2B-103: SELECTION FOR DISEASE RESILIENCE – PILOT STUDY

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

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Executive Summary

Rationale

Disease resilience is the ability of a host to maintain a reasonable level of productivity when challenged by infection (Albers et al. 1987). General immunity depends on innate and adaptive immunity which have are both influenced by genetic factors (e,g. Henryon et al. 2006, Clapperton et al. 2009, Flori et al. 2011). Further, herd health status affected estimates of genetic associations between some immune traits and growth (Clapperton et al. 2009). Therefore, information about the infection load of the environment is required when estimating genetic parameters for survival, health, growth and immune traits that describe aspects of disease resilience.

Methodology

Repeated weight measurements were recorded for 2388 pigs from January 2013 to October 2014. A proportion of pigs (910 pigs) had 20 immune traits recorded including differential blood counts, immunoglobulins and haptoglobin. These immune traits were recorded in weaner pigs at 37 days of age. Further information was available about the incidence of disease, medication and mortalities of pigs. A specific scoring methodology was developed for this project to record incidence of disease at each weighing of pigs. Four air quality measures (temperature, humidity, carbon dioxide and ammonia) were collected in individual pens of three pens housing weaner, porker and finisher pigs. Mixed models including fixed and random effects were developed for 15 growth and 20 immune traits.

Outcomes

Air quality measures. Coefficients of variations ranged from 10 to 53% for the four air quality measures. This variability demonstrates that the micro-environments of individual pens vary considerably within a shed.

Mortalities and treatments. The majority of mortalities (68% of all mortalities) occurred shortly after weaning leading to an average age of death of 58 days in this herd. The average age when pigs die after weaning affects the economic importance of post-weaning survival. Most treatments (57% of all treatments) were required for grower pigs. These medical interventions were often related to tail biting.

Scoring system for disease incidence was developed which provides an avenue to monitor incidence of diseases related to skin, tail and limbs, ear, eye and respiratory diseases as well as health issues related to intestine and hernia or the nervous system.

Disease resilience was defined as a two-dimensional trait which requires information about prevalent infection challenge and performance of pigs when challenged by infection. Information required to define disease resilience was outlined at an industry workshop.

Maternal genetic effects are potential breeding objective traits and should be considered more in pig breeding programs. Estimates of maternal genetic effects were slightly higher for growth (0.03) than backfat (0.01). Genetic analyses showed that selection for direct and maternal genetic effects will influence growth in a similar pattern. It should be explored further, whether selection for maternal genetic effects for lifetime growth rate favours higher pre-weaning growth followed by a reduction in growth shortly after weaning.

Mixed models that included fixed and random effects were developed for backfat depth as well as 15 growth and 20 immune traits. Main fixed effects were sex of the animal and characteristics of the birth litter including parity of the sow, litter size and weaning age. Random effects consisted of weekly batches, sire and common litter effect.

Variance components. Pigs were housed in weekly batches, which were fitted as a random effect to estimate the effects of the common environment experienced by pigs raised together. Batch accounted for 11 to 59% of phenotypic variation for growth traits. In comparison, heritabilities and common litter effect estimates varied from 0.04 to 0.37 and from 0.02 to 0.33, respectively for these growth traits. Most immune traits were moderately to highly heritable. There were 14 immune traits with heritability estimates that varied from 0.20 to 0.68. Weekly batch accounted for most of the phenotypic variation for immunoglobulins and haptoglobin demonstrating that these measures are good indicators of herd health. Immune traits were recorded shortly after weaning and were affected by common litter effects which accounted for 8 to 26% of the phenotypic variance.

Publications and international workshop. An international workshop on genetic improvement of resilience was held leading to the publication of 1 refereed book. In addition, the project has resulted in 1 refereed book chapter, 2 conference papers, 1 industry publications and 2 presentations thus far.

Implications

Heritability estimates were moderate to high for most for immune traits. These immune measurements were recorded shortly after weaning and offer opportunities for early selection of pigs with improved health status. Estimates of genetic correlations are required before these immune traits can be considered as selection criteria for pig breeding programs.

Micro-environments within a shed can be easily monitored with simple and cost-effective air quality measures. A better monitoring system of air quality of individual pens can be used to improve specific micro-environments within a shed. This will have positive effects for the health status of pigs in each shed and will also lead to better working conditions for staff.

Scoring system for disease incidence can be used to monitor incidence of various diseases more precisely on farms. Adoption of this scoring system of disease incidence requires appropriate software and training to ensure consistency of scores among operators.

New measurement technique was developed for haptoglobin. Options for the development of a commercial test should be explored taking into account that other commercial tests are already available for haptoglobin.

Further opportunities

At international workshop on resilience, other researchers (Hine et al. 2014) outlined the use of an immune responsiveness test in cattle. Selection of sires with improved immune responsiveness has been shown to lead to lower incidence of mastitis (44% reduction), pneumonia (25% reduction) and overall disease incidence (8% reduction) as reviewed by Mallard et al. (2014, WCDS Advances in Dairy Technology). A selection experiment in pigs conducted by the same group has demonstrated genetic differences for immune responsiveness in pigs and opportunities exist to develop an immune responsiveness test in pigs.

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Introduction

Selection for high productivity has been the long-term focus of pig breeding programs worldwide. However, the reviews by Rauw et al. (1998) and Prunier et al. (2010) highlighted that highly productive pigs may have increased difficulties in coping with environmental challenges and may be more susceptible to stress and disease through increased behavioural, physiological and immunological problems. In regard to commercial pig populations, increased sensitivity to infection levels has been demonstrated in commercial pig lines selected for efficient lean meat growth (Schinckel et al., 1999; Doeschl-Wilson et al., 2009) highlighting the need to incorporate disease resilience in selection decisions.

Disease resilience was defined by Albers et al. (1987) as the ability of a host to maintain a reasonable level of productivity when challenged by infection. Bishop and Woolliams (2004) proposed genetic improvement of 'generalised immunity' to increase pig performance and to reduce the impact of subclinical diseases by improving the pig's ability to respond effectively to pathogenic challenges. General immunity depends on innate and adaptive immunity. Breed differences and heritability estimates have been presented for traits quantifying innate and adaptive immunity demonstrating that these traits can respond to selection (Henryon et al. 2006, Clapperton et al. 2009). In addition, unfavourable genetic associations between some immune traits and growth have been reported, which were affected by the health status of the environment (Clapperton et al. 2009). Estimates of genetic correlations were generally more unfavourable in pigs carrying various pathogens in comparison to specific pathogen free (SPF) pigs. These first results demonstrate that information about the infection load of the environment is required for pigs tested for disease, growth, immune and physiological traits in order to accommodate potential genotype by environment interactions for traits describing disease resilience.

Henryon et al. (2001) found genetic variation for clinical and subclinical diseases even when simple on-farm measurements such as treatment of a pig for a specific disease or incidence of simple characteristics (lameness, respiratory diseases, diarrhoea, skin disorders, sneezing, coughing) were used to describe the incidence of various diseases. Further, rectal temperature and respiration rate have been used as additional physiological parameters to quantify the response of pigs to climatic stressors (Huynh et al., 2005) and to infection with a specific disease such as porcine reproductive and respiratory syndrome virus (PRRSV, Doeschl-Wilson et al., 2009).

Growth has been used as a proxy for growth and negative genetic associations between some immune traits and weight gain have been demonstrated (Clapperton et al., 2005, 2008, 2009). Growth as a proxy for health may be more useful than incidence of disease, since Henryon et al. (2006) found no genetic associations between baseline levels of a number of immune traits and resistances to respiratory, lameness and other diseases. Significant genetic associations were only found between haptoglobin and lameness. Further, disease resilience implies that a reasonable level of production is maintained by pigs when they face infection (Albers et al., 1987) highlighting the importance of repeated weight measurements over the growth trajectory of the pig.

A wide range of immune parameters have been shown to be moderately to highly heritable (Flori et al. 2011, Henryon et al. 2006, Clapperton et al. 2005, 2008, 2009). The range of immunity traits was grouped by Flori et al (2011) into traits describing global immunity, cell-mediated adaptive immunity, humoral-mediated adaptive immunity, innate immunity and other haematological traits. So far, there is no consensus among scientists about which specific immunity traits to use in pig breeding programs. However, Bishop et al. (2002) point out that heritability estimates tend to rise from traits describing general disease category to traits quantifying specific disease resistance to traits measuring specific immune response. This trend may also explain the significantly high heritability estimates (above 0.5) found by Flori et al. (2011) for 25 of the 32 immune traits investigated. In this study blood samples were collected three weeks after pigs had been vaccinated for Mycoplasma hyopneumoniae. Therefore, it seems beneficial to collect blood samples to record immunity traits following vaccination or following another unspecified immune challenge.

White blood cells may be used as an indicator of infection level for a group of pigs. Further, a higher heritability was found for white blood cells at a lower health status (Clapperton et al., 2008) indicating that genetic variability for this trait may be better expressed in low health environments. White blood cell count was also higher in dominant pigs in the study by Sutherland et al. (2006) and may be a useful indicator of social status of pigs within a group.

Acute phase proteins provide a tool for veterinary applications to measure health status that are based on the extent of inflammation and tissue damage (review by Petersen et al. 2004). Subclinical disease may not lead to overt disease but impact on suboptimal growth and reduced animal welfare. Higher haptoglobin levels are believed to be signs of subclinical disease and have been shown to be associated with reduced growth (Petersen et al., 2004; Clapperton et al., 2005). Further, a number of infections including Escherichia coli, Actinobacillus pleuropneumonia and Mycoplasma hyorhinis lead to increased haptoglobin levels in pigs (Petersen et al., 2004). The authors suggested using haptoglobin levels as a marker of herd health status in pigs.

Information about which animals were housed together along with pedigree information can be used to derive a number of environmental parameters identified by Madec and Leon (1999) and Black et al. (2001) that affect performance and health status of animals. This concept was used by Jones et al. (2011) who identified a number of group characteristics like number of pigs and litters per group, mean flight time of pigs in each group and proportion of Duroc pigs in a group that affected performance of individual pigs. Further, the dimensions and designs of each pen as well as the dimensions of the shed can be collated to obtain more detailed information about the pen environment within each shed. This should include information about feeder space (Madec and Leon, 1999) as well as proportion of slatted floors versus solid floors and level of soiling of the solid, which has been shown to be affected by temperature and body weight of pigs (Aarnink et al. 2006). Over the growth trajectory, pigs are housed in different environments (sheds, pens) and ideally this information should be available for each environment an animal is housed in during each growth phase.

Climatic conditions have been shown to affect pig performance (review by Black et al. 2001) and a number of physiological parameters (Huynh et al. 2005). Information available from the nearest meteorological station has been used successfully for evaluation of genotype by temperature interactions using Australian (Lewis and Bunter, 2011) and Dutch data (Bergsma and Hermesch, 2012). However, more specific information about temperature and humidity recorded in the shed may be recorded from time to time to describe specific environmental conditions within the shed more precisely.

Mean performance or mean disease incidence of each group has been used to describe the average environmental conditions a group of pigs experienced. Further, mean performance per group has been used in genetic studies to evaluate whether the response of individual genotypes to varying environmental conditions is heritable (e.g. Kolmodin et al. 2002). Growth rate is the primary target trait in regard to mean performance per group, since it quantifies disease resilience. Finally, environmental stressors have been shown to affect growth rate, whereas backfat is not always affected (Black et al. 2001).

In summary, genetic parameters are required for a range of disease, growth, immune and physiological traits taking variation in environmental conditions into account. New models will have to be developed to describe the response of individual genotypes in key traits to variation to environmental conditions as defined by group characteristics, pathogen load, air quality and climatic conditions. It is the aim of this pilot study to identify key environmental parameters and highlight potential selection criteria for disease resilience.

Methodology

Description of data collection

Overview

Data were collected at the piggery of the University of Queensland (UQ) in Gatton, Qld from January 2013 until October 2014 for this project. Information was available for 2,388 pigs which included 2,201 Large White, 130 Duroc and 57 crossbred pigs. There were 1,205 female and 1,183 male pigs. Information recorded for individual pigs included repeated weight records, incidence of disease at each weighing, differential blood counts and immune parameters. Differential blood counts were conducted at the diagnostic laboratory at UQ in Gatton while immune parameters were recorded at the Elisabeth Macarthur Agricultural Institute of NSW Department of Primary Industries in Menangle, NSW. These data were then combined with general pedigree and performance including death records available from the herd recording system at the UQ piggery.

Data recording for this project provided training opportunities for veterinary students at UQ who performed some of the data recording and collection of blood samples required for this project for weaner pigs at five weeks. Further, students were involved in recording air quality in the weaner, porker and finisher sheds in some occasions.

Data recording was based on weekly batches. At weaning two single-sex pens with approximately 28 pigs were recorded. Four weeks after weaning at around seven weeks of age, the two single-sex pens were split into three groups by creating a third pen consisting of female and male pigs. The other two pens remained as single sex pens with approximately 19 pigs per pen. At nine weeks pigs were moved from the weaner shed into the porker shed. The groups of pigs remained the same and no further mixing occurred at this stage. At 12 weeks pigs entered the grower/finisher shed. At 16 weeks pigs were split into four groups. The fourth group was set up by randomly taking out pigs from each of the other three existing pens. Therefore, the average group size decreased from 28 to 19 and 14 pigs during the growth period until 17 weeks.

Recording of weights and disease incidence checks were conducted at weaning, five, nine, 12 and 17 weeks. Blood samples were collected at 5 weeks of age, approximately 10 days after weaning for measurements of blood and immune parameters.

Growth

Pigs were weighed at weaning and at five, nine, 12 and 17 weeks at an age of 26.8, 37.0, 66.1, 86.9 and 123.9 days (Table 1). Variability in age was lower than variability in weight because recording procedures were based on recording weekly batches of pigs. Haemoglobin was recorded at 5 weeks on farm using the HemoCue® Hb201^{+} equipment (HemoCue®, 2011). Backfat at the P2 site (BF) was recorded at 17 weeks when pigs had a live weight of 84.1 kg.

The weight measurements were used to derive five growth rate traits for the periods from birth until each weighing at weaning (ADGw), and at five (ADG5), nine (ADG9), 12 (ADG12) and 17 (ADG17) weeks of age. In addition, growth rate was derived from weaning until each weighing (ADGw-5, ADGw-9, ADGw-12, ADGw-17) as well as each interim growth period (ADG5-9, ADG5-12, ADG5-17, ADG9-12, ADG9-17, ADG12-17).

Incidence of disease

At each weighing pigs were monitored for the incidence of a disease. A detailed scoring system was developed to monitor diseases of the skin, limbs, ears, eyes, respiratory system, intestine, hernia and the nervous system. These overall categories often had multiple sub-categories which often consisted of multiple levels to indicate the severity of a disease. In total, 63 individual scores were defined to describe the incidence of disease of each pig at each weighting. A detailed description of these scores is provided in Appendix 1.

Table 1. Data statistics for age and weight measurements.

Variable	N	Mean	Std Dev	Min.	Max.	CV%
	Age at recording					
Age at weaning (days)	2188	26.8	2.38	21	35	8.9
Age at 5 weeks (days)	1866	37.0	3.29	32	48	8.9
Age at 9 weeks (days)	2070	66.1	2.70	60	77	4.1
Age at 12 weeks (days)	1473	86.9	2.61	78	96	3.0
Age at 17 weeks (days)	1255	123.9	2.66	115	131	2.1
	Weight at recording					
Weight at weaning (kg)	2388	8.9	1.32	4.7	14.2	14.8
Weight at 5 weeks (kg)	2034	11.0	2.08	4.8	19.3	18.9
Weight at 9 weeks (kg)	2139	31.4	4.80	14	50	15.3
Weight at 12 weeks (kg)	1517	49.9	6.08	26	70	12.2
Weight at 17 weeks (kg)	1252	84.1	8.03	58	110	9.5
	Days between recordings					
Days from weaning to 5 weeks	2074	9.7	2.70	7	14	27.8
Days from weaning to 9 weeks	2101	39.1	0.95	38	43	2.4
Days from weaning to 12 weeks	1498	60.0	1.07	57	64	1.7
Days from weaning to 17 weeks	1242	97.0	1.41	94	102	1.4
Days from 5 to 9 weeks	2008	29.7	2.86	24	37	9.6
Days from 5 to 12 weeks	1444	49.4	2.93	39	53	5.9
Days from 5 to 17 weeks	1137	86.0	2.78	81	91	3.2
Days from 9 to 12 weeks	1489	20.5	1.47	13	28	7.2
Days from 9 to 17 weeks	1204	57.5	1.93	49	67	3.3
Days from 12 to 17 weeks	1144	37.0	1.72	35	45	4.6

Treatment and death records

Treatment and death records were collected on farm to document the date of a treatment (or death) for individual pigs. If known, the cause of the disease or the death of each pig was also recorded. Treatment records included information about the specific treatment provided to each pig.

Haematological traits

At 5 weeks of age, blood was collected into vacutainers with anticoagulants (EDTA) and stored at 1 to 4° C for up to 48 hours until haematology analysis using a calibrated automated haematology analyser (Cel-Dyn® 3700, Abott Diagnostics Europe, Wiesbaden, Germany; www.abbottdiagnostics.com). The haematological variables obtained from this analysis were white blood cell count (WBC) and

counts of neutrophils (NEU), lymphocytes (LYM), monocytes (MONO), eosinophils (EOS) and basophils (BASO). Further, red blood cell count (RBC) was obtained along with haemoglobin (HGB), haematocrit (packed cell volume, HCT), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), red cell distribution width (RDW). The mean corpuscular volume is the average size of red blood cell and is derived from haematocrit divided by red blood cell count. Similarly, mean corpuscular haemoglobin is derived from dividing haemoglobin by red blood cell count while mean corpuscular haemoglobin concentration is based on haemoglobin divided by haematocrit. Finally, platelet count (PLT) and mean platelet volume (MPV) were available from the analysis.

Immune traits

The predominant porcine serum immunoglobulins (IG) are IgG (85%), IgM (12%) and dimeric IgA (3%). The levels of these IG, along with the acute phase protein haptoglobin, are thought to be good indicators of infection, inflammation, extreme stress, burns or crush injuries. These four immune parameters were measured in 1,118 weaner pigs at 5 weeks of age using Enzyme-Linked Immunosorbent Assays (ELISA) developed at EMAI.

Two consignments of frozen pig sera were received at EMAI, the first from 443 pigs was collected and the IG levels determined in 2013. The second batch of 665 pigs was collected and the IG levels determined in 2014. The haptoglobin levels of both batches, 2013 and 2014, were determined in 2014.

Each of the 2013 sera were transferred to 5 ml serum vials and master plates which were sealed and stored at -20 C until required. As each sample was in only one master plate, all three immunoglobulin assays had to be conducted in one day to ensure a single freeze thaw cycle of the sample sera. This resulted in the assays for each IG class being conducted over a number of days. The procedure was modified when the 2014 batch of sera were processed. Each 2014 sera sample was divided between four separate master plates and a 5 ml serum vial which allowed each IG ELISA to be completed in a single day to minimize variation between the plates. The 2013 and 2014 haptoglobin assays had to be conducted over a number of days as up to three dilutions per sample were required to cover the entire range of responses displayed by the pigs.

The four assays developed were capture ELISA. The IG ELISA used goat polyclonal antibodies (Bethyl Laboratories®), specific for porcine IgG, IgA or IgM for capture and the same antibodies conjugated to alkaline phosphatase (AP) for detection. Anti-human haptoglobin polyclonal antibodies raised in a rabbit were used for capture, mouse ascites fluid as a secondary antibody and rabbit anti-mouse AP-conjugate as the detection antibody in the haptoglobin ELISA (Sigma-Aldrich®). Titrations were performed to determine the optimum dilutions of capture and detection antibodies for each assay.

Lyophilized purified pig IgG (Sigma-Aldrich®), made up to 0.62 mg/ml IgG, was aliquoted and frozen at -20 C. This was used as the IgG standard for both the 2013 and 2014 assays. Porcine IgA had been purified from sow's milk at EMAI using a modified version of Dziaba et al (1986) and was used as a standard for the 2013 sera. Purified porcine IgM (Life Diagnostics®) at a concentration 3.84 mg/ml and 98% purity was used as the standard for the 2013 samples. This was stored according to the manufacturer's instructions at 4°C but was not considered suitable for use in 2014. As porcine reference serum (Bethyl Laboratories®) could

be stored at -20 C it was tested extensively against the 2013 IgA and IgM standards for use in 2014. The IG levels of the reference serum were determined as 0.325mg ml^{-1} of IgA and 2.35 mg $ml^{-1}$of IgM. A Pig Haptoglobin ELISA Test Kit® (Life Diagnostics) was used to determine the haptoglobin level of the reference serum (0.689 mg/ml) which was used as the standard for haptoglobin assays.

Briefly, capture antibody was diluted in coating buffer (14.0 mM sodium carbonate, 35.0 mM sodium bicarbonate pH9.2) and 100ul/well left overnight at 4 C. Tris saline wween (25 mM tris, 150 mM sodium chloride, 0.05% tween) was used as a wash buffer and a diluent/blocker when 1% Bovine Serum Albumin (BSA) was added. After coating, the plates were washed, blocked, sealed, wrapped in foil and frozen at -20 C until required. This ensured that all plates were coated at the same time for each assay.

Standards were serially diluted in bulk using diluent, aliquoted into and stored as individual sets at -20 C until required. The range of each standard was IgG 100 – 1.56 ng/ml, IgM: 235 – 3.672 ng/ml, IgA: 500 – 0.686 ng/ml and Haptoglobin: 689.38 – 10.772 ng/ml. Dilution blocks and diluent were used to perform appropriate sera dilutions for each assay.

The initial dilution of pig sera for the haptoglobin assay was 1 in 50. The samples which did not fall within this range were diluted at 1 in 1000 and 1 in 30,000 if required. Each dilution series was conducted on a newly thawed aliquot of sera. The total range of the assay was 0.5 to 6326 ug/ml. Pigs which fell below this level were recorded as below detection (BD).

ELISA incubation conditions were 1 hour at 37 C and all working volumes of 100ul/well were used. Timers were used for accurate plate incubation intervals. Plates were washed using an automatic plate washer using a 5 wash cycle. The substrate used was BluePhos Microwell Phosphatase® by KPL®. The plates were incubated at 37 C for 30 minutes and read at 620 um using a Molecular Devices Spectra Max M2® spectrophotometer using SoftMax Pro 5® software.

Each plate contained duplicates of a reagent control, seven serially diluted concentrations of the standard and 40 pig samples. Four parameter fit curve analysis of the standards, corrected for the control was performed. The mean OD for each pig sample was plotted on the standard curve and the concentration of the assay subject calculated off the curve after correction for dilution.

Environmental measurements

Air quality was measured for each pen in the three sheds where pigs were housed from weaning to the end of the test period. Pigs for this Project were housed in ten pens directly after weaning. For each pen in the weaner shed, air quality measures were recorded in each corner area about 50 to 70 cm from the side of each pen. The corners in the front of each pen represented the feeding and dunging area and the sheltered resting area was at the back of each pen. The resting area consisted of a hutch that may have had boards and heat lamps in use at recording. These details along with time of measurement were noted when measurements for each pen were collected.

In the porker shed, air quality measures were also recorded in each corner of each pen about 50 to 70 cm from the side of all pens. For pens in the shed to house pigs at the end of test, air quality was measured in the front two corners about 50 to 70 cm from the side of each pen.

Air quality measures were recorded on 11 occasions from May 2013 to August 2014 in the weaner shed and on 6 days from May 2013 to July 2013 in the porker and finisher sheds.

Temperature, velocity and humidity were recorded with the vane anemometer testo 410-2 and CO_2 levels were measured with the measuring instrument testo 535 (www.testo.com.au). Ammonium levels were recorded using 2-cm long hydrion ammonia test paper strips.

Statistical analyses

Outliers exceeding four standard deviations from the mean were eliminated from the analyses for all traits. 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. Traits with a skewness or kurtosis number of smaller than -1.0 or greater than 1.0 were log transformed using a log to the base of 10. The log-transformed traits were neutrophils (lNEU), lymphocytes (lLYM), eosinophils (lEOS), mean corpuscular haemoglobin (lMCH), mean corpuscular haemoglobin concentration (lMCHC), red cell distribution width (RDW) and mean platelet volume (lMPV).

Fixed-effect models were developed for each trait with the GLM procedure (SAS, 2014). Significant fixed effects were then fitted in mixed models that included both fixed and random effects using the Mixed procedure (SAS, 2014). The random effects that were evaluated were sire, dam, common litter as well as the contemporary group of pigs, which was defined as the weekly batch of pigs entering the weaning shed on the same date. Heritability was derived as four times the sire variances divided by the phenotypic variance, which was the sum of the sire variance, variance due to common litter and residual variance.

The contemporary group is usually fitted as a fixed effect in models for genetic evaluation of pigs. However, it can also be fitted as a random effect, in particular when few animals are part of one contemporary group (Frey et al. 1997). When contemporary group is fitted as a random effect, it provides information about the proportion of variation that is explained by the contemporary group and hence the importance of common environmental influences affecting the performance of a group of pigs housed together. Please note, this random effect related to contemporary group was not included in the phenotypic variance (Vp) that was used to derive heritabilities and estimates of common litter effects. The random effect of contemporary group was omitted from the total phenotypic variance because it is also not part of the total phenotypic variance when it is fitted as a fixed effect. Therefore, estimates of heritabilities and common litter effects are comparable with results from other studies that fitted contemporary group as a fixed effect (e.g. Li and Hermesch, 2015). Further, estimates of heritability and common litter effects did not differ significantly between models that fitted contemporary group as either a fixed effect or a random effect in this study (results not shown).

Outcomes

Growth records

Growth rate and backfat at 17 weeks are the two traits that are used in pig breeding programs. Data statistics for these traits and other growth traits are shown in Table 2. Piglets had a higher growth rate prior to weaning (331.6 g/day) than until 5 weeks of age (299.5 g/day) due to the low growth rate in the ten days after weaning (192.0 g/day). Growth until a specific age increased as pigs got heavier and was about 100 g/day higher for post-weaning growth in comparison to lifetime growth.

The coefficient of variation (CV%) for growth is usually around 10% which was also observed for growth until 17 weeks of age. A longer test period was associated with lower CV% because random variation in individual weight measurements due to, for example, random variation in gut fill had a proportionally lower impact on weight gain and therefore growth rate. Growth from 9 to 12 weeks was more variable (CV% of 25.9%) in comparison to growth traits with similar weight gains (ADGw-9, ADG5-9). Pigs were moved to the porker shed at 9 weeks of age which may have contributed to this higher variation in growth from 9 to 12 weeks. Similarly, growth after weaning was highly variable (CV% of 65%) which may be due to the short test period, however, it also indicates that weaner pigs vary in regard to their ability to cope with the weaning process.

Disease incidence records

Most disease incidence scores were recorded from February to June 2013 at the beginning of data recording when veterinary students were involved in data recording. Specifically, veterinary students were collecting most records at 5 weeks in early 2013 and seemed to have applied a more stringent scoring system to record disease incidence than piggery staff.

Superficial wound of the skin was the most predominant disease recorded shortly after weaning due to fighting of piglets to establish a group hierarchy. Other disease scores recorded for the limbs and ears at that time also represented superficial wounds from fighting. Tail biting and ear biting were mostly observed in older pig at 9 and 12 weeks of age.

The summary shows that fighting in weaner pigs and tail or ear biting in older pigs were the most predominant disease scores in this high-health herd. There was variation among operators in regard to defining scoring levels for individual diseases because the incidence of specific disease scores was high for specific dates. It is unlikely that the incidence of superficial wounds for example vary considerably between weeks. Therefore, the same level of superficial wounds was scored differently by operators despite a detailed outline of each disease score. The description of each disease category was qualitative rather than quantitative which may have contributed to the variation in disease scores between operators.

Table 2 Data statistics for growth traits and backfat depth based on weight records at weaning and at specific weeks (wks) of age.

Trait	N	Mean	Std Dev	Min	Max	CV%
	Growth (g/day) until					
Weaning (ADGw)	2188	331.6	47.25	174.1	507.4	14.2
5 wks (ADG5)	1855	299.5	44.87	141.2	476.9	15.0
9 wks (ADG9)	2061	474.1	69.07	222.2	746.0	14.6
12 wks (ADG12)	1470	574.1	68.42	312.5	795.5	11.9
17 wks (ADG17)	1252	679.1	63.87	456.7	885.2	9.4
Backfat at 17 wks (BF, mm)	1308	10.3	1.35	5.0	16.0	13.1
Haemoglobin at 5 wks (HGB5, g/L)	1301	110.6	13.60	25.0	169.0	12.3
	Growth (g/day) for growth periods					
Weaning to 5 wks (ADGw-5)	1900	192.0	125.51	-275.0	707.7	65.4
Weaning to 9 wks (ADGw-9)	2090	573.0	109.58	159.0	1023.7	19.1
Weaning to 12 wks (ADGw-12)	1495	683.6	92.99	331.1	993.4	13.6
Weaning to 17 wks (ADGw-17)	1235	776.4	78.20	510.5	1020.8	10.1
5 to 9 wks (ADG5-9)	1812	695.9	136.66	203.2	1236.0	19.6
5 to 12 wks (ADG5-12)	1039	785.3	111.14	396.2	1189.7	14.2
5 to 17 wks (ADG5-17)	1083	845.8	87.35	544.4	1137.7	10.3
9 to 12 wks (ADG9-12)	1476	907.8	238.09	0.0	1846.2	26.2
9 to 17 wks (ADG9-17)	1191	920.4	121.24	474.6	1372.6	13.2
12 to 17 wks (ADG12-17)	1127	925.1	170.12	263.2	1542.9	18.4
	Weight gain (kg) for growth periods					
Weaning to 5 wks	2031	2.0	1.66	-2.9	9.2	82.0
Weaning to 9 wks	2135	22.5	4.23	6.2	38.9	18.8
Weaning to 12 wks	1516	41.1	5.58	20.2	60.6	13.6
Weaning to 17 wks	1252	75.3	7.66	48.5	100.0	10.2
5 to 9 wks	1814	20.5	4.21	6.1	37.5	20.5
5 to 12 wks	1039	38.4	5.29	18.6	58.7	13.8
5 to 17 wks	1100	72.7	7.18	47.6	96.7	9.9
9 to 12 wks	1478	18.6	4.82	0.0	38.0	25.9
9 to 17 wks	1194	52.9	6.98	28.0	78.0	13.2
12 to 17 wks	1131	34.1	6.50	8.0	58.0	19.0

These observations indicate that operators require more detailed training in order to quantify disease scores more consistently. Further, it should be explored whether certain disease scores can be described more objectively by developing a scoring system that is based on specific counts of disease observation rather than a qualitative description of a disease incidence.

Finally, these disease incidence scores are not useful for further analyses due to the large differences in scores between operators. It shows that it is not sufficient to have a detail description of disease scores. Specific training is also required to ensure that operators apply the same scores for specific disease incidences.

Treatment and death records

Information about pig mortalities were recorded from April 2013 to April 2014, while treatments of pigs were recorded from April 2013 to December 2014. This information is more reliable than disease incidence scores because each record describes a specific treatment or the death of a pig on farm. All of this information was recorded by staff on farm.

Most mortalities post weaning occurred in weaner pigs (68%, Table 3) while 15 and 17% of post-weaning mortalities were observed for grower and finisher pigs. The cause of death was not available for most pigs. These proportions of mortalities imply that pigs die at an average age of 58 days given the average age of weaner, grower and finisher pigs of 45, 70 and 100 days, respectively. This average age at mortality is an important parameter to derive the economic value of post-weaning survival (Hermesch et al., 2014).

Most pigs were treated for an injury or a disease as growers (57% of treatments). Number of treatments was similar for weaner and finisher pigs and the average age of treatment was 70 days based on all treatment observations. Most treatments were required for tail biting in the grower phase.

Table 3 Number of recorded deaths and treatments of pigs.

	Deaths		Treatments	
	N	% of mortalities	N	% of treatments
Weaner	122	68	83	24
Grower	27	15	195	57
Finisher	31	17	65	19
Total	180		343	

Haematological and immunological records

Means and standard deviations are shown for haematological traits in Table 4 and for immunological traits in Table 5. The coefficients of variation were high for a number of traits which was partly due to the non-normal distribution of some traits prior to log transformation. Haptoglobin was measured using two different procedures which resulted in different means. The second procedure resulted in haptoglobin values that were within the expected range of 0 to 2.2 mg/ml for healthy pigs while values were too low with a mean of 16 ng/ml (equal to 0.000016 mg/ml) based on the first procedure.

Table 4. Data statistics for haematological traits

Variable	N	Mean	Std Dev	Minimum	Maximum	CV%
WBC (10^9/L)	908	16.66	4.76	5.4	35.8	28.6
NEU (10^9/L)	902	6.63	2.66	1.1	19.0	40.2
LYM (10^9/L)	909	7.72	3.11	1.2	20.3	40.3
MONO (10^9/L)	910	1.57	0.61	0.1	3.9	38.7
EOS (10^9/L)	906	0.31	0.16	0.0	1.0	51.1
BASO (10^9/L)	910	0.32	0.18	0.0	1.0	56.3
RBC (10^{12}/L)	908	6.48	0.59	4.3	8.5	9.1
HGB (g/dL)	908	11.43	1.02	8.0	15.1	8.9
HCT (%)	907	36.33	3.17	23.7	48.8	8.7
MCV (fL)	908	56.14	3.50	43.7	67.5	6.2
MCH (pg/cell)	908	17.67	1.15	13.2	21.9	6.5
MCHC (g/dL)	907	31.47	0.93	27.5	33.8	3.0
RDW (%)	902	23.64	3.80	17.8	39.9	16.1
PLT (10^9/L)	908	666.91	230.51	43.3	1364.0	34.6
MPV (fl)	617	9.20	2.38	4.7	19.2	25.9

Abbreviations: WBC: white blood cell count, NEU: neutrophils, LYM: lymphocytes, MONO: monocytes, EOS: eosinophils, BASO: basophils, RBC: red blood cell count, HGB: haemoglobin, HCT: haematocrit (packed cell volume), MCV: mean corpuscular volume, MCH: mean corpuscular haemoglobin, MCHC: mean corpuscular haemoglobin concentration, RDW: red cell distribution width, PLT: platelet count, MPV: mean platelet volume.

Table 5. Data statistics for immunological traits

Variable	N	Mean	Std Dev	Minimum	Maximum	CV%
IgA (mg/ml)	1007	0.483	0.392	0.05	2.66	81.1
IgG (mg/ml)	1005	9.241	6.230	1.44	65.89	67.4
IgM (mg/ml)	1004	1.195	0.671	0.15	5.85	56.1
Haptoglobin (mg/ml)	922	0.364	0.791	0.00	6.23	217.5
Haptoglobin-2013 (ng/ml)	400	16.604	35.508	0.26	667.09	213.8

Abbreviations: IgA, IgG, IgM: Immunoglobulin A,G,M, respectively. Haptoglobin-2013 represents the first group of pigs measured in 2013.

Environmental measures

Individual air quality measures of individual pens were recorded in the weaner, porker and finisher (Table 6). These air quality measures were predominantly

recorded during the cooler months in winter, which still had temperatures of 24 to 27 degrees C. Air quality measures in the finisher shed were recorded at a slightly later time during the day than records collected in the weaner and porker shed. This delay in recording contributed to the higher temperatures observed in the finisher shed. Humidity and carbon dioxide values were slightly higher in the weaner and porker shed than the finisher shed.

Climate and carbon dioxide measures showed considerable variation with coefficients of variation ranging from 10 to 45%. In particular, carbon dioxide in the weaner shed was highly variable. The non-normal distribution of ammonia resulted in inflated coefficients of variation for this measurement. Average values for carbon dioxide and ammonia were considerably below the maximum recommended levels of 1,500 ppm for carbon dioxide and 11 ppm for ammonia shown in the Model Code of Practice for the Welfare of Animals – Pigs (2007).

Overall, this overview demonstrates considerable variation of environmental conditions between pens within a shed. The procedures used in this study can be easily implemented on farms to monitor the micro-environment of each pen. Such a monitoring process will lead to improved housing conditions for pigs on farm which is beneficial for welfare and performance of pigs.

Table 6. Data statistics for air quality measures recorded in weaner, porker and finisher pens

	N	Mean	STD	CV
			Weaner shed	
Temp (°C)	472	23.5	3.5	14.8
Humidity (%)	472	58.7	11.4	19.5
Carbondioxide (ppm)	417	1057.9	477.4	45.1
Ammonia (ppm)	471	6.5	3.3	50.7
			Porker shed	
Temp (°C)	221	23.8	2.3	9.6
Humidity (%)	221	57.1	8.3	14.6
Carbondioxide (ppm)	186	1044.9	238.2	22.8
Ammonia (ppm)	222	5.9	3.1	52.5
			Finisher shed	
Temp (°C)	364	26.8	9.3	34.6
Humidity (%)	364	52.1	8.5	16.4
Carbondioxide (ppm)	280	957.0	210.0	21.9
Ammonia (ppm)	364	5.8	3.1	53.2

Significant fixed effects for traits

Pigs were housed in weekly batches and batch, based on date of weaning each week, was the main significant effect for all growth, haematological and immunological traits (Tables 7, 8 and 9). Further significant effects were the sex of the animal and characteristics of the birth litter, e.g. parity of birth litter, litter size of birth litter and age at weaning. Age at weaning was preferred over age at recording because pigs were housed in weekly batches and were recorded on the same day for each batch. Further, coefficients of determination were the same for models fitting age at weaning or age at recording. Live weight of pigs fitted as a linear and quadratic covariable was an important effect for backfat (Table 7) while time difference (in days) from collecting blood samples and analysis of samples in the laboratory was significant for some haematological traits (Table 8).

For most growth traits, fixed effects accounted for 15 to 25% of the observed variation. The highest coefficient of determination was observed for growth shortly after weaning (0.41 for ADGw-5). The coefficients of determination were also higher for early growth traits until 5 weeks (0.32 for ADGw and 0.27 for ADG5) due to the effects related to characteristics of the birth litter. Fixed effect models were also analysed after omitting characteristics of the birth litter from models to investigate the importance of these effects for individual traits. As expected, characteristics of the birth litter accounted for a higher proportion of the variation (14%) for pre-weaning growth (ADGw) in comparison to growth until the end of the test period (4% for ADG12 and ADG17). Characteristics of the birth litter accounted for 5% and 3% of the variation for growth until 5 and 9 weeks (ADG5, ADG9).

All of these growth traits included the pre-weaning period, which contributed to the significance of characteristics of the birth litter for these traits. The proportion of variation explained by birth litter characteristics were generally lower ranging from 0 to 4% for various post-weaning growth traits. It is noteworthy perhaps, that characteristics of the birth litter have little effect for growth traits recorded shortly after weaning (ADGw-5, ADGw-9).

Coefficients of determination varied considerable for haematological trait (Table 8) ranging from 0.10 for neutrophils (LNEU) to 0.49 for mean corpuscular haemoglobin concentration (LMCHC). Birth litter characteristics were of less importance for most haemotological traits accounting for 1 to 2% of observed variation with the exception of mean corpuscular haemoglobin (LMCH), mean corpuscular haemoglobin concentration (LMCHC) and platelet count (PLT). For these traits, birth-litter characteristics explained 4, 8 and 3% of the observed variation.

The fixed effect model explained 33 to 67% of the variation in immunoglobulin and haptoglobin traits (Table 9). Characteristics of the birth litter were of minor importance explaining maximal 2% of the observed variation. This may be surprising given that these immunological traits are recorded shortly after weaning.

Table 7. Proportion of variance explained by fixed effects and significance of fixed effects for growth traits and backfat depth.

Trait	R^2	Batch	Sex	Bpar	Bls	Age	Wt
ADGw	0.32	***	***	***	***	***	-
	0.18	***	***	-	-	-	-
ADG5	0.27	***	***	***	***	ns	-
	0.22	***	***	-	-	ns	-
ADG9	0.18	***	*	***	***	**	-
	0.15	***	*	-	-	-	-
ADG12	0.19	***	ns	***	***	ns	-
	0.15	***	ns	-	-	ns	-
ADG17	0.19	***	***	***	***	ns	-
	0.15	***	***	-	-	ns	-
BF	0.26	***	***	ns	ns	*	***/***
	0.26	***	***	ns	ns	-	***/***
HGB5	0.17	***	***	**	ns	**	-
	0.16	***	***	-	ns	-	-
ADGw-5	0.41	***	ns	**	ns	ns	-
	0.40	***	ns	-	ns	ns	-
ADGw-9	0.19	***	ns	***	ns	ns	-
	0.18	***	ns	-	ns	ns	-
ADGw-12	0.20	***	ns	***	**	***	-
	0.16	***	ns	-	-	-	-
ADGw-17	0.19	***	***	***	**	**	-
	0.15	***	***	-	-	-	-
ADG5-9	0.18	***	ns	**	*	***	-
	0.15	***	ns	-	-	-	-
ADG5-12	0.24	***	ns	***	***	*	-
	0.21	***	ns	-	-	-	-
ADG5-17	0.22	***	**	**	**	**	-
	0.19	***	**	-	-	-	-
ADG9-12	0.15	***	ns	ns	ns	ns	-
ADG9-17	0.17	***	***	*	*	ns	-
	0.16	***	***	-	-	-	-
ADG12-17	0.18	***	***	ns	ns	ns	-

For abbreviations of traits see Table 2. Other abbreviations are: R^2: coefficient of determination, Bpar: parity of birth litter, Bls: litter size of birth parity, Age: age of pig at weaning, Wt: weight of pig at recording the trait.

Table 8. Proportion of variance explained by fixed effects and significance of fixed effects for immune traits.

Trait	R^2	Batch	Sex	Bpar	Bls	Age	Labtime
WBC	0.14	***	***	**	*	ns	ns
	0.12	***	***	-	-	ns	Ns
LNEU	0.10	***	***	ns	ns	ns	ns
LLYM	0.14	***	ns	**	*	ns	Ns
	0.12	***	ns	-	-	ns	ns
MONO	0.16	***	ns	ns	ns	ns	**
LEOS	0.15	***	**	*	ns	ns	ns
	0.14	***	***	-	-	ns	ns
BASO	0.18	***	***	*	ns	ns	***
	0.17	***	***	-	ns	ns	***
RBC	0.29	***	ns	**	ns	ns	ns
	0.27	***	ns	-	ns	ns	ns
HGB	0.27	***	***	***	ns	*	ns
	0.25	***	***	-	ns	-	ns
HCT	0.34	***	***	***	ns	*	**
	0.32	***	ns	-	ns	-	**
MCV	0.26	***	***	***	ns	ns	ns
	0.24	***	***	-	ns	ns	ns
LMCH	0.16	***	***	***	ns	ns	ns
	0.13	***	***	-	ns	ns	ns
LMCHC	0.49	***	***	*	ns	ns	***
	0.48	***	***	-	ns	ns	***
LRDW	0.33	***	ns	***	**	***	ns
	0.25	***	ns	-	-	-	ns
PLT	0.16	**	*	***	ns	ns	ns
	0.13	***	ns	-	ns	ns	ns
LMPV	0.28	***	**	*	ns	ns	**
	0.26	***	**	-	ns	ns	**

For abbreviation see Table 4; note the letter L at the beginning of the trait abbreviation indicates that the trait was log transformed. Other abbreviations are: R^2: coefficient of determination, Bpar: parity of birth litter, Bls: litter size of birth parity, Age: age of pig at weaning, Labtime: time from collection of blood until laboratory analysis.

Table 9. Proportion of variance explained by fixed effects and significance of fixed effects for immunoglobulin and haptoglobin traits

Trait	R^2	Date	Sex	B-par	B-LS	Age	Labtime
LIGA	0.673	***	ns	*	ns	***	ns
	0.661	***	ns	-	ns	-	ns
LIGG	0.442	***	ns	***	*	ns	ns
	0.420	***	ns	-	-	ns	ns
LIGM	0.422	***	ns	ns	*	***	ns
	0.405	***	ns	ns	-	-	ns
LHAP	0.326	***	ns	ns	*	ns	ns
	0.323	***	***	ns	-	ns	ns

For abbreviation see Table 5; note the letter L at the beginning of the trait abbreviation indicates that the trait was log transformed. Other abbreviations are: R^2: coefficient of determination, Bpar: parity of birth litter, Bls: litter size of birth parity, Age: age of pig at weaning, Labtime: time from collection of blood until laboratory analysis.

Estimates of variance components

Estimates of random effects, expressed as a proportion of the phenotypic variance, and heritability estimates are shown in Table 10 and Table 11 for growth and haematological and immune traits. The weekly batch effect was highest for post-weaning growth (ADGw-5) which also had the highest heritability estimate of 0.37 based on the full model. This trait is highly variable and these high estimates indicate that both management and genetic factors can be used firstly to reduce variation in growth shortly after weaning and secondly to explore the benefits of selecting weaners with higher growth shortly after weaning for improved growth and health status of pigs overall. The weaning process is challenging for pigs and this new growth trait may be an early indicator trait for the ability of pigs to cope with environmental and disease challenges in general.

Heritability estimates for growth traits were lower when characteristics of the birth litter were included as fixed effects in the model (Table 10). This reduction in heritability has not been observed previously and may be a specific characteristic of this data set. However, this aspect deserves further investigation.

Common litter effects were higher for early growth (0.31 for ADGw) in comparison to later growth (0.02 for ADG12-17). This reduction in common litter effect for growth or weight traits during the growth trajectory has been observed before (e.g. Zang et al. 2000).

Among haematological and immune traits, the immunoglobulin traits are most suited to monitor herd health because the batch effect accounted for 55 to 142% of the phenotypic variance. Please note, the batch effect can explain more than 100% of the phenotypic variance because it was not included in the phenotypic

variance. These high batch effects correspond to the high coefficients of determinations found for immunoglobulin traits (Table 9).

Table 10. Phenotypic variance (Vp), variation due to weekly batch (s^2), heritability (h^2) and common litter effect (c^2) for growth traits as well as backfat and haemoglobin recorded on farm.

Trait	Vp	s^2	h^2	c^2
ADGw	1870	0.13	0.10	0.31
	1953	0.15	0.23	0.33
ADG5	1570	0.24	0.14	0.22
	1666	0.22	0.27	0.24
ADG9	4078	0.16	0.12	0.14
	4196	0.17	0.22	0.13
ADG12	4062	0.15	0.13	0.13
	4124	0.14	0.20	0.14
ADG17	3472	0.13	0.04	0.10
	3663	0.12	0.20	0.10
BF	1.38	0.06	0.10	0.11
HGB5	159.166	0.14	0.06	0.20
ADGw-5	9103	0.59	0.37	0.19
	9849	0.51	0.34	0.25
ADGw-9	9631	0.20	0.14	0.10
	10322	0.20	0.24	0.13
ADGw-12	7499	0.13	0.16	0.11
	7811	0.14	0.22	0.13
ADGw-17	5230	0.13	0.05	0.10
	5462	0.11	0.19	0.10
ADG5-9	15875	0.16	0.10	0.08
	16250	0.17	0.14	0.10
ADG5-12	9913	0.23	0.11	0.11
	10399	0.22	0.18	0.14
ADG5-17	6276	0.23	0.06	0.09
	6495	0.19	0.15	0.09
ADG9-12	49803	0.20	0.03	0.08
	49801	0.18	0.03	0.09
ADG9-17	12919	0.12	0.13	0.09
	13049	0.11	0.17	0.09
ADG12-17	24785	0.16	0.19	0.02
	24859	0.16	0.18	0.03

Table 11. Phenotypic variance (Vp), variation due to weekly batch (s^2), heritability (h^2) and common litter effect (c^2) for haematological and immunological traits

Trait	Vp	s^2	h^2	c^2
WBC	21.3380	0.03	0.37	0.10
LNEU	0.0285	0.02	0.31	0.08
LLYM	0.0318	0.09	0.12	0.11
MONO	0.3247	0.08	0.19	0.14
LEOS	0.0488	0.06	0.52	0.10
BASO	0.0282	0.08	0.10	0.11
RBC	0.2531	0.27	0.20	0.16
HGB	0.7641	0.16	0.24	0.14
HCT	6.6525	0.23	0.12	0.12
MCV	9.7946	0.18	0.58	0.24
LMCH	0.0008	0.08	0.64	0.23
LMCHC	0.0001	0.14	0.00	0.14
LRDW	0.0029	0.10	0.24	0.18
LRDW	0.0033	0.23	0.68	0.16
PLT	47825.2000	0.07	0.27	0.14
LMPV	0.0087	0.18	0.16	0.26
LIGA	0.0413	1.42	0.32	0.15
LIGM	0.0290	0.55	0.22	0.18
LIGG	0.0315	0.63	0.30	0.23
LHAP	1.6919	0.42	0.08	0.17

Multiple haematological traits had high heritability estimates of 0.3 or above (Table 11). These first results are promising in regard to developing selection strategies for improved disease resilience. High heritabilities had previously been found by Flori et al. (2011) for multiple immune parameters recorded shortly after pigs had entered a pig test station in France. Further, Clapperton et al. (2008) found higher heritability estimates for 6 out of 9 immune parameters recorded at the start of test rather than at the end of the test period further supporting the strategy to record immune traits shortly after weaning rather than at the end of the test period.

Application of Research

Heritability estimates were moderate to high for most for immune traits recorded shortly after weaning. These immune measurements were recorded shortly after weaning and offer opportunities for early selection of pigs with improved health status. Estimates of genetic correlations are required before these immune traits can be considered as selection criteria for pig breeding programs.

Micro-environments within a shed can be easily monitored with simple and cost-effective air quality measures. A better monitoring system of air quality of individual pens can be used to improve specific micro-environments within a shed. This will have positive effects for the health status of pigs in each shed and will also lead to better working conditions for staff.

Scoring system for disease incidence can be used to monitor incidence of various diseases more precisely on farms. Adoption of this scoring system of disease incidence requires appropriate software and training of staff to ensure consistency of scores among operators.

Research results were presented at industry and scientific meetings throughout the duration of the project. Further, an international workshop on genetic improvement of resilience was held resulting in a refereed book. Twelve speakers from Australia, Scotland and New Zealand participated in this workshop which was held in Armidale on the 29th and 30th of October 2014.

Publications arising from this Research

The following 5 publications and 2 presentations are available from this project:

Hermesch, S (2012) Breeding pigs with improved disease resilience. In '2012 AGBU Pig Genetics Workshop Notes.' (Eds S Hermesch, K Dobos.) pp. 69-72. (AGBU: Armidale).

Hermesch, S., Parke, K. and Bauer (2013). Breeding more disease-resilient pigs. UQ staff research seminar series, UQ, Gatton, 21 May 2013.

Hermesch, S, (2014) Breeding disease resilient pigs, In'Breeding Focus 2015 – Improving resilience' (Eds S Hermesch, S Dominik) pp. 5-18. (AGBU: Armidale).

Abstract. Animal breeding continues to play a role in improving the stability of farming systems by selecting resilient animals and developing methods of selection for disease resilience, disease resistance and disease tolerance. Routine veterinary observations on clinical and sub-clinical diseases as well as growth in challenging environmental conditions may be used as measures of disease resilience. However, disease resilience can only be measured reliably when a sufficient infection challenge is present in the standard farming system. Deliberately exposing a large number of animals to high infection levels to obtain more accurate measures of their disease resilience is not feasible due to welfare concerns and reduced profitability. Improvement in disease resistance and disease tolerance will lead to superior disease resilience. However, within-host infection levels have to be known for a reliable distinction between

disease resistance and disease tolerance and this information is not expected to be available for farm animals. Genetic variation has been identified for direct measures of disease resistance, i.e. pathogen load, and indicators of disease resistance, i.e. susceptibility to disease and immune parameters. Selection strategies for direct measures of disease resistance (pathogen load) with beneficial health and welfare consequences for groups of animals lead to more robust environments that have lower levels of disease-causing organism and are less challenging for animals. Selection strategies for disease resistance with these consequences should be implemented in breeding programs. Multiple parameters including mean growth, mean pathogen load or mean of certain immune traits for groups of pigs as well as information on variation in air quality or heat load could be used to quantify the general infection challenge better. Variation in some of these environmental measures has already been observed in pig farms with good health and management procedures indicating that it is possible to select for disease resilience in commercial pig breeding programs.

Hermesch, S, Parke, CR, Bauer, MM, Gilbert, H (2014) 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'. Paper 367.

Abstract: Maternal genetic effects are potential breeding objective traits. Growth (LADG) and backfat (BF) at 93.9 kg body weight were recorded for 163,139 pigs in 10 herds from 2000 until 2012. Proportions of variances due to direct genetic, maternal genetic and common litter effects were 0.16, 0.03 and 0.11 for LADG and 0.28, 0.01 and 0.05 for BF, respectively. Multiple weight measurements were recorded on 896 pigs in 2013 at weaning, five, nine, 12 and 17 weeks in one herd. These individual growth traits were regressed on direct and maternal effects of LADG from the first analyses. Regression coefficients for direct or maternal genetic effects indicated that selection for these genetic effects will influence growth in a similar pattern. Whether selection for maternal genetic effects of LADG favours higher pre-weaning growth followed by a reduction in growth shortly after weaning should be explored.

Hermesch, S (2015). Towards a definition of disease resilience. INRA staff research seminar, Castanet-Tolosan, France, 1 June 2015.

Sales, N, McKenna, T, Bauer, MM, Parke, CR, Hermesch, S J Pluske, J Pluske (Eds) (2015b) 'Porcine haptoglobin levels measured at 7–14 days after weaning were independent of age, weight or gender', Manipulating pig production XV, Animal Production Science, 55, 1457, http://dx.doi.org/10.1071/ANv55n12Ab100.

Hermesch, S, Dominik, S (2014) 'Breeding Focus 2014 - Improving resilience.' pp. 156. (Animal Genetics and Breeding Unit: Armidale). The contents of this book are:

Doeschl-Wilson, A.B. and G. Lough, "Inferring genetic resilience of animals to infectious pathogens - opportunities and pitfalls", pp. 19-30.

Collins, A.S. "On-farm measures to monitor the health and immune status of pigs", pp.31-48.

Hine, B.C., Mallard, B.A., Ingham, A.B. and I.G. Colditz, “Immune competence in livestock”, pp 49-64.

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Conclusion

A comprehensive data set has been generated with information about 15 growth and 20 immune traits as well as incidence of disease and mortalities. The majority of growth and immune traits were moderately to highly heritable and genetic correlations should be estimated to evaluate their use as selection criteria for improved health status of pigs.

Procedures have been developed to monitor environmental conditions on farm. These procedures may firstly include the use of mixed models to obtain estimates of batch effects for specific immune and growth traits as measures of herd health. Secondly, simple air quality measurements were used to demonstrate that considerable variation exists between micro environments within sheds on farms. These should be monitored on farms to ensure good air quality in all components of sheds that house pigs on farms.

Limitations/Risks

The following limitations and risks may exist for the application of the research findings:

Air quality was shown to vary between micro-environments within a shed. Further, a scoring system was developed for recording of disease incidence on farm. Training of staff will be required for the adoption of air quality measures and disease incidence scores on farms. Software and databases will have to be developed for data collection.

Immunoglobulins and haptoglobin were identified as potential measures of herd health. However, it may not be feasible to measure immune traits for all pigs of a group. Sampling procedures need to be defined that ensure good group estimates of health status of pigs while avoiding the need to record all pigs within a group. These sampling procedures may involve recording only a proportion of pigs per

group or combining blood or saliva samples from multiple pigs for laboratory analysis.

Recommendations

The majority of immune traits had moderate to high heritability estimates. These immune traits were recorded shortly after weaning and provide early information for genetic improvement of health status of pigs. Genetic correlations between these immune traits and growth, health and survival traits should be estimated.

There was considerable variation in air quality measures collected for individual pens within weaner, porker and finisher pigs. The simple air quality measurements used in this study should be adopted more broadly by industry to monitor and improve micro environments within sheds on farms.

Immunoglobulins and haptoglobin differed considerably between weekly batches of pigs and provide opportunities to monitor herd health status more precisely. These traits should be recorded for groups of pigs to monitor health status on farm over time.

A scoring system was developed to record disease incidences on farm. This scoring system should be incorporated in software used by veterinarians to document disease incidence more accurately on farms.

New measurement technique was developed for haptoglobin. Options for the development of a commercial test should be explored taking into account that other commercial tests are already available for haptoglobin.

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Appendix 1: Description of disease incidence scores

Part 1, Description of disease incidence scores - Skin

Sub-category	Abbreviation	Description
Abscess	A1	Localised abscess in an otherwise bright, alert and responsive pig that is eating and drinking normally
	A2	Multiple abscesses or a localised abscess with signs of concurrent ill thrift
	A3	Abscess resulting in impediment to pig's ability to walk, eat, drink or otherwise behave normally
Erysipelas	E1	Characteristic skin lesions in an otherwise bright, alert and responsive pig that is eating and drinking normally
	E2	A pig demonstrating signs of ill thrift, fever, deterioration, lameness/stiffness/reluctance to move, extensive skin lesions and/or inabiliy to access adequate feed or water
Wounds	W1	Superficial wound in a localised area
	W2	Superficial wounds affecting an extensive area or multiple parts of body (e.g. wounds from fighting)
	W3	Erosive or ulcerated skin lesion exposing muscle, bone or tendon
Pressure	PS1	Superficial wound in a localised area
sore	PS2	Superficial wounds affecting an extensive area or multiple parts of body
	PS3	Erosive or ulcerated skin lesion exposing muscle, bone or tendon
Pityriasis rosea	PR1	Characteristic skin lesions in an otherwise bright, alert and responsive pig that is eating and drinking normally
Greasy pig	GP1	Characteristic skin lesions in an otherwise bright, alert and responsive pig that is eating and drinking normally
	GP2	A pig demonstrating signs of ill thrift, fever, deterioration, lameness/stiffness/reluctance to move, extensive skin lesions and/or inabiliy to access adequate feed or water

Appendix 1: Part 2, description of disease incidence scores - Tail and limbs

Sub-category	Abbreviation	Description
Tail biting	TB1	Tail intact; superficial wound in a localised area; minimal bleeding and no evidence of discharge or infection
	TB2	Tail not intact with evidence of bleeding and/or infection
	TB3	Tail extensively damaged or missing and deeper tissue exposed; wound may extend into base of spine
Limb illness	LI1	Limb broken
	LI2	Completely non weight-bearing on a limb
	LI3	Partial weight-bearing on a limb
	LI4	Swelling of any joint to > twice normal size regardless of impact on gait +/- ability to access feed/water
	LI5	Swelling of any joint to less than twice normal size; gait may be mildly affected but pig is able to weight bear on all limbs and is able to access feed and water without difficulty
	LI6	Digit missing and/or underlying bone/tendons exposed
	LI7	Superficial damage/tear to claw
	LI8	Marked superficial wounds affecting multiple limbs and/or extensive areas of an individual limb
	LI9	Erosive or ulcerated skin lesion exposing to muscle, bone or tendon
	LI10	Bursitis - swelling at bony prominence that is not inflamed and does not affect gait
	K	Kyphosis
Difficulty	DS1	Paralysis
standing	DS2	Downer pig, recumbent and unable to stand and/or walk
	DS3	In extreme distress when encouraged to stand
Difficulty	DW1	Freely able to stand and weight bear on all limbs, but extreme distress when encouraged to walk
walking	DW2	Freely able to stand & weight bear on all limbs but ability to access feed/water affected, or predisposed to bullying
	DW3	Freely able to stand on all limbs; gait is affected but pig is able to access feed/water without difficulty

Appendix 1: Part 3, description of disease incidence scores - Ear, eye and respiratory

Sub-category	Abbreviation	Description
Aural	AH1	Ear swollen, shrunken, misshapen but skin intact and no sign of infection
haemotoma	AH2	Ear swollen or misshapen with signs of infection, broken skin and/or discharging wound
Ear biting	EB1	Ear intact; Superficial wound in a localised area; minimal bleeding & no evidence of discharge/infection
	EB2	Ear not intact with evidence of bleeding and/or infection and/or haematoma formation
	EB3	Ear extensively damaged with bleeding +/- infection +/- haematoma formation +/- exposure of deeper tissue
Head tilt	HT1	Symptoms of middle ear infection - head tilt, head/ear shaking, +/-otherwise bright, alert and responsive and eating and drinking normally, +/-symptoms similar to meningitis if severe (see neurological disorders)
Blind	B2	Blind in both eyes
	B1	Blind in one eye
Other	Eye	Any ocular condition resulting in impediment to pig's ability to walk, eat, drink or otherwise behave normally
Sneezing/	RS1	Coughing or sneezing in an otherwise bright, alert & responsive pig that is eating and drinking normally
Coughing	RS2	Difficulty breathing (thumping) &/or coughing with evidence of lost condition and/or systemic or other concurrent illness or impediment to feed/water intake
	RS3	Severe respiratory distress
	NB	Epistaxis or nose bleed

Appendix 1: Part 4, description of disease incidence scores - Intestine and hernia

Sub-category	Abbreviation	Description
Diarrhoea	D1	Mild scours with no blood in an otherwise bright, alert and responsive pig that is eating/drinking normally
	D2	Profuse and/or bloody scours (2a if results in deterioration as per line below)
	D3	Scours associated with poor body condition, concurrent systemic illness, or impacted ability to access feed or water
	D4	Scour of any nature associated with extreme abdominal pain
	D5	Death with septicaemia, dehydration, +/- diarrhoea
Pot Belly	PB	Bloated abdomen
Rect. Strict.	RS	Losing condition, bloated abdomen, +/- history of rectal prolapse
Atresia ani	AA	No anus
Umbilical	UH	Umbilical hernia
Scrotal	SH	Scrotal hernia in males
Inguenial -	IH1	Extensively damaged, infected, ulcerated, bleeding, fly blown or with concurrent poor condition/ other disease
Female	IH2	Hernia resulting in impediment to pig's ability to walk, eat, drink or otherwise behave normally
	IH3	Any hernia large relative to the size of the pig, larger than 30cm in any sized pig, or touching the ground
	IH4	Hernias that are outside the above criteria
Prolapse	PR1	Small (less than trotter size of same size pig) fresh, intact prolapse in an otherwise bright, alert and responsive pig that is eating and drinking normally - Isolate on farm & treat, or transport to abattoir individually within 72 hours
	PR2	Extensively damaged, bleeding, infected or fly blown prolapse
	PR3	Prolapse that is not able to be replaced by a competent person, using pain relief, within 48 hours
	PR4	Any untreated prolapse > 72 hours old

Appendix 1: Part 5, description of disease incidence scores – Nervous system

Sub-category	Abbreviation	Description
Difficulty standing	NS1	Paralysis
	NS2	Downer pig, recumbent and unable to stand and/or walk
	NS3	Symptoms of meningitis; recumbent, paddling, reduced awareness/responsiveness, abnormal eye movements
Head tilt	NH1	Symptoms of middle ear infection - head tilt, head/ear shaking; otherwise bright, alert & responsive, eating/drinking normally, +/-symptoms similar to meningitis if severe
	NH2	Symptoms of meningitis - recumbent, paddling, reduced awareness/response, abnormal eye movements, head tilt
Anxiety	ANX	Anxiety