Merredin site was significantly lower than that of the other sites.

![Figure 3](image3.png)

**Figure 3** Average yields for various sites for the 2011/12 season

However, for the same season, the faecal DE for the Merredin site was higher than that of other sites (Figure 4). When location was considered in an Analysis of Variance, the DE for the Merredin site was significantly higher for all of the other sites except for that of Scadden.

![Figure 4](image4.png)

**Figure 4** Average faecal DE (MJ/kg) for various sites for the 2011/12 season
For the 2011/12 season, the protein for the Merredin site was also significantly higher than that of other sites (Figure 5).

![Figure 5](image_url) Average protein for various sites for the 2011/12 season

The opposite was the case when grain hardness was considered with that for Merredin being significantly lower than that of other sites (Figure 6).

![Figure 6](image_url) Average grain hardness for various sites for the 2011/12 season

To understand how other grain characteristics might influence the DE content of these wheats, NIRS predictions were made using the spectrum shown in Figure 7. The four highest spectra after 1200nm were samples from Merredin. The impact due to environmental effects
at the Merredin site showed that the physical grain characteristics have been altered in ways that are not typical to what is considered “normal”, i.e., indicated by the yellow spectra in Figure 7.

![Figure 7](image.png)

**Figure 7** The spectrum used for NIRS predictions

3.4. **Spectral data**

There were clear indications, based on the grouping of spectra after 1450nm, relating to variety differences (Figure 7). Diepeveen et al. (2011) also showed that by removal of environmental variation, there was a correlation between genetic marker trait groups and key spectral positions: 490 nm, 575 nm, 1030 nm, 1790 nm, 2150 nm and 2250nm.

4. **Application of Research**

Cluster analyses indicated that there was a variety effect on yield and DE with Cascade being a relatively lower yielding variety but with a relatively high DE. Chemical analyses confirmed these results but also indicated that even if the season and/or site improved the yield of Cascade, it still had a relatively high DE. Correlations of attributes supported this result.

When location was considered, the yield and grain hardness for the Merredin site were significantly lower than for the other sites, whilst the faecal DE and protein were generally significantly higher for all sites. This finding, together with that from analyzing the NIRS spectrum, indicated that the environmental conditions at that site had an impact on the grain quality. As demonstrated by Diepeveen et al. (2012), removing the environmental differences enabled more accurate prediction of grain-traits than currently used by NIRS calibrations methods.
5. Conclusions

Across the sites there were differences in grain quality impacting on the composition of the grain. The main chemical determinants of the DE or digestibility of the grain were related to the fibre components. With regard to the NIRS, all traits have key-areas that are in the visual light region of the spectrum (~440nm-700nm) and several other near-infrared regions.

6. Limitations/Risks

Due to funding limitations this research is only preliminary and hence should be considered as such. However, to further this research a funding application has been submitted to the GRDC. The concept proposed is that more value can be obtained from NIRS fingerprints based on a focus on specific regions of the spectra and allowing for environmental variability. The innovation is based on using potentially new technology (hand-held NIRS and web-base access to super computing) combined with novel analyses of the data to deliver a capability to growers for defining predictions of digestibility/fibre content of grain which may be perceived to be, for example, down-graded.

7. Recommendations

Findings from this research clearly indicate that for some characteristics there is a difference between the data adjusted for the environment and that which is not. This finding should be considered in future data analyses.

8. References
