# DEVELOPMENT OF PRACTICAL STRATEGIES TO CONSIDER ENVIRONMENTAL SENSITIVITY, SURVIVAL AND PRODUCTIVITY IN PIG BREEDING PROGRAMS

# 2B-104

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

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# Executive Summary

Pig genotypes may vary in their responses to differences in environmental conditions. Optimal performance, high survival rates and good health status of pigs are only achieved if the genetic merit of pigs is matched by appropriate environmental conditions. This project has developed methodology to a) characterise environmental conditions, b) evaluate genotype by environment interactions and c) evaluate alternative selection strategies. Results of this project have been presented to industry to foster adoption.

Providing the best environment possible to pigs is the first priority. The methodology developed in this project can be used to describe fluctuations in environmental conditions over time using information readily available on farms. The models can take systematic changes in husbandry practices into account and provide alternative avenues to consider information about multiple traits in an overall environmental index. Information about growth and feed intake was most informative for describing environmental conditions and for estimating genotype by environment interactions.

Variation in estimates of environmental variables based on backfat, muscle depth and feed intake generated economic differences of $17 per pig. A standard piggery has hundreds or thousands of pigs finishing the growth period each month. Farmers should improve environmental conditions on farms to improve health, welfare and productivity of pigs.

Multiple genetic models were developed for evaluation of genotype by environment interaction. Sire by environment interaction models and multi-trait models provide simple methodology that can be used to evaluate the extent of genotype by environment interaction. This can be extended to evaluation of response of selection lines, or sire lines using random regression models, and allows appropriate selection of sires so that their progeny are allocated to the environments best suited to them.

Contrary to expectations, it was found that the line selected for low residual feed intake, which represents superior feed efficiency, was less environmentally sensitive than the selection line for high residual feed intake. This favourable association demonstrates good opportunities for genetic improvement of both robustness and efficiency.

Alternative selection strategies were evaluated quantifying the increase in additional genetic gain in the breeding objective obtained from recording more traits. Sensitivity analyses demonstrated the importance of accurate genetic correlations, in particular for traits with less information and for trait combinations with unfavourable associations. Genetic parameters should be updated regularly in breeding programs.

Post-weaning survival was the most important trait in the breeding objective based on the genetic standard deviations of breeding objective traits. Results indicated that it would take about 12 generations to improve post-weaning survival by one percent because information for this trait is limited at selection. The use of genomic information to boost genetic improvement of post-weaning survival should be explored.

Genetic improvement of robustness and health remains challenging. The genetic models developed in this study can also be applied to alternative traits, and can be adjusted easily for big systematic effects on an individual farm basis. These innovations can be applied in breeding programs that have large data sets, preferably from multiple farms, with appropriate data structure available.

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# 1. Introduction

Productivity may have unfavourable associations with physiological parameters of animals, leading to problems in behaviour and also ability of pigs to combat diseases (e.g. review of Prunier et al., 2010). On farm, these unfavourable associations often manifest themselves as variation in performance of groups of pigs and health problems leading to increased mortalities. The exact underlying causes of the reduction in performance of a specific group are often not known and producers are not always able to target specific husbandry strategies to maintain consistent performance. Therefore, methodology are required to quantify changes in environmental conditions better. Further, more comprehensive selection strategies may consider aspects of robustness (environmental sensitivity and survival of pigs) as well as productivity traits (growth, leanness and feed efficiency) in order to improve consistent performance and survival of pigs due to better health status.

Pig genotypes have been shown to differ in their response to disease challenges (e.g. Schinckel et al., 1999; Doeschl-Wilson et al., 2009). On farm, disease challenges for a specific group of pigs are often not known and average performance of a group of pigs or sows have been used to quantify environmental conditions for growing pigs (Li and Hermesch, 2016a) or sows (Knap and Su, 2008; Herrero-Medrano et al. 2015). These studies found that sires differed in the response of their progeny to variation in environmental conditions, which constitutes an example of a genotype by environment interaction.

The results by Li and Hermesch (2016a, b) offer new opportunities for pig breeding programs so select sires whose progeny perform more consistently across environments and therefore have lower environmental sensitivity. The studies showed that considerable variation existed in environmental conditions observed in Australian herds with good pig husbandry practices. Least squares means for growth rate and backfat of each contemporary group of pigs were used to quantify environments. Ranges of 87 to 145 g/day in the least squares means of contemporary groups for growth and 1.6 to 3.5 mm in the least squares means of contemporary groups for backfat were found within herds. These least squares means were used in random regression models as the independent environmental variable to quantify the response of progeny of sires to variation in both environmental variables. These genetic analyses provided estimates of reaction norms, which are effectively regression coefficients for each sire quantifying the change in performance of progeny with changes in the environmental variable. Significant reaction norms were found for growth rate for both environmental variables. Genotype by environment interactions were not found for backfat demonstrating that progeny of sires had similar responses in backfat to changes in environmental conditions.

An alternative approach to considering genotype by environment interactions in pig breeding programs is to define a trait like growth rate as a different trait in each environmental class. Li and Hermesch (2013) divided the environmental trajectory based on least squares means for growth rate into seven environmental classes leading to seven growth rate traits. Differences were found in variance components and heritabilities for growth rate across the environmental trajectory. Further, genetic correlations between these seven growth rate traits varied from 0.61±0.16 to 0.99±0.02. The statistical significance of these genetic correlations is determined by the amount of data available for each trait and the representation of sires across the environmental trajectory. These aspects are important for defining guidelines to generate data structures on farm that allow reliable estimation of genotype by environment interactions. However, a genetic correlation of below 0.8 is generally regarded as of biologically significance, meaning that the traits should be treated as being genetically different.

From the outline so far, it is clear that the definition of the environmental variable is crucial for quantifying genotype by environmental interactions. Least squares means of contemporary groups may be obtained for every trait that is available on farm leading to a multitude of genotype by environment estimates for each trait as was found by Calus and Veerkamp (2003) in dairy for example. Multiple descriptors of genotype by environment interactions for each trait are not practical and methodology will have to be developed to combine various environmental variables into an overall environmental index.

This brief review highlights the existence of interactions between pigs' genetic makeup and the environment in which they perform. These interactions are expressed as suboptimal performance, reduced survival and some loss of selection efficiency. All result in lower than ideal rate of genetic progress. The exact costs of these losses are significant although they can only be approximated at this stage. The proposed project seeks practical ways to minimise these costs.

# 2. Methodology

This Final Project Report provides an overview of the methodology and research outcomes of this project and summarises the main findings and their implications for industry. The research conducted for this project has been published to a large extend in peer-reviewed publications, which are listed in this Final Report. In particular, the invited review by Hermesch et al. (2015), which was presented at the Australasian Pig Science Association in 2015, is an output from this project and it provides a detail summary of genetic improvement of productivity and robustness in pig breeding programs with a focus on Australian research.

The following methodological sections relate to the objectives of this project:

- a) defining environments better for genetic analyses (Section 2.1),
- b) development of genetic models for evaluation of genotype by environment interactions (Section 2.2),
- c) evaluation of selection strategies (Section 2.3), and
- d) fostering adoption of research results (Section 2.4).

## *2.1.* Better definition of environments

### Overview of methodology

Environmental conditions are quantified by estimating the average performance of pigs raised together at a similar time on farms. These estimates for contemporary groups may be based on growth rate, backfat or feed intake records. This approach needs further improvements because estimates of contemporary groups may be confounded with major changes in environmental conditions associated with changes in management practices over time. Models were developed that take major changes in environmental conditions into account.

Further, it is not feasible to use multiple environmental variables for each trait in practical pig breeding programs. Therefore, various environmental variables will have to be combined into one overall environmental index. This will then lead to one definition of genotype by environment interaction for a trait that can be used in selection decisions. Haskell et al. (2007) used principal component analyses to quantify the importance of individual environmental variables. More recently, Huquet et al. (2012) proposed a new definition of the environment based on the local production environment of monthly test days using multiple factor analyses to form environmental clusters. This study in dairy is the first one to define the environment based on monthly test day profiles, which is an approach that could be applied to pig breeding. This unique approach also offers the possibility to investigate genotype by environment interactions either via multi-trait analyses, based on distinct clusters of environments, versus more complex reaction norm models, which require continuous environmental parameters available from the first axis of the factor analysis.

The different approaches to combine multiple environmental descriptors into an overall environmental index were evaluated in this study. An environmental index was derived by weighing environmental variables with the economic value for each trait. An economic value for a trait quantifies the change in profit when the trait is changed by one unit. It is independent from other economic values and can be applied to other non-genetic factors. Therefore, this approach provides a measure of economic implications of differences between environments.

## Application of methodology – Australian data - herd A

**Performance recorded** included feed intake records collected between 2004 and 2010 for entire males from 2 lines were used in the analyses. These boars were housed in the normal production environment until 112 days of age on average and then moved to pens equipped with electronic feeders. After an adjustment period of five to seven days, boars were weighed and recording of feed intake and other performance traits commenced. Only boars with a test age of between 109 and 133 days were included in analyses. The average weight at start of test was 71.3 kg (±7.6; ± standard deviation). Boars were on test for an average of 36 days. For analyses, daily feed intake was defined as the average amount of feed consumed per day during the testing period (kg/day). Measurements for backfat, which was the average of measurements at the last rib and the base of tail, and muscle depth, recorded between the third and fourth last ribs, were taken at the end of the test period with real time ultrasound. The average weight at the end of the test period was 102.5 (±10.7) kg, at an average age of 157 (±7) days. Growth rate was derived for pigs from birth until the end of test. All performance traits were restricted to within four standard deviations of the raw mean in order to be included in analyses.

Boars that were tested in the same week and year were assumed to be under the same managerial and environmental conditions, and were therefore allocated to the same contemporary group. The minimum size of contemporary groups was set at 15 pigs, giving 255 contemporary groups, which ranged from 16 to 107 pigs, with an average size of 30 pigs per contemporary group. There were on average 11 sires represented in each contemporary group. After data cleaning, there were 7,746 individual records, which represented 448 sires and 2,565 dams with 4,245 litters.

**Analyses** involved two steps. In the first step of analyses, environmental descriptors were derived based on four traits (average daily gain, backfat, daily feed intake and muscle depth). For each trait, estimates of contemporary group effects were obtained from animal models using ASReml (Gilmour et al., 2009), fitting contemporary group as a random effect. Other factors in the model fitted for each trait were line as a fixed effect and the random effects of animal and common litter effect. Growth rate and daily feed intake were also adjusted for season, which was defined as three-month periods across years (4 levels). Both backfat and muscle depth were adjusted for weight at recording which was fitted as a linear covariable. Daily feed intake was adjusted for weight of animals at start of test.

Estimates of contemporary group effects were extracted from each of these models and used as the environmental descriptors in the second part of analyses to evaluate sire by environment interactions. Further, these estimates were combined through principal component analysis using a specific function in R (prcomp function, R Core Team, 2015). Principal component analysis combines variables by producing weighted linear combinations that capture maximum variation. It is therefore dependent on scale, so contemporary group estimates were scaled to a variance of 1.0. The first principal component was used as the overall descriptor. Environments were categorised by partitioning each environmental descriptor into quintiles. Pigs were assigned an environment according to the contemporary group they belonged to, with each pig having an environment based on the contemporary group estimates of the four traits, as well as the overall descriptor.

## Application of methodology – Australian data – herd B

***Performance records*** from 90,524 growing pigs collected from 2008 to 2014 in one herd were used for genetic analyses. These growing pigs represented entire males and females from seven different lines. The majority of pigs were recorded at an average age of 154.20 (± 9.96) days and an average body weight of 96.72 (± 12.30) kg. At this age, body weight was recorded to derive average daily gain (ADG, g/day). Further measurements included backfat (BF, mm), meat percentage (MP, %) and muscle score (MS). Muscle score was a subjective score with nine levels. Higher scores represented a superior pig.

A proportion of pigs were tested for daily feed intake using FIRE feeders based on procedures outlined by Casey (2003). Feed intake records were collected from 2011 to 2014. Pigs entered electronic feeders at an average age of 50.52 (± 9.18) days and a body weight of 28.06 (± 3.72) kg. The test period was 78.66 (± 3.30) days long. Additional traits available for these pigs were average daily gain prior to test (ADG1) and growth rate during test (ADG2) as well as daily feed intake (DFI) and feed conversion ratio (FCR).

Outliers exceeding four standard deviations were eliminated from genetic analyses for all age, weight and trait records. Further, the distribution of traits was evaluated with the Univariate procedure (SAS, 2014) which provided the histogram and information about skewness and kurtosis for each trait.

**Fixed effect models** were explored with the GLM procedure (SAS, 2014) and further evaluated with the Mixed procedure to fit sire as a random effect. Significance of fixed effects was the same for both procedures, which differed only in omitting or fitting sire as a random factor. Pigs were housed in weekly batches and week was significant for all traits. The overall data covered six years with 318 weekly groups, which resulted in an average contemporary group size of approximately 290 pigs each week for lifetime growth and the associated traits describing lean meat content of pigs. However, only a proportion of pigs were recorded for daily feed intake and on average 24 pigs were recorded each week for traits describing aspects of feed efficiency. Li and Hermesch (2015) compared using month of birth and week of birth within herds as a definition of contemporary group and concluded that a balance should be achieved between obtaining accurate estimates of environmental conditions from larger groups versus definition of contemporary groups that reflect environmental factors as best as possible. Therefore, month of recording was also explored because it provides more accurate estimates of environmental effects. This is particularly important for traits associated with recording feed intake that were only available for a proportion of pigs.

All pigs were recorded for average daily gain, fat depth, meat percentage and muscle score shortly before slaughter and sex differences were accounted for in the model. In contrast, only boars were recorded for daily feed intake and the associated traits (ADG1, ADG2, DFI and FCR). Line differences were observed for all traits. In addition, a line by sex interaction was prevalent for lifetime growth (ADG). Birth farm was significant for all traits except daily feed intake. The pen that housed pigs during the test period to record feed intake was a significant fixed effect for daily feed intake and feed conversion ratio but not for growth rate during test (ADG2). Further, a line by pen interaction was observed for daily feed intake. This interaction was less important for feed conversion ratio and was not significant once feed conversion ratio was adjusted for the weight of pigs at start of test. This weight adjustment accounted for an additional seven percent of the phenotypic variation of daily feed intake in comparison to accounting for only two percent of the variability observed for feed conversion ratio. A quadratic term was not significant for both, daily feed intake and feed conversion ratio and weight at start of test was fitted as a linear covariable. Weight at recording is usually fitted as a linear covariable for backfat, which was also implemented in the current analyses for all three carcase traits. The quadratic term for weight at test was significant for meat percentage and muscle score only. Finally, age at recording various traits was evaluated for all traits. Variation in age at recording was significant as a linear and quadratic covariable for lifetime growth, early growth (ADG1), backfat and muscle score. Further, test length was a significant covariable for daily feed intake.

**Accounting for major environmental changes over time**. The aim was to quantify variation in environments due to non-specific changes in environments that affect performance of pigs. However, over time, systematic shifts in environments may occur due to systematic changes in management or recording procedures on farm. These systematic changes may include a change in market weight or different measurement techniques. For example, a shift in market weight affects lifetime average daily gain. Further, carcase measurements may be systematically affected over time by changes in measurement techniques and procedures. These systematic shifts in average performance of pigs need to be taken into account when evaluating variation in environmental conditions over time. This can be achieved by identifying periods for which a specific management and recording procedure is applicable. These time- periods represent a new fixed effect and weekly batches can then be fitted as nested effects within time-periods that correspond to specific differences in management or recording procedures. Adjusting the estimates of weekly batches for the differences between periods will reduce the overall variation in estimates of environmental conditions; however, the remaining variation in environmental descriptors may be a better estimate of unspecific environmental effects experienced by pigs. Such a procedure was evaluated for all traits and week of birth was nested within time-period for lifetime growth rate to account for a difference in market weight.

Estimates of birth week or birth month were then centred on zero for each trait. These estimates represent the environmental variable describing environmental conditions based on each trait. The environmental variables were derived from information about average daily gain (EADG), backfat (EBF), daily feed intake (EDFI), test daily gain (ETDG) and feed conversion ratio (EFCR). For each trait, estimates for contemporary groups were obtained for monthly and weekly batches using an animal model with common litter effect as an additional random effect.

**Economic indexes to describe environments**. Environmental variables based on individual traits (EADG, EBF, EDFI, EFCR) were then combined into one overall environmental index by weighing each environmental variable with the corresponding economic value of the underlying trait that was used to estimate each environmental variable. Economic values were available from Hermesch et al. (2014) for Australian production and market conditions. Two economic indexes ($/pig) were derived to quantify economic implications of variation in environmental conditions based on economic values presented by Hermesch et al. (2014). The first economic index included daily feed intake (IDFI), while the second economic index (IFCE) used feed conversion ratio to account for feed costs. The economic indexes were:

IDFI = 0.16*EADG - 1.7*EBF – 36.12*EDFI and

IFCR = 0.09*EADG - 1.7*EBF – 27.44*EFCR.

These two economic indexes are expressed in $/pig and they quantify the economic implications of changes in environmental conditions for a group of pigs. Each index value needs to be multiplied by the average number of pigs per group to obtain economic implications of variation in environmental conditions at the group level.

## Application of methodology – INRA selection lines.

Two lines of pigs have been divergently selected at INRA for residual feed intake (RFI) for eight generations (G0 to G7) (Gilbert et al. 2007). The purpose of the study was to quantify the environmental variation and to evaluate the environmental sensitivity in the RFI lines. Responses of environmental sensitivity for average daily gain and backfat thickness were evaluated.

Data comprised two lines divergently selected for RFI (highRFI for high RFI; lowRFI for low RFI), where the lowRFI line is the more efficient line. Pigs were tested from ten weeks of age to 110 kg body weight. All pigs were weighed at the beginning and at the end of the test, and test average daily gain was computed. Pigs had also records for carcass backfat thickness, which was the average of three measurements taken on the mid-dorsal line at the level of shoulder, last rib, and hip joint. The contemporary group had a maximum of 48 pigs on test. Number of pigs with validated records in each contemporary group ranged from 16 to 47 for growth rate N groups = 80; N pigs = 3189) and from 19 to 47 for backfat thickness (N groups = 44; N pigs = 1668).

The full data set with 3,996 pigs in total including 3,189 pigs with records was analysed with an animal model using ASReml (Gilmour et al., 2009) to estimate the contemporary group effect. The models for average daily gain included fixed effects of the herd of birth, sex and pen as well as covariates of age and/or birth weight at the beginning of test, plus the random effects of the animal and contemporary group. The models for backfat included fixed effects of the herd of birth, sex and pen, and covariates of age and/or birth weight at the end of the test, plus the random effects of the animal and contemporary group.

These analyses were the first step in evaluating the response of selection lines to differences in environments. The analyses provided estimates of contemporary groups for growth and backfat as descriptors of environmental conditions. Further details about data and analyses are available from Gilbert et al. (2014).

## *2.2.* Development of genetic models for evaluation of genotype by environment interactions and maternal genetic effects

### Genetic analyses of Australian data – herd A

Sire by environment interaction for growth was evaluated using the environments characterised from the five environmental descriptors derived in the first step. The five environmental descriptors were estimates of contemporary group effects for the four traits (growth rate, backfat, daily feed intake and muscle depth), as well as the overall descriptor based on the first principal component of the four original environmental descriptors based on each trait. Environments were categorised by partitioning each environmental descriptor into quintiles, and pigs were assigned an environment according to their contemporary group. A separate sire interaction model for growth was used for each descriptor fitting line and season as fixed effects as well as sire, sire by environment, litter and contemporary group as random effects.

### Genetic analyses of Australian data – herd B

An animal model and a sire model were developed for average daily gain, backfat, feed intake and feed conversion ratio. These were used initially to obtain least squares means for birth week of pigs, which are descriptors of environmental conditions experienced by each contemporary group of pigs as outlined above. Alternative genetic models were then compared for fitting random effects and the most complex model was:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z}_1\mathbf{a} + \mathbf{Z}_2\mathbf{m} + \mathbf{Wc} + \mathbf{e}$$

where **y** represents the vector of observations, **b** the vector of fixed effects outlined in section 2.1. for this herd, **a** the vector of random additive genetic effects of animals (or sires), **c** the vector of common litter effects and **e** the vector of residual effects. The terms **X** and **W** are incidence matrices for fixed effects and common litter effects, while $\mathbf{Z}_1$ and $\mathbf{Z}_2$ are incidence matrices relating records to animal (or sire) and dam effects, respectively. The expectations of random effects were zero and the variances were assumed to be var(**a**) = $\sigma^2_a\mathbf{A}$, var(**m**) = $\sigma^2_m\mathbf{A}$, var(**c**) = $\sigma^2_c\mathbf{I}$, and var(**e**) = $\sigma^2_e\mathbf{I}$, where **A** is the numerator relationship matrix and **I** the identity matrix. Variance components were estimated with ASReml (Gilmour et al., 2009) using different random and fixed effects. Results from these models were compared in order to evaluate estimates of maternal genetic effects for these traits. Maternal genetic effects represent the genes of the dam that affects performance of progeny, which may be considered more in pig breeding programs.

### Genetic analyses of INRA selection lines.

Linear mixed models were applied to data from females and castrated males from the sixth and seventh generation to evaluate line by environment interactions for average daily gain and backfat thickness. There were 27 groups of pigs with 1,089 pigs in total. Least square means of the contemporary groups obtained in the first step of analyses as outlined in the previous section were fitted as overall covariates and separately for each line (proc MIXED; SAS 2014). These linear models were:

$y_{ijklm} = \mu + herd_i + sex_j + line_k + a_1 \cdot BW + a_2 \cdot age + b \cdot LsCG_m + b_{line} \cdot LsCG_m + sire_l + e_{ijklm}$,

where herd, sex and line were the fixed effects, age and BW were covariates of the age and BW at beginning of test (ADG) or the age and BW at end of test (BFT), b is a general regression coefficient on estimates of contemporary groups (LsCG), $b_{line}$ is a regression coefficient depending on the line (2 levels) on LsCG, sire is a random effect of the sire (not structured by the parental matrix), and e is the random residual.

These models were used to evaluate the response of each selection line to differences in environmental conditions (quantified by $b_{line}$), and to characterise the environmental sensitivity of each selection line for average daily gain and backfat thickness.

Further, a linear model (proc MIXED, SAS 2014) with the fixed effects of the herd of birth (2 levels), sex (3 levels) and line (2 levels) was applied on age and body weight at beginning and at end of test on the 1082 pigs from G6 and G7, to test the line effect on the covariates used in the models.

## *2.3.* Evaluation of selection strategies

### Extension of breeding objectives.

Development of selection strategies is based on the definition of breeding objectives, which define the selection emphasis for individual traits, and identification of selection criteria, which provide information for economically important traits. The previous Pork CRC project by Hermesch et al. (2013; 2B-102) provided economic methodology to derive economic values for a number of robustness traits in addition to the more traditional traits describing productivity. This current project further modified existing economic methodology from the previous project to reflect refinements of trait definitions for sow longevity and sow mature weight, which are robustness and welfare traits.

The sow model employed in PigEV to quantify the economic benefits of improving sow longevity by one parity includes details about maintenance requirements, growth and performance of sows as well as performance of their progeny. The underlying equations to quantify these parameters have been documented and published by Amer et al. (2014). This additional information will enable users to better understand the consequences of input parameters on economic values for sow longevity. In particular, the performance of progeny from gilt litters versus older sows will affect the economic value for sow longevity.

## Sensitivity analysis of input parameters for economic weights

The economic importance of some traits is affected by the level of performance and some marketing parameters. Economic values quantify economic importance of breeding objective traits and differences in economic values resulting from different production and marketing scenarios should be considered for the development of breeding objectives in pig breeding programs.

Sensitivity analyses were performed to demonstrate variability in economic importance of specific traits due to variation in performance levels. The effects of a 20-percent increase in single-input parameters on economic weights of traits in the breeding objective, while other input parameters remained constant, were obtained for sire lines. The implications of a 20-percent increase in feed price, slaughter weight, slaughter price, price for a weaner pig, average age of mortality of pigs that die post weaning and mean and standard deviation of backfat were investigated and published in Hermesch et al. (2014).

## Evaluation of selection strategies

Breeding objectives need to be extended to better reflect the economic importance of a wider range of traits. Often bio-economic models have been used to define breeding objective. The complexity of these bio-economic models may have hindered extension of breeding objectives over time. Recently, Amer et al. (2014) and Hermesch et al. (2014) presented an alternative approach to derive the economic value of individual traits directly using independent sub models, which facilitates future extensions of breeding objective.

Hermesch et al. (2014) presented economic values for traits of growing pigs, which can be used to setup breeding objectives for sire lines. The relative economic importance of traits was outlined based on the genetic standard deviation of each trait indicating the importance of post-weaning survival for selection decisions. However, predicted responses from different selection strategies were not evaluated by Hermesch et al. (2014). Therefore, six selection strategies were evaluated in this project applying two breeding objectives that are relevant for Australian sire lines.

The traits included in the breeding objectives were average daily gain (ADG), backfat (BF) and feed conversion ratio (FCR) or daily feed intake (DFI). Further, post-weaning survival (PWS) as well as loin and belly weight (LW, BW) were considered. Economic values for the breeding objective traits were based on Hermesch et al. (2014) and Hermesch and Jones (2010) (Table 1). Two breeding objectives were considered including either feed conversion ratio or daily feed intake to account for feed costs. The economic value for average daily gain was 0.09 $/g per pig when feed conversion ratio was part of the breeding objective and the economic value was 0.16 $/g when the breeding objective included daily feed intake. The economic value for average daily gain is lower when feed conversion ratio is part of the breeding objective because feed conversion ratio accounts for savings in feed costs due to higher growth (Hermesch et al., 2014). In contrast, feed intake does not account for savings in feed intake due to higher growth, which is reflected in the higher economic value for growth for a breeding objective that includes feed intake.

Six different indexes were compared for both breeding objectives. The base index (index 1) included records for average daily gain and backfat only. The number of traits that were recorded on farm (selection criteria) was then extended through stepwise inclusion of piglet birth weight (PBW, index 2), post-weaning survival (index 3), loin and belly weight (index 4), juvenile insulin-like growth factor 1 (IGF1, index 5) and finally feed conversion ratio or feed intake (index 6). Piglet birth weight and juvenile IGF1 were not included in the breeding objectives. However, these traits are of interest for breeding programs as selection criteria because both traits have favourable genetic associations with efficient lean meat growth (Hermesch et al., 2001; Bunter et al., 2005). They are recorded in young growing pigs. Therefore, the information is available prior to selection, which is beneficial for breeding programs. Genetic parameters are outlined in Table 1 based on these previous studies outlined above as well as Hermesch (2008). No information was found about genetic or phenotypic correlations between post-weaning survival and other performance traits, which consequently were assumed to be zero. Index calculations were performed using the MTIndex program of van der Werf (http://www.personal.une.edu.au/~jvanderw).

Index calculations require information about the number of animals, and their relation to the selection candidate, that have certain performance records available at the point of selection. It was assumed that average daily gain, backfat and piglet birth weight were available for the selection candidate, six full sibs and 30 half sibs. Although post-weaning survival is available for all animals, only surviving pigs are selected and no distinction can be made between pigs with high or low liability for survival. For this trait, family selection is more effective because it is a threshold character with low incidence (Falconer and Mackay, 1996). Therefore, it was assumed that information about post-weaning survival was only available for the sire because the mean reliability for survival of sires is better known based on information about progeny from multiple litters. The carcase traits loin and bellow weight were available for two full sibs and ten half sibs. For juvenile IGF1, information was available for the selection candidate, one full sib and ten half sibs. Feed intake is most expensive to measure and it was assumed that feed conversion ratio or daily feed intake were only recorded on the selection candidate and five half sibs.

The response to selection in the breeding objective and individual traits was compared for the six indexes evaluated for each breeding objective. The response in the breeding objective was expressed in $/pig and it provides information about the potential economic benefits of considering more traits in selection decisions.

## *2.4.* Fostering adoption of research results

### Demonstration of PigEV.

Multiple webinars were held to provide an overview of PigEV to breeders. Each webinar was limited to about one hour and three different topics were outlined in these webinars. The first topic provided an overview of PigEV outlining the structure of the program. The second and third topics focused on traits of the growing pig and the sow. Staff from all main breeding companies and multiple departments of primary industries participated in these webinars. There was high interest in these webinars and 10 webinars were held over a 3-month period.

## Extension of PigEV (Pig EV V1.01)

The economic values derived in PigEV can be used to evaluate different management strategies. This aspect is of interest to other researchers and producers and received high interest in the webinars. Based on suggestions from participants, PigEV V1.01 was developed which includes an additional worksheet that allows producers to compare alternative management strategies.

Economic values represent the change in profit resulting from a change in a trait by one unit independent of changes in other traits. This principle can be used to evaluate the economic consequences of implementing alternative management procedures. Initially, the performance in multiple traits needs to be known for the base situation. This will be compared with the level of performance in these traits for the new management procedure. This may be a new feed additive or changed housing conditions. The change in each trait resulting from implementing the new procedure is then multiplied by the corresponding economic value for each trait. This represents the change in revenues resulting from the change in management procedures due to each trait, which is summed across traits to give the overall change in revenues. This overall change in revenue (or gross profit) is then compared with the costs of implementing the new management procedure to evaluate whether it is profitable to implement resulting in a net profit.

Every step of this procedure has been automated in the new worksheet in PigEV. Further, change in net profit is expressed per pig, per litter or per gilt to make it flexible for users. An image of the worksheet is shown in Figure 1.

**Table 1 Genetic standard deviations (GSD), heritabilities ($h^2$), economic values (EV) and genetic (below diagonal) or phenotypic (above diagonal) correlations for traits, used to evaluate six selection indexes for two breeding objectives**

| | GSD | $h^2$ | $EV_{FCR/DFI}$ [A] | ADG | BF | FCR | DFI | PWS | LW | BW | IGF1 | PBW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADG | 30.000 | 0.31 | 0.09/0.16[A] | | 0.11 | -0.20 | 0.32 | 0.00 | -0.14 | 0.20 | 0.09 | 0.38 |
| BF | 1.000 | 0.33 | -1.70 | 0.02 | | 0.06 | 0.11 | 0.00 | -0.37 | 0.11 | 0.06 | -0.14 |
| FCR | 0.150 | 0.12 | -27.44/0.00[A] | -0.37 | 0.10 | | 0.00 | 0.00 | -0.14 | 0.02 | 0.15 | -0.10 |
| DFI | 0.094 | 0.24 | 0.00/-36.12[A] | 0.50 | 0.35 | 0.00 | | 0.00 | -0.05 | 0.05 | 0.09 | 0.10 |
| PWS | 0.038 | 0.05 | 182.88 | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 |
| LW | 0.680 | 0.42 | 3.60 | -0.15 | -0.54 | -0.40 | -0.20 | 0.00 | | -0.29 | -0.05 | 0.05 |
| BW | 0.390 | 0.27 | 1.20 | 0.16 | 0.30 | 0.25 | 0.20 | 0.00 | -0.51 | | 0.05 | -0.05 |
| IGF1 | 13.070 | 0.21 | 0.00 | 0.06 | 0.21 | 0.65 | 0.41 | 0.00 | -0.20 | 0.20 | | 0.04 |
| PBW | 0.064 | 0.04 | 0.00 | 0.56 | -0.43 | -0.30 | 0.20 | 0.00 | 0.20 | -0.20 | -0.33 | |

Trait abbreviations: ADG: average daily gain (g/d), BF: back fat (mm), FCR: feed conversion ratio (kg feed/ kg gain), DFI: daily feed intake (kg/day), PWS: post-weaning survival (0/1), LW: loin weight (kg), BW: belly weight (kg), IGF1: juvenile insulin-like growth factor-I (ng/ml), PBW: piglet birth weight (kg).

[A] Economic values differ for breeding objectives with either DFI (first value) or FCR (second value)

**PigEV - V1.01**

| | |
|---|---|
| Worksheet: | **PigEV** - **Economic Weight summary** |
| Model title | PigEV - An economic model that quantifies the economic benefits of improving genetic traits of growing pigs and sows |
| Model designer: | Peter Amer, Cameron Ludemann and Susanne Hermesch |
| Funding: | CRC for High Integrity Australian Pork |
| **Licensed to:** | **AGBU**<br>**UNE, Armidale NSW 2351** |

| **Growing-pig traits** | **Used (0=no, 1=yes)** | Performance - Base | Performance-new | Difference for used traits (new - base) | Economic value (EV) | Unit of EV | Change in revenue due to trait | Change in revenue due to trait - expressed per pig ($/pig) | Change in profit due to trait - expressed per litter ($/litter) | Change in profit due to trait - expressed per gilt ($/gilt) |
|---|---|---|---|---|---|---|---|---|---|---|
| Average daily gain | 1 | 650 | 720 | 70 | 0.09 | $/pig | 6.18 $/pig | 6.18 | 55.57 | 204.73 |
| Feed conversion ratio | 1 | 2.3 | 2.2 | -0.1 | -27.44 | $/pig | 2.74 $/pig | 2.74 | 24.67 | 90.89 |
| Daily feed intake | 0 | 2.5 | 2.4 | 0 | 0.00 | $/pig | 0.00 $/pig | 0.00 | 0.00 | 0.00 |
| Carcase P2 Fat Depth | 0 | 11 | 11.5 | 0 | -1.70 | $/pig | 0.00 $/pig | 0.00 | 0.00 | 0.00 |
| Post weaning survival | 0 | 0.97 | 0.97 | 0 | 176.31 | $/pig | 0.00 $/pig | 0.00 | 0.00 | 0.00 |
| **Sow traits** | | | | | | | | | | |
| Gilt age at puberty | 0 | 180 | 178 | 0 | -2.51 | $/gilt | 0.00 $/gilt | 0.00 | 0.00 | 0.00 |
| Number born alive | 0 | 11.2 | 11.2 | 0 | 24.95 | $/litter | 0.00 $/litter | 0.00 | 0.00 | 0.00 |
| Survival at birth | 0 | 0.93 | 0.93 | 0 | 29.09 | $/litter | 0.00 $/litter | 0.00 | 0.00 | 0.00 |
| Preweaning survival | 0 | 0.91 | 0.91 | 0 | 296.64 | $/litter | 0.00 $/litter | 0.00 | 0.00 | 0.00 |
| Daily gain maternal | 0 | 650 | 650 | 0 | 0.83 | $/litter | 0.00 $/litter | 0.00 | 0.00 | 0.00 |
| Weaning weight | 0 | 7.1 | 7.1 | 0 | 0.00 | $/litter | 0.00 $/litter | 0.00 | 0.00 | 0.00 |
| Number of parities (longevity) | 0 | 3.6 | 3.6 | 0 | 99.00 | $/sow | 0.00 $/sow | 0.00 | 0.00 | 0.00 |
| Mature weight overall | 1 | 295 | 300 | 5 | | | | | | |
| *Sow mature weight gilt energy* | | | | | -0.40 | $/gilt | -2.01 $/gilt | -0.06 | -0.52 | -2.01 |
| *Sow mature weight sow maintenance* | | | | | -0.37 | $/litter | -1.83 $/litter | -0.20 | -1.83 | -6.76 |
| *Sow mature weight capital costs* | | | | | -1.29 | $/litter | -6.46 $/litter | -0.72 | -6.46 | -23.82 |
| *Sow mature weight cull value* | | | | | 2.66 | $/sow | 13.28 $/sow | 0.35 | 3.16 | 11.65 |
| **Costs to implement procedure** | **Used (0=no, 1=yes)** | **Value in $** | **Costs** | | | | | **Total change in revenue ($/pig)** | **Total change in revenue ($/litter)** | **Total change in revenue ($/gilt)** |
| Costs per pig | 1 | 2 | 2.00 | | | | | **8.30** | **74.58** | **274.69** |
| Costs per litter | 0 | 45 | 17.98 | | | | | **Change in profit ($/pig)** | **Change in profit ($/litter)** | **Change in profit ($/gilt)** |
| Costs per gilt | 0 | 170 | 66.24 | | | | | **6.30** | **56.60** | **208.44** |

| ***Factors for discounting or compounding expressions:*** | **Value** |
|---|---|
| *Factor to express a trait of the pig at slaughter per litter* | 8.99 |
| *Factor to express a trait of the pig at slaughter per gilt* | 33.12 |
| *Factor to express a trait of the litter per slaughter pig* | 0.11 |
| *Factor to express a trait of the litter per gilt* | 3.68 |
| *Factor to express age at puberty per slaughter pig* | 0.029 |
| *Factor to express age at puberty per litter* | 0.26 |
| *Factor to express age at puberty per gilt* | 0.96 |
| *Factor to express sow mature weight per slaughter pig* | 0.027 |
| *Factor to express sow mature weight per litter* | 0.24 |
| *Factor to express sow mature weight per gilt* | 0.88 |

**Figure 1. New worksheet in PigEV V1.01 to compare profitability of implementing a new management procedure**

# 3. Outcomes

## *3.1.* Variation in estimates of different environmental variables

### Variation in environments – Australian data – herd A

Estimates of contemporary group effects ranged from -53.5 to 56.6 g/day for average daily gain, from -1.66 to 2.18 mm for backfat, from -0.46 to 0.49 kg/day for daily feed intake, and from -5.04 to 10.49 mm for muscle depth.

The contemporary group estimates based on the four traits were combined through principal component analysis. The first principal component (PC1) explained 37.5% of the variation, and the second principal component (PC2) explained 26.1%. For the first principal component, the greatest emphasis was placed on growth rate and daily feed intake, with loadings of -0.60 and -0.64 respectively. The loading in the first principal component for backfat was -0.35 and -0.31 for muscle depth. Meanwhile, principal component two placed the greatest emphasis on the carcass traits, with loadings of -0.59 for backfat, -0.65 for muscle depth, 0.40 for average daily gain and 0.26 for daily feed intake. These loadings suggest associations between the descriptors based on growth and daily feed intake, and also between the descriptors based on backfat and muscle depth.

### Variation in environments – Australian data – herd B

**The fixed effect models** explained between 10 to 47 % of the variation observed for performance traits (Table 2). The trait that had the least amount of variation explained was growth rate, and adjusting for age at testing increased the coefficient of determination slightly from 0.121 to 0.134. The high coefficients of determination observed for backfat were due to differences between contemporary groups (week or month of birth). Further, the weight adjustment for carcase traits (backfat, muscle point and muscle score) explained a significant amount of variation leading to higher coefficients of determination for these traits in comparison to growth rate. The age adjustment only explained a small additional proportion of the variability observed in these carcase traits. This effect was statistically significant due to the large number of observations that were available for analyses.

The large number of observations available for these traits each week suggests using week of birth as the contemporary group definition. Month of birth was also fitted as a contemporary group definition for a comparison with traits associated with recording feed intake. Fitting month of birth instead of week of birth reduced coefficients of determination by about 0.01 to 0.015 (1 to 1.5%).

Fixed effect models and the proportion of variation explained by individual models are shown in Table 3 for traits associated with recording feed intake. Adding age at start of test to the model for growth prior to the test period increased the coefficient of determination by about eight percent from 0.228 to 0.347. Using birth week as the contemporary group effect instead of month of birth, explained an additional three to eight percent of the observed variation. The largest increase was observed for daily feed intake and feed conversion ratio, while coefficient of determination for growth rate during the test period was least affected by the definition of contemporary group in models.

**Table 2. Coefficient of determination ($R^2$) and fixed effects fitted for performance traits.**

| Trait | $R^2$ | Week | Month | Sex | Line | Line x Sex | Birth farm | Weight[1] | Age[1] |
|---|---|---|---|---|---|---|---|---|---|
| ADG | 0.121 | *** | | *** | *** | *** | *** | | |
| ADG | 0.134 | *** | | *** | *** | *** | *** | | ***/***1 |
| ADG | 0.106 | | *** | *** | *** | *** | *** | | |
| ADG | 0.120 | | *** | *** | *** | *** | *** | | ***/***1 |
| BF | 0.470 | *** | | *** | *** | ns | *** | ***/ns | |
| BF | 0.472 | *** | | *** | *** | ns | *** | ***/ns | ***/***1 |
| BF | 0.460 | | *** | *** | *** | ns | *** | ***/ns | |
| BF | 0.461 | | *** | *** | *** | ns | *** | ***/ns | ***/***1 |
| MP | 0.381 | *** | | *** | *** | ns | *** | ***/*** | |
| MP | 0.381 | *** | | *** | *** | ns | *** | ***/*** | */* |
| MP | 0.368 | | *** | *** | *** | ns | *** | ***/*** | |
| MP | 0.368 | | *** | *** | *** | ns | *** | ***/*** | */* |
| MS | 0.280 | *** | | *** | *** | ns | *** | ***/*** | |
| MS | 0.282 | *** | | *** | *** | ns | *** | ***/*** | */* |
| MS | 0.271 | | *** | *** | *** | ns | *** | ***/*** | |
| MS | 0.273 | | *** | *** | *** | ns | *** | ***/*** | */* |

Abbreviations: Age: age at end of test; ADG: lifetime average daily gain; BF: backfat; MP: meat percentage; MS: muscle score; *** p-value < 0.0001, ** p-value < 0.001, p-value < 0.01; [1]: weight or age at end of test fitted as a linear/quadratic covariable

**Table 3. Coefficient of determination ($R^2$) and fixed effects fitted for feed intake traits.**

| Trait | $R^2$ | Week | Month | Line | Birth farm | Pen | Line x Pen | Start Weight[3] | Age[1] |
|---|---|---|---|---|---|---|---|---|---|
| ADG1 | 0.228 | *** | | *** | * | | | | |
| ADG1 | 0.347 | *** | | *** | * | | | | ***/*[1] |
| ADG1 | 0.171 | | *** | *** | * | | | | |
| ADG1 | 0.286 | | *** | *** | * | | | | **/ns |
| ADG2 | 0.206 | *** | | *** | ** | *** | | | ns |
| ADG2 | 0.245 | *** | | *** | ** | *** | | ***/ns | ns |
| ADG2 | 0.158 | | *** | *** | ** | *** | | | ns |
| ADG2 | 0.203 | | *** | *** | ** | *** | | ***/ns | ns |
| DFI | 0.370 | *** | | *** | ns | *** | * | | */*[2] |
| DFI | 0.439 | *** | | *** | ns | *** | * | ***/ns | */*[2] |
| DFI | 0.307 | | *** | *** | | *** | * | | */ns |
| DFI | 0.388 | | *** | *** | ns | *** | * | *** | */ns |
| FCR | 0.265 | *** | | *** | ** | *** | * | | ns |
| FCR | 0.283 | *** | | *** | *** | *** | ns | ***/ns | ns |
| FCR | 0.208 | | *** | *** | ** | *** | * | | ns |
| FCR | 0.225 | | *** | *** | ** | *** | ns | ***/ns | */ns |

<u>Abbreviations</u>: ADG1: average daily gain prior to feed-intake test; ADG2: average daily gain during feed-intake test period; DFI: daily feed intake; FCR: feed conversion ratio; *** p-value < 0.0001, ** p-value < 0.001, p-value < 0.01; Age[1]: age at start of feed-intake test (fitted for ADG1) or length of test period for feed intake (for DFI and FCR) fitted; start weight[2] and age[2]: results for linear/quadratic covariable.

## Estimates of contemporary groups.

There were 318 weekly contemporary groups and 127 of these had records available related to feed intake data (Table 4). Estimates were all centred on zero and standard deviations and minima and maxima illustrate variation in environmental conditions. Environments varied by 89 g/d for lifetime growth, which increased to 110 g/d when effects of shifts in market weight over time were considered. Similarly, substantial variation was observed for backfat with a maximum range of 6.6 mm. Although, early growth has a lower mean than lifetime growth, environmental variability was larger with a standard deviation of 21.187 for solutions and a maximum range of environments of 118 g/d. Further, test daily gain, daily feed intake and feed conversion ratio all showed considerable environmental variability for these weekly definitions of contemporary groups illustrated by maximum ranges of 251 g/d, 0.591 kg/d and 0.461, respectively.

Estimates of contemporary groups differed more for daily feed intake (EDFI) than estimates for feed conversion ratio (EFCR), which may indicate that daily feed intake captures differences in environments better. Anorexia is an adaptive response of animals to defend a disease challenge (i.e. review by Johnson, 1998).

Whether anorexia, the lack or loss of appetite for food is contributing to the increased variation in feed intake in this high-health herd is unknown. Sandberg et al. (2006) suggested using the large variation in feed intake during pathogen challenges as a viable strategy for selection. The increased variation in the environmental variable based on feed intake indicates that feed intake should be monitored in order to evaluate environmental conditions for groups of pigs.

**Table 4. The number of contemporary groups (N), standard deviation (SD), average standard error (SE), and maximum range (Range) of estimates of weekly contemporary groups effects for individual traits, used as environmental variables**

| Environmental variable | N | SD | Minimum | Maximum | Range | SE |
|---|---|---|---|---|---|---|
| EADG[A] (g/d) | 318 | 22.11 | -59.19 | 51.38 | 110.57 | 9.77 |
| EADGadj. (g/d) | 318 | 16.22 | -47.82 | 41.56 | 89.38 | 9.77 |
| EBF (mm) | 318 | 1.81 | -3.03 | 3.67 | 6.70 | 0.31 |
| EMP | 318 | 2.99 | -6.70 | 12.4 | 19.1 | 0.83 |
| EMS | 318 | 0.19 | -0.63 | 0.36 | 0.99 | 0.10 |
| EADG1 (g/d) | 127 | 21.19 | -58.51 | 60.03 | 118.54 | 25.49 |
| EDFI (kg/d) | 126 | 0.14 | -0.34 | 0.26 | 0.59 | 0.17 |
| ETDG (g/d) | 127 | 44.33 | -112.03 | 139.67 | 251.70 | 69.19 |
| EFCR | 126 | 0.097 | -0.22 | 0.24 | 0.46 | 0.15 |

[A] EADG: environment described by average daily gain; EADGadj: environment described by average daily gain, with shifts in market weight considered; EBF: environment described by backfat; EMP: environment described by muscle percentage; EMS: environment described by muscle score; EADG1: environment described by growth rate prior to feed intake test; EDFI: environment described by daily feed intake; ETDG: environment described by test daily gain; EFCR: environment described by feed conversion ratio.

Regression of performance traits on these environmental variables assumes that these parameters are known without error. This is not the case for these estimates and uncertainty of these variables is estimated by their standard errors. These were higher for environmental variables based on traits related to recording feed intake due to the low number of animals recorded each week in comparison to other traits recorded on all pigs. For these traits, it may be better to use monthly definitions of contemporary groups, which are summarised in Table 5 for all traits. Overall, environmental variables varied less for all traits when using monthly batches of contemporary groups in comparison to weekly batches. This reduction in variability of environmental variables was larger for traits based on recording feed intake indicating that sampling errors may have contributed to the large variation observed for weekly contemporary groups. Standard errors were reduced by a third for environmental variables of these traits. Therefore, monthly contemporary groups should be used for these traits with fewer records for each contemporary group.

In summary, these analyses showed that considerable environmental variation existed for all traits, which will be used to investigate economic implications of this environmental variability and to analyse how different genotypes respond to this variation in environments.

**Table 5. The number of contemporary groups (N), standard deviation (SD), average standard error (SE), and maximum range (Range) of estimates of monthly contemporary groups for individual traits, used as environmental variables**

| Environmental variable | N | SD | Minimum | Maximum | Range | SE |
|---|---|---|---|---|---|---|
| EADG[A] (g/d) | 72 | 13.88 | -28.97 | 38.28 | 67.25 | 4.25 |
| EADGadj. (g/d) | 72 | 20.68 | -50.14 | 48.46 | 98.6 | 4.249 |
| EBF (mm) | 72 | 1.79 | -2.80 | 3.28 | 6.08 | 0.128 |
| EMP (%) | 72 | 2.90 | -5.58 | 9.05 | 14.63 | 0.337 |
| EMS | 72 | 0.17 | -0.51 | 0.27 | 0.78 | 0.038 |
| EADG1 (g/d) | 28 | 18.21 | -37.32 | 29.25 | 61.57 | 7.539 |
| EDFI (kg/d) | 28 | 0.12 | -0.26 | 0.16 | 0.41 | 0.05 |
| ETDG (g/d) | 28 | 35.09 | -75.72 | 68.17 | 143.9 | 20.77 |
| EFCR (kg/kg) | 28 | 0.08 | -0.13 | 0.19 | 0.32 | 0.04 |

[A] EADG: environment described by average daily gain; EADGadj.: environment described by average daily gain, with shifts in market weight considered; EBF: environment described by backfat; EMP: environment described by muscle percentage; EMS: environment described by muscle score; EADG1: environment described by growth rate prior to feed intake test; EDFI: environment described by daily feed intake; ETDG: environment described by test daily gain; EFCR: environment described by feed conversion ratio.

## Associations between environmental variables

High lifetime growth was favourably associated with low backfat at the environmental level (Table 6). The environmental variable based on lifetime growth (environmental parameter based on ADG) had no association with environments of early growth (environmental parameters based on ADG1) in contrast to stronger positive correlations with growth during test (environmental parameters based on ADG2). Early growth is affected by the environment provided by the dam and the weaning process, which have a reduced effect on growth over the whole growing period. Correlations between environmental variables of traits associated with recording feed intake were all positive. The environmental variable based on feed intake in particular had high positive correlations with environmental variables based on growth during test and feed conversion ratio. Changes in environments leading to higher (or lower) average feed intake of a group of pigs also lead to higher (or lower) growth and feed conversion ratio.

**Table 6. Pearson correlations between environmental variables (above diagonal: monthly contemporary groups; below diagonal: weekly contemporary groups).**

| | Environmental variable based on: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ADG | ADGadj | BF | MP | MS | ADG1 | TDG | DFI | FCR |
| ADG | | 0.63 | -0.37 | -0.40 | -0.08 | 0.16 | 0.34 | 0.20 | -0.06 |
| ADGadj | 0.72 | | -0.36 | -0.34 | 0.33 | 0.07 | 0.61 | 0.66 | 0.35 |
| BF | -0.33 | -0.34 | | 0.82 | 0.02 | -0.41 | 0.06 | -0.15 | -0.38 |
| MP | -0.33 | -0.30 | 0.79 | | -0.03 | -0.27 | -0.15 | -0.18 | -0.10 |
| MS | -0.07 | 0.28 | 0.01 | 0.00 | | -0.64 | -0.08 | 0.05 | 0.17 |
| ADG1 | 0.32 | 0.18 | -0.37 | -0.22 | -0.54 | | 0.33 | 0.48 | 0.38 |
| TDG | 0.30 | 0.51 | 0.02 | -0.14 | -0.04 | 0.29 | | 0.74 | 0.08 |
| DFI | 0.19 | 0.51 | -0.16 | -0.18 | 0.03 | 0.41 | 0.70 | | 0.71 |
| FCR | -0.08 | 0.19 | -0.28 | -0.09 | 0.11 | 0.28 | 0.00 | 0.68 | |

[A] ADG: environment described by average daily gain; ADGadj: environment described by average daily gain, adjusted for change in market weight; BF: environment described by backfat, MP: environment described by muscle percentage; MS: environment described by muscle score; ADG1: environment described by average daily gain prior to feed intake test; TDG: environment described by test daily gain; DFI: environment described by daily feed intake; FCR: environment described by feed conversion ratio.

## Economic differences between environments

Evaluating the spread in economic indexes that combine environmental variables based on individual traits show the economic differences between environments. Economic indexes that included feed conversion ratio or daily feed intake are shown in Table 8 for the proportion of contemporary groups that had these traits available. Economic indexes were also centred on zero similar to environmental variables of traits. Standard deviations and ranges of these economic indexes were larger for indexes involving daily feed intake rather than feed conversion ratio. This was due to the larger variation in environmental variables for feed intake in comparison to feed conversion ratio as illustrated above. For monthly contemporary groups, the economic index including daily feed ($IndexDFI) had a standard deviation of 4.377 $/pig and a maximum range of 17.409 $/pig. In comparison, the standard deviation and maximum range were 2.549 $/pig and 11.779 $/pig respectively for the corresponding economic index for feed conversion ratio ($IndexFCR).

Including differences in market weight increased variability in the environmental variable for lifetime growth. However, differences in economic indexes that included this environmental variable for growth were actually smaller than the corresponding differences in economic indexes that did not include variation in market weight in the environmental variable for growth. This is unexpected and may indicate interactions between environmental variables for individual traits that cancel each other out in these economic indexes.

Economic differences between groups of pigs were expressed in $ per pig. Each value needs to be multiplied by the number of pigs per group to quantify economic differences between groups and the full economic implications of variation in environmental conditions on farms. Given that monthly groups include hundreds of pigs in a standard piggery, variation in environmental conditions has high economic implications and investing in improving environmental conditions practising good health and management is economically beneficial and should be considered. Improved environmental conditions are also beneficial for welfare of pigs and optimal environmental conditions should be provided to pigs on farms.

**Table 8. Economic differences ($/pig) centered on zero between contemporary groups based on differences in environmental variables for individual traits.**

| $Index | N | SD | Minimum | Maximum | Maximum range |
|---|---|---|---|---|---|
| | Weekly contemporary groups | | | | |
| $IndexFCR | 126 | 3.273 | -8.906 | 7.328 | 16.235 |
| $IndexFCRwt | 126 | 2.871 | -6.676 | 6.537 | 13.213 |
| $IndexDFI | 126 | 5.274 | -13.994 | 11.595 | 25.589 |
| $IndexDFIwt | 126 | 4.300 | -10.030 | 10.188 | 20.218 |
| | Monthly contemporary groups | | | | |
| $IndexFCR | 28 | 2.549 | -6.874 | 4.906 | 11.779 |
| $IndexFCRwt | 28 | 2.032 | -4.831 | 4.120 | 8.950 |
| $IndexDFI | 28 | 4.377 | -10.304 | 7.105 | 17.409 |
| $IndexDFIwt | 28 | 3.112 | -6.112 | 5.708 | 11.820 |

Abbreviations of economic indexes: $IndexFCR: economic index includes feed conversion ratio, $IndexFCRwt: economic index includes feed conversion ratio and management changes were taken into account for estimates of environmental variables; $IndexDFI: economic index includes daily feed intake, $IndexDFIwt: economic index includes daily feed intake and management changes were taken into account for estimates of environmental variables

**Variation in environments – INRA selection lines.**

Estimates of contemporary groups ranged from -56g/d for most unfavourable environments +54g/d for most favourable environmental conditions (Figure 2) based on growth rate, which was adjusted for age and body weight at the beginning of test. The standard deviation of contemporary group estimates was 25 g/d. The range of contemporary group estimates varied from -3.08 to 3.8 mm for backfat with a standard deviation of 2.0 mm. Largest variations in contemporary estimates were found in later generations, when more contemporary groups and more parities were available. Models with other choices of covariates gave similar values, except for backfat thickness when age at the end of test was included and the range was larger (-3.83 to 4.27 mm).

The standard errors of contemporary group estimates ranged from 13 to 20 g/d for average daily gain and from 0.8 to 1.0 mm for backfat thickness.

Correlations between estimates of contemporary groups using different models were higher than 0.98 for average daily gain and 0.91 for backfat thickness showing that these estimates were fairly robust in regard to choice of models.

Correlations between contemporary group estimates between the two traits growth rate and backfat were low and negative, and significantly different from zero. These correlations ranged from -0.08 to -0.24 indicating that favourable environments for average daily gain would also be favourable for backfat thickness.

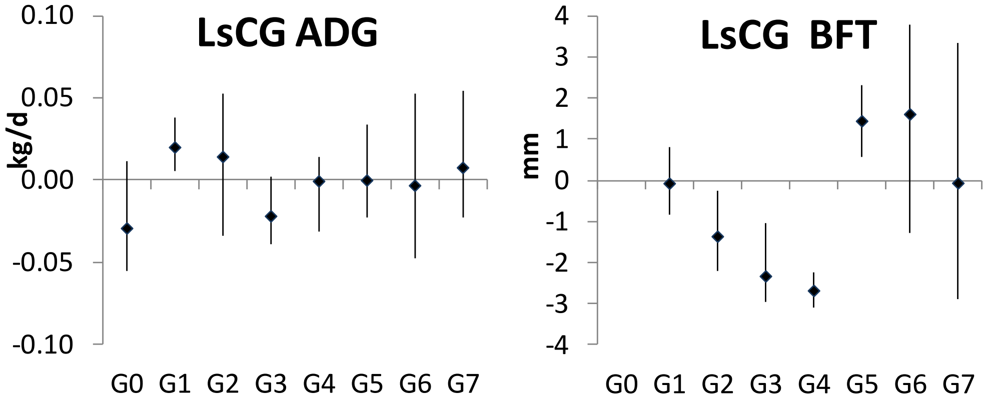


**Figure 2. Distribution of mean (diamonds), max and min estimates for least square means of contemporary groups (LsCG) for average daily gain (ADG) and backfat thickness (BFT), shown for each generation of selection (G0 to G7; from Gilbert et al., 2014).**

## *3.2.* Development of genetic models for the evaluation of genotype by environment interactions

### Genetic analyses – Australian data – herd A

Estimates of variance components for additive genetic effects and common litter effects for average daily gain did not differ significantly between models fitting different environmental descriptors (Table 9), indicating that these estimated genetic parameters for growth rate were not affected by the choice of environmental descriptor.

There was no or minimal sire by environment interaction detected for average daily gain using the environmental descriptor based on muscle depth, backfat and daily feed intake, with the interaction terms accounting for 0.01%, 0.3% and 0.8% of the phenotypic variance, respectively. However, there was significant sire by environment interaction for average daily gain when using the environmental descriptor based on the first principal component, which accounted for 1.8% of the phenotypic variance. Although not substantially different, the environmental descriptor based on average daily gain alone accounted for even more phenotypic variance at 2.1%. Therefore, the ability to detect sire by environment interaction for growth rate was greatest using either the environmental descriptor based on average daily gain or the overall descriptor.

The trait used to quantify the environment is usually based on the same trait that is being modelled. For example, numbers born alive was used to quantify disease environments, in which sow reproductive performance was assessed using numbers born alive (Herrero-Medrano et al., 2015). This was also the case for the environmental descriptor based on average daily gain used in this current study. While average daily gain appears to be the driver of the first principal component, this overall descriptor may appear to be a more objective measure of the environment as it does not solely depend on the trait being modelled. However, use of the first principal component does not appear to capture more variation in the environment to increase the ability to detect sire by environment, and the descriptor based on ADG alone appears sufficient.

**Table 9. Sire by environment interaction (S×E) for growth rate, using environmental descriptors based of average daily gain (EADG), backfat (EBF), daily feed intake (EDFI), muscle depth (EMD), and all 4 traits combined using the first principal component (EPC1)**

| Environmental variable | $\hat{\sigma}^2_A$ ± SE | $\hat{\sigma}^2_{CG}$ ± SE | $\hat{\sigma}^2_{S\times E}$ ± SE | $\hat{\sigma}^2_P$ ± SE | $\hat{h}^2$ ± SE | $\hat{c}^2$ ± SE |
|---|---|---|---|---|---|---|
| EADG | 1022 ± 173 | 532 ± 65 | **87.0** ± 37.9 | 4060.3 ± 87.5 | 0.25 ± 0.04 | 0.10 ± 0.01 |
| EBF | 1104 ± 171 | 586 ± 68 | 12.6 ± 28.9 | 4099.0 ± 90.1 | 0.27 ± 0.04 | 0.11 ± 0.01 |
| EDFI | 1067 ± 171 | 584 ± 68 | 32.4 ± 30.9 | 4095.1 ± 89.9 | 0.26 ± 0.04 | 0.11 ± 0.01 |
| EMD | 1123 ± 171 | 587 ± 68 | 0.28 ± 30.2 | 4099.2 ± 90.1 | 0.27 ± 0.04 | 0.11 ± 0.01 |
| EPC1 | 1009 ± 173 | 561 ± 67 | **74.1** ± 36.5 | 4079.8 ± 88.8 | 0.25 ± 0.04 | 0.10 ± 0.01 |

Abbreviations of estimates: $\hat{\sigma}^2_A$ = additive genetic variance (calculated as 4 times the sire variance component estimate), $\hat{\sigma}^2_{CG}$ = contemporary group variance component, $\hat{\sigma}^2_{S\times E}$ = sire by environment interaction variance component, $\hat{\sigma}^2_P$ = phenotypic variance, $\hat{h}^2$ = heritability, $\hat{c}^2$ = proportion of phenotypic variance attributed to common litter effect
Note: Significant S×E in bold

The environmental descriptors were partitioned into quintiles to allow for about 1,500 pigs classified in each environment. This resulted in 10-17% of sires with progeny across all five environments, and 22-25% with progeny in only one environment. The ability to detect sire by environment is greatest when sires are represented across all environments, which can be achieved if the descriptor is partitioned into fewer environments. However, this needs to be balanced out with the need for sufficient differences between environments in order to detect sire by environment interactions for growth.

## Genetic analyses – Australian data – herd B

Variance components were estimated using various fixed and random effect models to evaluate the effect of alternative models on estimates (Table 10). Heritability estimates decreased for all traits once additional random effects were added to the model. For model three, which included three random effects, heritability estimates were low to moderate ranging from 0.142 to 0.210 for the four traits recorded on all animals (average daily gain, backfat, muscle depth and muscle score). Heritability estimates were considerably higher for daily feed intake in comparison to feed conversion ratio. Common litter effect was a significant random effect for all traits ranging from 0.027 to 0.164 and should be fitted for these traits.

Estimates of maternal genetic effects were generally low accounting for 1 to 2.5 % of the phenotypic variance for most traits. Maternal genetic effects affected growth traits the most and were highest for early growth (ADG1; $m^2$: 0.082) which had no significant direct additive genetic effect (heritability) once maternal genetic effects were fitted. This indicates that the genes of the dam are more important than the genes of the animal itself for this early-growth trait. The genes of the dam affect all progeny in the litter, which implies that even low estimates of maternal genetic effects are important breeding objective traits. The economic values for maternal genetic effects are derived by multiplying the economic value of each trait defined for the direct additive genetic effect with the number of piglets per litter (Amer et al., 2014). Further, maternal genetic effects have no costs for phenotyping or genotyping because all relevant information is already available in commercial data sets. Therefore, even low estimates of maternal genetic effects should be considered in breeding programs.

**Table 10. Heritabilities ($h^2$), common litter effect ($c^2$), maternal genetic effects ($m^2$) with standard errors (se, in brackets) and phenotypic variance (Vp) for performance traits**

| Trait | Model | $h^2$ (se) | $c^2$ (se) | $m^2$ (se) | Vp |
|---|---|---|---|---|---|
| ADG | 1 | 0.366 (0.009) | | | 4741 |
| | 2 | 0.255 (0.010) | 0.088 (0.003) | | 4577 |
| | 2[1] | 0.250 (0.010) | 0.084 (0.003) | | 4502 |
| | 3 | 0.210 (0.011) | 0.079 (0.003) | 0.026 (0.0036) | 4539 |
| BF | 1 | 0.235 (0.008) | | | 4.37 |
| | 2 | 0.193 (0.008) | 0.038 (0.003) | | 4.32 |
| | 2[1] | 0.194 (0.008) | 0.038 (0.003) | | 4.31 |
| | 3[2] | 0.170 (0.001) | 0.032 (0.003) | 0.014 (0.0002) | 4.30 |
| MP | 1 | 0.231 (0.008) | | | 30.6 |
| | 2 | 0.195 (0.008) | 0.030 (0.002) | | 30.3 |
| | 3 | 0.172 (0.009) | 0.027 (0.002) | 0.012 (0.002) | 30.2 |
| MS | 1 | 0.233 (0.008) | | | 0.398 |
| | 2 | 0.173 (0.008) | 0.046 (0.003) | | 0.391 |
| | 2[1] | 0.175 (0.008) | 0.046 (0.003) | | 0.390 |
| | 3 | 0.142 (0.009) | 0.038 (0.003) | 0.019 (0.003) | 0.389 |
| ADG1 | 1 | 0.303 (0.051) | | | 1691 |
| | 2 | 0.047 (0.032) | 0.199 (0.025) | | 1608 |
| | 2[1] | 0.033 (0.027) | 0.146 (0.024) | | 1341 |
| | 3 | 0.000 (0.000) | 0.146 (0.027) | 0.082 (0.023) | 1613 |
| | 2[3] | 0.070 (0.033) | 0.203 (0.024) | | 1648 |
| | 3[3] | 0.022 (0.025) | 0.164 (0.026) | 0.067 (0.022) | 1651 |
| TDG | 1 | 0.376 (0.051) | | | 12796 |
| | 2 | 0.278 (0.052) | 0.082 (0.024) | | 12549 |
| | 3 | 0.249 (0.057) | 0.073 (0.025) | 0.020 (0.022) | 12503 |
| | 2[3] | 0.261 (0.048) | 0.101 (0.022) | | 12668 |
| | 3[3] | 0.254 (0.053) | 0.075 (0.023) | 0.013 (0.019) | 11999 |
| TDG | 1 | 0.368 (0.050) | | | 12141 |
| | 2 | 0.293 (0.052) | 0.064 (0.023) | | 11964 |
| | 3 | 0.258 (0.058) | 0.054 (0.025) | 0.024 (0.022) | 11906 |
| DFI | 1 | 0.474 (0.055) | | | 0.0577 |
| | 2 | 0.369 (0.059) | 0.080 (0.024) | | 0.0568 |
| | 2[1] | 0.365 (0.059) | 0.079 (0.024) | | 0.0560 |
| | 3 | 0.368 (0.071) | 0.079 (0.025) | 0.001 (0.024) | 0.0563 |
| | 2[3] | 0.342 (0.055) | 0.122 (0.024) | | 0.0586 |
| | 3[3] | 0.351 (0.064) | 0.102 (0.025) | 0.013 (0.022) | 0.0523 |
| DFI | 1 | 0.476 (0.055) | | | 0.0514 |
| | 2 | 0.393 (0.059) | 0.067 (0.024) | | 0.0505 |
| | 2[1] | 0.382 (0.058) | 0.066 (0.024) | | 0.0494 |
| | 3 | 0.383 (0.071) | 0.065 (0.025) | 0.006 (0.024) | 0.0504 |
| FCR | 1 | 0.190 (0.043) | | | 0.0391 |
| | 2 | 0.082 (0.036) | 0.122 (0.026) | | 0.0387 |
| | 3 | 0.070 (0.036) | 0.113 (0.027) | 0.013 (0.017) | 0.0386 |
| | 2[3] | 0.100 (0.036) | 0.137 (0.025) | | 0.0400 |
| | 3[3] | 0.086 (0.037) | 0.140 (0.026) | 0.010 (0.016) | 0.0390 |
| FCR | 1 | 0.190 (0.044) | | | 0.0382 |
| | 2 | 0.076 (0.035) | 0.130 (0.026) | | 0.0377 |
| | 3 | 0.063 (0.035) | 0.121 (0.028) | 0.014 (0.017) | 0.0377 |

Trait abbreviations: ADG: average daily gain; BF: backfat; MP: muscle percentage; MS: muscle score; ADG1: average daily gain prior to feed intake test; TDG: test daily gain; DFI: daily feed intake; FCR: feed conversion ratio. [1] adjusted for age as outlined in Tables 2 and 3; [2] LogL converged, parameters did not converge; [3]birth month was fitted instead of birth week

## Environmental sensitivity of residual feed intake (RFI) lines at INRA.

Differential selection lines for residual feed intake (RFI) did not differ significantly for growth rate and backfat. This was expected, as selection for RFI aims to change the components of feed efficiency that are independent from growth rate and body composition, at least at the phenotypic level (Kennedy et al., 1993). Estimates of the general regression coefficient (b) from the regression of growth or backfat performance on contemporary group estimates were not significantly different from 1 for all models (Table 11). The line-specific regression coefficient estimates ($b_{line}$) for the highRFI line represent the contrasts between regression coefficients on estimates of contemporary groups between the highRFI versus the lowRFI line. These estimates were positive for the highRFI line for growth ranging from +0.37 to +0.47 kg/d. The standard errors were relatively large (0.23 to 0.24) and the magnitude of the line difference in terms of regression coefficients was not accurately estimated. However, the estimations systematically indicated a positive increase of the slope for the highRFI line compared to the lowRFI line, corresponding to an increased variability of average daily gain with changing quality of the environment in the highRFI line. This finding is further illustrated in Figure 3, which shows the response of the divergent RFI selection lines to changes in the growth environment. The slope was higher for the highRFI line, which indicates higher environmental sensitivity for this line. This potentially decreased robustness in the highRFI line is unexpected and needs confirmation. This result, together with previous studies that showed no impaired responses to immune stress in lowRFI lines (Gilbert and Dekkers, 2013), questions the role of RFI as a buffer nutrient compartment to respond to stress (Rauw, 2007).

**Table 11. Estimates of the general regression coefficients (b) and of the regression coefficient, with standard errors (± SE), for the highRFI line on estimates of contemporary groups (ECG) for average daily gain (ADG, kg/d) and backfat thickness (BFT, mm; from Gilbert et al., 2014).**

| ECG[a] | b | $b_{line}$ – highRFI line[b] | P value |
|---|---|---|---|
| ADG all | 0.95 ± 0.17 | 0.46 ± 0.24 | 0.05 |
| ADG age a | 0.97 ± 0.16 | 0.37 ± 0.23 | 0.11 |
| ADG BW a | 0.95 ± 0.16 | 0.45 ± 0.23 | 0.05 |
| BFT all | 0.99 ± 0.10 | 0.17 ± 0.14 | 0.23 |
| BFT age e | 0.99 ± 0.10 | 0.10 ± 0.14 | 0.45 |
| BFT BW e | 1.05 ± 0.10 | 0.08 ± 0.14 | 0.55 |

[a] Contemporary group estimates were obtained for ADG or BF using models with adjustments for both age and body weight (all) or models with adjustment for only age (age) or only body weight (BW) fitted as covariates at the beginning of test for ADG (age a, BW a) or at the end of test for BFT (age e, BW e). [b] $b_{line}$ for low RFI line = 0.

The contrasts between regression coefficients for each line were not significantly different from zero for backfat, showing that the environmental sensitivity for backfat thickness was not affected by divergent selection on RFI. This finding corresponds to results by by Li and Hermesch (2016a) who found no breed difference for environmental sensitivity of body composition.

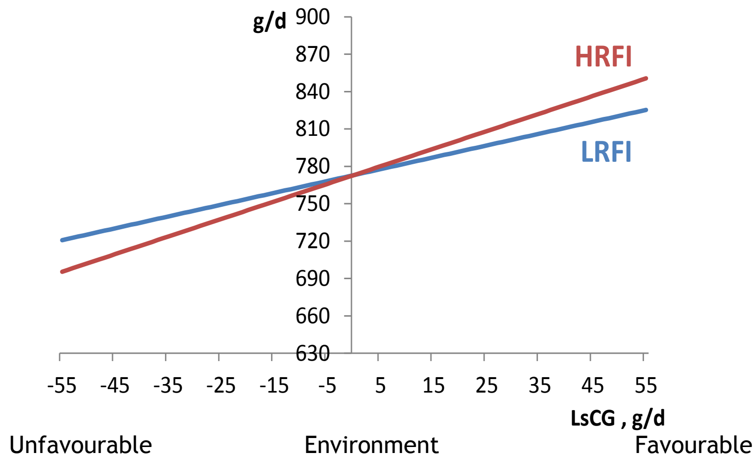


**Figure 3. Response of divergent selection lines for residual feed intake to variation in environmental conditions (HRFI: high residual feed intake line (less efficient); LRFI: low residual feed intake line (more efficient) (based on Gilbert et al., 2014).**

## *3.3.* Evaluation of selection strategies

### Sensitivity analysis of input parameters for growing pig.

The sensitivities of economic weights for traits of growing pigs were evaluated by increasing a single input parameter by 20% at a time while other input parameters of each model were not varied. For feed conversion ratio, an increase in feed costs per pig and live weight of pigs at slaughter by 20% resulted in a proportional increase in the magnitude of the economic weight for feed conversion ratio due to the linear relationship between the economic weight of feed conversion ratio and feed costs or live weight. Further, there was a proportional increase in the economic weight for lifetime daily feed intake when feed cost was increased by 20% and a slightly higher (21.9%) increase in the economic weight for daily feed intake when live weight increased by 20% (Table 12). Daily non-feed cost ($C_{NF}$) is affected by the return per pig, which is based on price of finished pig carcass and carcass weight. For the scenario with feed conversion ratio in the breeding objective, economic value for growth only accounts for non-feed costs while the economic value for growth that also include daily feed intake in the breeding objective accounts for non-feed costs as well as feed costs. Therefore, an increase in price of finished pig carcass or carcass weight had a larger impact on the economic weight for growth with feed conversion ratio in the breeding objective than on economic weight for growth with daily feed intake in the breeding objective. A number of cost factors influence the economic value for post-weaning survival in both scenarios. Therefore, the magnitude of change in economic weights for post-weaning survival was less than 20% for a 20% increase in any single input parameter. Finally, the greatest change in an economic weight was observed for carcass backfat (149.3%) which resulted from a 20% increase in mean carcass backfat.

**Table 12. Sensitivity of economic weights in the sire-line index relative to the scenario with no changes to input parameters (BASE) in PigEV models to derive economic values.**

| Trait | Percentage changes in economic weights in sire-line index relative to BASE economic weights for a 20% increase in each respective parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $F_P$ | $Cwt_P$ | $P_P$ | $V_W$ | $Wt_P$ | μCBF | σCBF | $Age_M$ |
| Lifetime feed conversion ratio (FCR, kg feed·kg liveweight gain$^{-1}$) | 20% | 0 | 0 | 0 | 20% | 0 | 0 | 0 |
| Average daily gain (with FCR in the breeding objective) | 0% | 61.1% | 61.1% | -24.1% | -5.1% | 0% | 0% | 0% |
| Lifetime piglet daily feed intake (DFI, kg·day$^{-1}$) | 20.0% | 0% | 0% | 0% | 21.9% | 0% | 0% | 0% |
| Average daily gain (with DFI in the breeding objective) | 0% | 33.9% | 33.9% | -13.4% | -5.1% | 0% | 0% | 0% |
| Post-weaning survival (cost-saving approach, pig survival·pig weaned$^{-1}$) | 1.9% | 14.0% | 14.0% | 5.6% | -4.8% | 0% | 0% | 11.1% |
| Post-weaning survival (lost-revenue approach, pig survival·pig weaned$^{-1}$) | -4.1% | 13.0% | 13.0% | 5.2% | -14.2% | 0% | 0% | 10.3% |
| Carcass backfat (mm) | 0% | 0% | 0% | 0% | -0.5% | 149.3% | 13.0% | 0% |

Abbreviations: $F_P$:cumulative mass (kg dry matter) of feed consumed during the finishing period of a growing pig; $Cwt_P$: carcass weight (kg) of a finished pig; $P_P$: price of a finished grower pig carcass ($AU·kg carcass$^{-1}$); $V_W$: purchase value of the weaner pig ($AU·pig$^{-1}$); $Wt_P$: slaughter weight (kg) of grower pigs; μCBF: mean carcass backfat (mm) ; ¤CBF :standard deviation of carcass backfat (mm); $Age_M$: average age of pigs that die post weaning (days).

## Evaluation of selection strategies

The response to selection is shown per generation assuming a selection intensity of one. This response is similar to expected annual genetic gains because the selection intensity achieved in practice is similar to the generation interval of about 1.65 years. The overall response in the breeding objective with feed conversion ratio was $3.61 per pig for index 1 in Table 13. This index has traditionally been used in pig industries. It leads to favourable responses in feed conversion ratio and loin weight due to favourable genetic associations with average daily gain and backfat. Individual piglet weight at birth has a low heritability and recording this trait (index 2) is of limited value for genetic improvement of efficient lean meat growth in growing pigs.

Post-weaning survival was the most important breeding objectives trait in both breeding objectives based genetic standard deviations of traits. This trait accounted for 38% (breeding objective with feed conversion ratio) or 35% (breeding objective with daily feed intake) of the selection emphasis relative to genetic standard deviations of traits. Using information about post-weaning survival for the sire in index 3 resulted in a predicted response of 0.0009 (or 0.09%) which implies that it would take about 12 generations to improve post-weaning survival by one percent. The index calculations in this study assumed no genetic associations between post-weaning survival and other traits.

Additional analyses demonstrated (results not shown) that response in post-weaning survival was lowly negative when unfavourable genetic correlations with a magnitude of 0.2 were assumed with other breeding objective traits. Knap (2014) demonstrated favourable genetic trends for survival of pigs from birth to slaughter based on combined pre- and post-weaning survival. Genetic trends for post-weaning survival were not explicitly shown.

**Table 13. Traits measured in index, accuracy of index (Acc), overall selection response (ΔG in $/pig) and response in breeding objective traits per generation with selection intensity of one – breeding objective includes feed conversion ratio instead of daily feed intake**

| Index | Traits measured[1] | Acc | ΔG | ADG | BF | FCR | PWS | LW | BW |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ADG, BF | 0.36 | 3.61 | 15.63 | -0.467 | -0.036 | 0.00000 | 0.121 | -0.0228 |
| 2 | Index 1 + PBW | 0.36 | 3.63 | 15.90 | -0.466 | -0.037 | 0.00000 | 0.119 | -0.0202 |
| 3 | Index 2 + PWS | 0.37 | 3.72 | 15.55 | -0.455 | -0.036 | 0.00090 | 0.116 | -0.0197 |
| 4 | Index 3 + LW + BW | 0.41 | 4.13 | 13.75 | -0.429 | -0.047 | 0.00081 | 0.224 | -0.0611 |
| 5 | Index 4 + IGF1 | 0.44 | 4.43 | 12.99 | -0.416 | -0.062 | 0.00075 | 0.220 | -0.0644 |
| 6 | Index 5 + FCR | 0.46 | 4.59 | 12.62 | -0.396 | -0.069 | 0.00073 | 0.230 | -0.0684 |

Trait abbreviations: ADG: average daily gain (g/d), BF: back fat (mm), FCR: feed conversion ratio (kg feed/ kg gain), DFI: daily feed intake (kg/day), PWS: post-weaning survival (0/1), LW: loin weight (kg), BW: belly weight (kg), IGF1: juvenile insulin-like growth factor-I (ng/ml), PBW: piglet birth weight (kg).

Adding information about loin weight and belly weight led to the highest marginal gain in the overall breeding objective with feed conversion ratio. The response increased by 11.0% from 3.72 to 4.13 $/pig due to genetic gain in loin weight for the breeding objective with feed conversion ratio. No favourable response was achieved in belly weight due to unfavourable genetic correlations with loin weight or backfat. In comparison, adding IGF1 and feed conversion ratio to the selection index for the breeding objective with feed conversion ratio increased the overall response to $4.43 and $4.59 per pig equivalent of an increase of 7.3% and 3.6% relative to the preceding index. Therefore, recording feed conversion ratio does not lead to substantial additional response once other traits with favourable genetic correlations to feed conversion ratio (IGF1, loin weight, average daily gain and backfat) have already been considered.

Responses in average daily gain and feed conversion ratio contributed most to the overall response of the breeding objective with feed conversion ratio accounting for 39% and 27% in index 1 to 25% and 41% in index 6, respectively. As more traits were added to the index, responses in backfat decreased while responses in the additional carcase trait loin weight increased. Backfat and loin weight accounted for 22% to 15% and 12% to 18% of the overall responses in the breeding objective, which demonstrates that selection for carcase traits related to lean meat content continues to provide economic returns.

Including daily feed intake in the breeding objective is an alternative selection strategy to consider feed cost (Table 14). Selection response in daily feed intake was only achieved after juvenile IGF1 or daily feed intake were recorded (index 4 and 5). All other selection strategies did not lead to any response in daily feed intake due to its unfavourable genetic correlation with average daily gain of 0.50. Consequently, the response in the overall breeding objective with daily feed intake was lower in comparison to the previous breeding objective with feed conversion ratio ranging from $3.48 to $4.00 per pig for index 1 to 6. The favourable genetic correlation between daily feed intake and backfat implied that more response was obtained in backfat in comparison to the breeding objective with feed conversion ratio. Further, the added response in the breeding objective due to recording an additional trait was highest for daily feed intake contrary to recording feed conversion ratio in the previous breeding objective. Therefore, considering feed costs in the breeding objective with daily feed intake is most effective if daily feed intake is also recorded.

**Table 14. Traits measured in index, accuracy of index (Acc), overall selection response (ΔG in $/pig) and response in breeding objective traits per generation with selection intensity of one – breeding objective includes daily feed intake instead of feed conversion ratio**

| Index | Traits measured[1] | Acc | ΔG | ADG | BF | DFI | PWS | LW | BW |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ADG, BF | 0.383 | 3.48 | 11.84 | -0.583 | 0.000 | 0.00000 | 0.179 | -0.049 |
| 2 | Index 1 + PBW | 0.386 | 3.51 | 12.15 | -0.580 | 0.000 | 0.00000 | 0.176 | -0.046 |
| 3 | Index 2 + PWS | 0.396 | 3.60 | 11.86 | -0.566 | 0.000 | 0.00093 | 0.172 | -0.044 |
| 4 | Index 3 + LW + BW | 0.406 | 3.69 | 11.47 | -0.560 | 0.000 | 0.00091 | 0.226 | -0.059 |
| 5 | Index 4 + IGF1 | 0.416 | 3.78 | 11.30 | -0.556 | -0.003 | 0.00088 | 0.228 | -0.062 |
| 6 | Index 5 + DFI | 0.440 | 4.00 | 10.13 | -0.557 | -0.015 | 0.00084 | 0.221 | -0.064 |

[1]: for trait abbreviations see Table 13.

## Consistency of economic values and implications of genetic correlations

These results were further explored by checking whether economic values for average daily gain and daily feed intake were consistent between both breeding objectives given the assumed breeding objective for feed conversion ratio. Because feed conversion ratio is a ratio of growth rate and daily feed intake, each economic value for feed conversion ratio and average gaily gain (or daily feed intake) has an equivalent economic value for average daily gain (or daily feed intake) for the breeding objective that includes daily feed intake instead of feed conversion ratio. This check revealed that the economic value for daily feed intake was slightly lower than expectations, while the economic value for average daily gain should have been higher. The economic value for daily feed intake was -36.1 in the original breeding objective versus an expectation of – 34.5. The economic value for average daily gain used in the original calculations was 0.16 versus an expected economic value of 0.175. Therefore, economic values were changed by -4% for daily feed intake and + 9% for average daily gain leading to economic and genetic responses, shown in Table 15. These changes in economic values affected response in daily feed intake most, which was reduced by 27% percent demonstrating that traits with least information are affected most by changes in economic values. In contrast, response in average daily gain increased only by 15% despite the fact that the change in the economic value for average daily gain was larger in comparison to the change in the economic value for daily feed intake. Although the economic response in the breeding objective increased by 3% from 4.00 $/pig to 4.14 $/pig, the breeding objective with daily feed intake still showed a lower overall economic response than the breeding objective that included feed conversion ratio. Therefore, differences in economic values did not explain these differences in economic response, and the impact of changes in genetic parameters were evaluated in subsequent sensitivity analyses.

Sensitivity analyses were then conducted to explore implications of changes in genetic correlations between growth and feed conversion ratio or daily feed intake in both breeding objectives. Growth and feed conversion ratio had a favourable genetic correlation of 0.37 in the breeding objective with feed conversion ratio, which was reduced to 0.27 and 0.17 (Table 16) in the sensitivity analyses. This change in genetic correlations had similar effects on responses for average daily gain and feed conversion ratio which decreased by 9 and 7, and 18 and 16%, respectively. Further, the overall economic response decreased from $ 4.59 per pig to $ 4.40 and $ 4.22 per pig, which is more in line with the economic response achieved for the breeding objective with daily feed intake.

**Table 15. Accuracy (Acc), economic response (ΔG ($/pig)) and genetic responses in average daily gain (ADG), backfat (BF), feed conversion ratio (FCR) and daily feed intake (DFI) for two breeding objectives (BO) and the alternative BO that used the modified economic values (EV).**

| | Acc | ΔG ($/pig) | ADG | BF | FCR | DFI |
|---|---|---|---|---|---|---|
| BO with FCR | 0.46 | 4.59 | 12.62 | -0.40 | -0.069 | |
| BO with DFI | 0.44 | 4.00 | 10.13 | -0.56 | | -0.015 |
| modified EV | 0.45 (+2%) | 4.14 (+3%) | 11.63 (+15%) | -0.53 (-5%) | | -0.011 (-27%) |

**Table 16. Implication of changing the genetic correlation between average daily gain (ADG) and feed conversion ratio (FCR) in the breeding objective (BO) with FCR for accuracy (Acc), economic response (ΔG ($/pig)) and genetic responses in ADG, backfat (BF) and FCR.**

| BO with FCR | | Acc | ΔG ($/pig) | ADG | BF | FCR |
|---|---|---|---|---|---|---|
| Gen. corr. of | 0.37 | 0.46 | 4.59 | 12.62 | -0.40 | -0.069 |
| | 0.27 | 0.45 (-2%) | 4.40 (-4%) | 11.56 (-9% ) | -0.41 (+3%) | -0.064 (-7%) |
| | 0.17 | 0.43 (-4%) | 4.22 (-8%) | 10.39 (-18% ) | -0.42 (+5%) | -0.058 (-16%) |

In contrast to the favourable genetic correlation between average daily gain and feed conversion ratio, there was a strong unfavourable genetic correlation between average daily gain and daily feed intake. The sensitivity analyses were based on a reduction of this unfavourable genetic correlation from 0.50 to 0.40 and 0.30 (Table 17). This shift in genetic correlations had the largest impact on response in daily feed intake, which increased by 33% and 66%, respectively. It demonstrates the importance of using accurate estimates of this genetic correlation between average daily gain and feed intake in breeding objectives that are based on daily feed intake to account for feed costs. Response in average daily gain increased by 9% and 18% due to these changes in the genetic correlation between average daily gain and daily feed intake, while response in backfat was reduced by 5 and 9%, respectively. The economic response in the overall breeding objective increased by 6% and 12%, which was similar to the economic response observed for the breeding objective that included feed conversion ratio.

In summary, these additional analyses demonstrate the importance of obtaining accurate estimates of genetic correlations between average daily gain and daily feed intake. Changes in this unfavourable genetic correlation affected response in daily feed intake and average daily gain more in comparison to changes in the favourable genetic correlation between average daily gain and feed conversion ratio. Changes in economic values had a smaller effect than changes in genetic correlations and obtaining accurate estimates of genetic parameters is important. This is of particular importance for traits with less information and for trait combinations that have unfavourable genetic correlations.

**Table 17. Implication of changing the genetic correlation between average daily gain (ADG) and feed conversion ratio (FCR) in the breeding objective (BO) with FCR for accuracy (Acc), economic response (ΔG ($/pig)) and genetic responses in ADG, backfat (BF) and FCR.**

| BO with DFI | | Acc | ΔG ($/pig) | ADG | BF | DFI |
|---|---|---|---|---|---|---|
| Gen. corr. of | 0.50 | 0.44 | 4.00 | 10.13 | -0.56 | -0.015 |
| | 0.40 | 0.46 (+2%) | 4.24 (+6%) | 11.07 (+9%) | -0.53 (-5%) | -0.020 (+33%) |
| | 0.30 | 0.48 (+4%) | 4.49 (+12%) | 12.02 (+18%) | -0.51 (-9%) | -0.025 (+66%) |

### Including RFI in breeding objectives

The index calculations were finalised by developing an index that included residual feed intake (RFI) to account for feed costs instead of feed conversion ratio or daily feed intake. Multiple studies from the divergent selection lines for RFI at INRA and Iowa State University (ISU) have shown that selection for reduced RFI, which represent more efficient pigs, have either no or even a slightly beneficial effect on aspects of robustness. These associations were outlined in the review paper by Hermesch et al. (2015) for APSA 2015. Despite this knowledge, RFI has not been included in breeding objectives and has not been explored as a breeding objective trait because it was unclear how to include RFI in selection decisions.

Existing index calculations outlined in previous sections were extended to include RFI as the breeding objective trait. For this approach, the economic value for RFI is the same as the economic value for DFI. Further, the economic value for growth should include feed costs, because RFI does not include improvements in efficiency due to improved growth (Hélène Gilbert, personal communication). Therefore, the economic values for RFI and growth are the same as the economic values for daily feed intake and growth. This new alternative selection strategy is of interest because selection emphasis on reducing feed intake is only targeted towards the part of feed intake that is not related to lean meat growth. This may explain why selection for low RFI did not affect aspects of robustness unfavourably in the divergent selection lines at ISU and INRA as was expected.

## *3.4.* Fostering adoption of research results

A contract for the release of PigEV was prepared and signed by the Pork CRC and the parent organisations of AGBU. A sublicense agreement for breeders was developed. The program PigEV is being used in the industry and new breeding objectives have been setup by breeding companies in Australia based on new economic weights derived from the use of PigEV. Evaluation of breeding objectives for breeding programs is ongoing and PigEV will remain an important tool for breeders in future evaluations of breeding objectives.

## *3.5.* Publications arising from this project

### Invited review

An invited review paper about selection strategies for productivity and robustness was written for APSA 2015 (Hermesch et al., 2015). The review summarises the main research results from Sub-Program 2B and as such was a major review. The abstract and conclusions of this review were:

**Abstract**. Pig breeding programs worldwide continue to focus on both productivity and robustness. This selection emphasis has to be accompanied by provision of better-quality environments to pigs to improve performance and to enhance health and welfare of pigs. Definition of broader breeding objectives that include robustness traits in addition to production traits is the first step in the development of selection strategies for productivity and robustness. An approach has been presented which facilitates extension of breeding objectives. Post-weaning survival, maternal genetic effects for growth as an indicator of health status and sow mature weight are examples of robustness traits. Further, breeding objectives should be defined for commercial environments and selection indexes should account for genotype by environment interactions (GxE). Average performances of groups of pigs have been used to quantify the additive effects of multiple environmental factors on performance of pigs. For growth, GxE existed when environments differed by 60 g/day between groups of pigs. This environmental variation was observed even on well-managed farms. Selection for improved health of pigs should focus on disease resistance to indirectly reduce pathogen loads on farms and on disease resilience to improve the ability of pigs to cope with infection challenges. Traits defining disease resilience may be based on performance and immune measures, disease incidence or survival rates of pigs. Residual feed intake (RFI) is a trait that quantifies feed efficiency. The responses of divergent selection lines for RFI to various environmental challenges were often similar or even favourable for the more efficient, low RFI line. These somewhat unexpected results highlight the need to gain a better understanding of the metabolic differences between more or less productive pigs. These physiological differences lead to interactions between the genetic potential of pigs for productivity and robustness and the prevalence of specific environmental conditions

**Conclusions**. Pig breeding programs around the world continue to improve both productivity and robustness by extending selection emphasis to a wider range of traits. No trait group can be seen in isolation. Further, genetic improvement itself cannot be viewed in isolation and needs to be accompanied by improvement in management strategies. Selection and management strategies will both lead to continued improvements in performance, health and welfare of pigs. The main conclusions of this review are:

1) Improving environmental conditions on farm is the first priority. Genetic analyses disentangle genetic from environmental effects and provide descriptors of environmental conditions in the absence of explicit environmental measures. Estimates of environmental descriptors from genetic analyses could be used to monitor environmental conditions on farm, which depend on multiple specific environmental factors including

the incidence of disease. Further, new technologies in precision agriculture and veterinary practice offer new opportunities to quantify environmental and pathogen challenges better.

2) A flexible approach has been presented that facilitates extension of breeding objectives to include further traits that describe productivity and robustness of animals. The level of performance affects the economic importance of some breeding-objective traits and breeding objectives should be defined for the commercial environments of the production of pork.
3) Defining traits for breeding programs to improve health status of pigs remains challenging. The rate of genetic improvement increases as more sources of phenotypic information and genetic information, via marker-assisted selection or genomic selection, are incorporated in genetic evaluations. Information about repeated measures of growth and feed intake, survival of pigs, disease incidence and medication records as well as immune parameters will aid genetic improvement of disease resilience.
4) Selection for improved health of pigs should incorporate disease resistance traits for infectious diseases such as *Escherichia coli* infections because selection for improved disease resistance reduces pathogen load on farm and therefore improves environmental conditions for all pigs. The specific infection pathways of each pathogen have to be considered in selection strategies for each specific disease resistance trait.
5) It is possible to improve productivity and robustness simultaneously. The responses of divergent selection lines for residual feed intake to challenging environments, or controlled heat or PRRS challenges were often similar or even favourable for the more efficient, low RFI line. Further research is required to evaluate why the associations between productivity and robustness traits have been variable between studies. This requires better understanding of the metabolic differences between more or less productive pigs to comprehend the interactions of the genetic potential of pigs for productivity and robustness and the prevalence of specific environmental conditions.

## References of publications arising from this project.

During this project the following publications and presentations were prepared and finalised leading to 10 refereed scientific publications in addition to 1 industry publication and 2 presentations.

### Journal papers

Amer, PR, Ludemann, CI, Hermesch, S (2014) Economic weights for maternal traits of sows, including sow longevity. *Journal of Animal Science* **92**, 5345-5357.

Hermesch, S, Li, L, Doeschl-Wilson, AB, Gilbert, H (2015b) Selection for productivity and robustness traits in pigs. *Animal Production Science* **55**, 1437-1447.

Hermesch, S, Ludemann, CI, Amer, PR (2014a) Economic weights for performance and survival traits of growing pigs. *Journal of Animal Science* **92**, 5358-5366.

Li, L, Hermesch, S (2016a) Environmental variation and breed sensitivity for growth rate and backfat depth in pigs. *Animal Production Science* **56**, 61-69.

Li, L, Hermesch, S (2016b) Evaluation of sire by environment interactions for growth rate and backfat depth using reaction norm models in pigs. *Journal of Animal Breeding and Genetics* **133**, 429-440.

**Conference papers**

Gilbert, H, David, I, Billon, Y, Hermesch, S (2014) Does selection for RFI affect the sensitivity to environmental variation in pigs? In '10th World Congress of Genetics Applied to Livestock Production. Vancouver, Canada'. pp. Paper 123.

Guy, SZY, Hermesch, S, Thomson, PC (2015) Backfat as an Environmental Descriptor in Defining Growth Rate of the Pig: A GxE Analysis. In 'Proc. Assoc. Advmt. Anim. Breed. Genet. Lorne, Australia'. Volume 21 pp. 457-460. (Association for the Advancement of Animal Breeding and Genetics).

Hermesch, S, Arnal, M, Börner, V, Dominik, S (2015a) Selection strategies for breeding objectives in growing pigs. In 'Proc. Assoc. Advmt. Anim. Breed. Genet. Lorne, Australia'. Volume 21 pp. 1-4. (Association for the Advancement of Animal Breeding and Genetics)

Hermesch, S, Parke, CR, Bauer, MM, Gilbert, H (2014b) Maternal genetic effects for lifetime growth should be considered more in pig breeding. In '10th World Congress of Genetics Applied to Livestock Production. Vancouver, Canada'. pp. Paper 367.

Hermesch, S, Sokolinski, R, Johnston, R, Newman, S, JR Pluske, JS Pluske (Eds) (2015c) 'Economic evaluation of environmental variation observed in a pig nucleus farm in Australia., Manipulating pig production XV. Proceedings of the Fifteenth Biennial Conference of the Australasian Pig Science Association.' Melbourne, Australia. (Australasian Pig Science Association (Inc.): 55:1466

**Industry publications**

Hermesch, S, 2015a. Making genes fit for a pig. Pork CRC Projects 2B-101, 2B-102, 2B-103, 2B-104,. Australian Pork Newspaper. Collins Media Pty Ltd, Cleveland. 10.

**Presentations**

Hermesch, S, 2015b. Maternal genetic effects should be considered more in pig breeding. Castanet-Tolosan, France.

Hermesch, S, 2015c. Selection strategies for feed efficiency in pigs. Omaha, Nebraska, US, 2015, (http://www.swinefeedefficiency.com/icfes.html).

# 4. Application of Research

Contemporary group estimates based on performance and feed efficiency traits provide a simple and practical way to quantify the environment using standard performance records collected on farm. Variation in environments was evident for herds of high health status, providing opportunities to evaluate and select for sire lines that show lower environmental sensitivity, and opportunities to improve the environment.

Combining environmental variables into an overall environment index may capture different aspects of the production environment better. However, growth rate appears to be the trait that captures the most environmental variation, highlighting the importance of sufficient, and accurate, weight records. Feed intake was a further trait that showed considerable environmental variation and information about feed intake for groups of pigs should be considered to monitor environmental conditions if feed intake data are available.

The overall environment index produced by a linear combination of traits, weighted by economic values, allows producers to quantify the economic consequences of variation in environment. This puts a dollar value to providing optimum environmental conditions to pigs with favourable effects on productivity and welfare of pigs. This approach provides further incentives for producers to improve the environments since this environmental index is expressed in $/pig.

Selection for both productivity and robustness is possible since there is evidence from divergent selection lines for residual feed intake that more efficient pigs are less environmentally sensitive than less efficient pigs of the high residual feed intake line. This finding is beneficial because it benefits both selection for low feed conversion ratio to reduce feed costs and more consistent performance across different environmental conditions.

Genetic models developed in this study allow evaluation of genotype by environment interaction, using contemporary group estimates as environmental descriptor. Sire by environment interaction models and multi-trait models provide simple methodology that can be used to evaluate the extent of genotype by environment interaction. This can be extended to evaluation of response of selection lines, or sire lines using random regression models, and allows appropriate selection of sires so that their progeny are allocated to the environments best suited to them. The genetic models developed in this study can also be applied to alternative traits, and can be adjusted easily for big systematic effects on an individual farm basis.

The PigEV worksheet extension allows breeders to extend breeding objectives easily and provides producers with a tool to evaluate whether a change in management strategy is worthwhile.

Sensitivity analysis of input parameters for breeding objectives allow decisions to be made about selection strategies and traits included in breeding objectives on a case-by-case basis (i.e. flexibility for an individual's breeding objective).

# 5. Conclusion

Selection for robustness and health requires a comprehensive breeding program that considers a wider range of sources of information available from farms and other organisations (e.g. climatic data from Bureau of Meteorology). Further, precision farming will provide new data that will be beneficial for describing robustness and health on farms. These type of data should be used to improve the definition of traits describing robustness and health further. Examples have been evaluated in this project and the methodologies developed in this study can be applied to other scenarios once data are available from industry.

Providing the best environment possible to pigs and sows is the first priority. The methodology developed in this project can be used to describe fluctuations in environmental conditions over time using information readily available on farms. The models can take systematic changes in husbandry practices into account and provide alternative avenues to consider information about multiple traits in an overall environmental index. Information about growth and feed intake was most informative for describing environmental conditions.

Low estimates of sire by genotype interactions were found for growth rate using data recorded within individual herds. Alternative genetic models were used to quantify the magnitude of sire by environment interactions. A simple multi-trait approach is suggested for consideration of sire by environment interactions in breeding programs.

The predicted annual genetic gain in the overall breeding objective was mainly influenced by productivity traits. Robustness traits, including post-weaning survival, contributed less to this predicted annual genetic gain because they had lower heritabilities and less information available at selection. This highlights the need for better phenotypic data, which may be complemented, by genomic data to enhance genetic improvement of robustness traits.

Post-weaning survival was the most important trait in the breeding objective when expressed based on the genetic standard deviations of breeding objective traits. However, information about post-weaning survival is limited for selection candidates and only sires can be differentiated. The index calculations conducted in this study indicated that it would take about 12 generations to improve post-weaning survival by one percent.

Low estimates of maternal genetic effects were confirmed in this study for growth. Estimates for maternal genetic effects were negligible for feed intake or traits describing body composition (fat and muscle depth). These genetic effects represent the genes of the sow affecting growth of progeny, which provide further avenues for genetic improvement.

Selection for higher growth rate of growing pigs will lead to larger mature sizes of sows. The economic weight for sow mature size is negative due to the increase in maintenance and capital costs of larger sows. Sow mature size should be recorded on farms and should be included in breeding objectives in order to monitor and possibly limit further genetic gain in sow mature size.

Genetic improvement of productivity is simple in comparison to genetic improvement of robustness and health traits because data are readily available for productivity traits and no genotype by environment interactions are considered in selection for productivity. More extensive training of industry personnel is required to better understand the complexity of genetic improvement of robustness and health.

# 6. Limitations/Risks

The application of the research findings requires extensive data and increased expertise of staff in principles of genetic improvement. Continued investments in enhancing recording procedures and data management on farms as well as continued training of staff responsible for implementing genetic improvement systems on farms are required.

Multiple people working in the Australian pig industry are currently being trained by researchers from Animal Genetics and Breeding Unit via formal or informal postgraduate studies in quantitative genetics and animal breeding. This will foster the implementation of the research findings of this project.

Research findings have been developed in collaboration with major breeding companies and research activities are part of the adoption process.

# 7. Recommendations

Avenues of using data from commercial farms in breeding programs should be explored because variation in environmental conditions is expected to be larger between herds. Larger variation in environmental conditions between farms leads to an increase in the magnitude and economic importance of genotype by environment interactions.

More weight records should be collected on farms because growth is regarded as a health indicator, it was most informative in describing environmental conditions and genotype by environment interactions were found for growth in multiple herds.

Genetic parameters should be evaluated regularly because estimates of genetic correlations affect response to selection considerably. In particular, genetic correlations between traits with limited information have the biggest impact on response to selection. These traits include robustness traits describing environmental sensitivity and survival as well as the efficiency traits feed intake or feed conversion ratio. Updating genetic correlations between traits as more information becomes available is important for breeding programs.

Further information about genetic parameters for post-weaning survival should be evaluated as it becomes available from the literature and additional analyses. The use of genomic information to boost genetic improvement of post-weaning survival should be explored.

Weight of sows should be recorded on farms at a consistent time (e.g. shortly before farrowing or shortly after weaning). Sow mature weight should be included in the breeding objective and selection decisions. Ignoring sow mature weight in breeding programs will increase sow mature size further because selection for growth rate leads to larger mature size.

Maternal genetic effects for growth should be considered in breeding programs. Sufficient information is now available in most pig breeding programs that have data available over multiple years. Maternal genetic effects are part of the breeding objectives and as such provide further avenues to increase economic returns.

Pen information should be recorded on farms for growing pigs, which will allow finer description of environmental effects. Further, this information will allow research into indirect genetic effects, which has been shown to be associated with maternal genetic effects.

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