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Optimising the progeny of first-litter sows in the Australian herd

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Executive Summary

In commercial pork production, progeny born to primiparous sows (gilt progeny; GP) are slower growing and of a lower health status than those piglets born to older sows in subsequent parities (sow progeny; SP). Hence, they represent an area of significant loss of productivity. The major aims of the current project were to characterise performance differences between GP and SP in commercial production systems, to identify some of the underlying anatomical and physiological factors responsible for these differences, target some nutritional and management strategies to address these deficiencies through late gestation and (or) lactation feeding strategies, and conduct a MOFC (margin over feed cost) analysis of the overall impact of sow parity on progeny performance.

A series of experiments were carried out over a number of years and across multiple commercial sites in Australia to test the general hypotheses that GP would be lighter and grow slower than SP at all stages of production and have reduced reproductive performance in the breeding herd. It was expected that GP would have access to colostrum and milk with a lower energetic value due to lower fat, protein and lactose contents, and a lower immunoglobulin G (IgG) concentration. It was therefore anticipated that GP would be compromised in terms of the pre- and postnatal development and function of several organs and tissues (such as skeletal muscle and the gastrointestinal tract) in lactation, have reduced reproductive performance and acquire less maternal immunity, leading to a lower chance of lifetime survival in comparison to SP. It was further hypothesised that feeding conjugated linoleic acid (CLA), medium-chain fatty acids (MCFA), or 1,3-butanediol to sows in late gestation and (or) lactation would improve GP energy levels, improve colostrum and milk composition and intake by GP, and therefore improve the growth performance and pre-weaning survival of GP. Furthermore, an experiment was conducted to test the propositions that feeding a pellet of a larger diameter (~ 9 mm; 12 mm in length), as opposed to a standard' pellet 4 mm in length, as a 'creep' in lactation could be beneficial to piglets born to first-litter sows, and that increased feed intake after weaning irrespective of parity might reduce the number of pigs removed from the overall production flow.

In all studies, GP, relative to SP, were born, weaned and sold lighter. These data clearly showed that a large proportion of the difference in performance between GP and SP in the weaner and grower-finisher stages was a consequence of GP being weaned lighter. These results highlighted the critical importance of the pre-weaning period for determining the growth performance of GP up until sale, as well as the importance of the management of primiparous sows in late gestation and lactation. Segregation of GP and SP, both from birth to slaughter and in the grower-finisher period only, were unsuccessful as management strategies for improving the growth performance of GP (and SP).

The project also investigated differences in the concentrations of macronutrients, energy, and IgG of colostrum and milk between primiparous and multiparous sows throughout lactation (from birth to day 21). This experiment showed that the composition and overall net energy (NE) content of colostrum and milk of primiparous and multiparous sows was largely similar, with lower lactose concentrations in primiparous sow milk in comparison to multiparous sows in late lactation only (days 14 to 21). A follow up experiment showed that various tissues of GP (such as the brain, spleen, liver, quadriceps muscle and small intestine) grew at a different rate to those of SP, particularly around birth, and similar to that of intra-uterine growth restricted (IUGR) piglets. These results indicate that the postnatal performance of GP may be restricted by their delayed anatomical and functional development in late gestation, having impacts on transfer of maternal immunity, and early GIT and musculoskeletal development. Therefore, strategies to improve birth weight and growth rates in GP may be limited by these factors.

Feeding CLA and (or) MCFA in late gestation and lactation was mostly unsuccessful in improving piglet growth performance, colostrum and (or) milk composition, or piglet energetic metabolite concentrations. However, feeding CLA improved overall liveborn pre-weaning survival (although increased stillbirth rate), and piglets from primiparous and multiparous sows fed CLA had (numerically) the highest serum IgG concentrations at day 3 post-partum. These findings indicated that attempts to increase GP energy levels, growth performance and IgG absorption through feeding CLA and (or) MCFA were largely not effective. Therefore, nutritional or other management strategies to improve GP performance may be more successful if targeted elsewhere, but feeding CLA may be effective at different inclusion rates, which requires further investigation.

In this regard, two further experiments were conducted. The first study showed that feeding a diet supplemented with the ketogenic compound 1,3-butanediol in late gestation diets of both gilts and sows increased 24-hour individual weights and total litter weights in both gilt and sow progeny. The percentage of progeny that were light-for-age (<1.1 kg) at 24 h of age was decreased by feeding 1,3-butanediol, particularly in gilts. The second study showed that total creep feed disappearance in lactation was higher in litters offered the larger diameter pellet, but this did not translate to an improvement in litter weaning weight for piglets born to gilts. Piglets born to gilts were weaned lighter than piglets born to sows. In the post-weaning period, male and female pigs offered the larger diameter pellet during lactation showed tendencies to be removed at both a lower rate and receive less medications than pigs offered the smaller diameter pellet during suckling. Growth rate and feed intake were both stimulated in pigs offered the larger diameter pellet during lactation.

In conclusion, and as was supported by MOFC (margin over feed cost) analysis conducted as part of this project, the project has shown that GP represent a substantial loss of production in commercial pig production systems, and focusing on improving their performance in the pre-weaning period is crucial to improving their lifetime productivity. Thus, management strategies to improve lifetime performance of GP should target foetal growth in late gestation to improve their physiological development, particularly of the GIT and skeletal muscle. Management strategies should target growth of GP in the pre-weaning period to increase weaning weights, as this determines their lifetime performance. Efforts in this area may be more beneficial if focused on increasing colostrum and milk production in primiparous sows, or improving the efficiency of IgG absorption in GP, rather than improving colostrum or milk composition in these animals. The project demonstrated that feeding some compounds such as 1,3-butanediol can elicit improvements in weights immediately after farrowing, in both gilts and sows, and that the proportion of light-for-age pigs was improved in gilts by feeding this compound. Moreover, a management strategy such as offering a larger diameter pellet, whilst not improving pre-weaning indices of growth and performance, appeared to positively influence post-weaning performance.

(NOTE: This Executive Summary contained excerpts from JR Craig's PhD thesis submitted to Murdoch University (May 2019), entitled: 'Understanding the early growth and development of gilt progeny to improve their lifetime performance and survival".)

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1. General Introduction and Background to Research

Progeny born to first parity sows (primiparous sows), known as gilt progeny (GP), represent a significant problem for the pork industry as they are born and weaned lighter than their counterparts born to multiparous sows (Miller et al., 2012a; Carney-Hinkle et al., 2013), take longer to reach a saleable market weight (Schinckel et al., 2010), and have a higher incidence of health problems and mortality (Holyoake, 2006; Miller et al., 2012b). The reasons for these shortcomings are not well understood but are largely thought to be a consequence of the naivety of their dams, which are mated at an early age in commercial production, soon after they have reached sexual maturity (Dial et al., 1992), and are experiencing gestation, farrowing and lactation for the first time. This in turn may have consequences for the primiparous sow's physical development, metabolism during gestation and lactation, and their maternal behaviour. For example, primiparous sows continue to grow and partition energy and nutrients into body reserves in the first gestation and lactation, which reduces the energy available for foetal growth (Everts and Dekker, 1994; Ji et al., 2005), mammary development (Farmer and Hurley, 2015), and milk production (Clowes et al., 1998; Pluske et al., 1998; Zak et al., 1998). Their ability to digest and metabolise several nutrients may be lower in comparison to multiparous sows (Kemme et al., 1997; Renteria-Flores et al., 2008; Jacyno et al., 2016), and they may experience catabolism late in lactation (Moeller et al., 2004; Yang et al., 2009). These phenomena can limit their milk production and compromise future reproductive performance.

Colostrum and milk from primiparous sows contain lower concentrations of immunoglobulins (i.e. IgG), possibly contributing to the poorer health of GP by providing inadequate immunity in the early stages of life (Klobasa et al., 1986). Furthermore, their inexperience in the first gestation and lactation can affect their farrowing and nursing behaviours, having negative consequences for their piglets' health and welfare (Thodberg et al., 2002a,b; Alonso-Spilsbury et al., 2007; Ison et al., 2017). Piglet factors, such as low birth weights and reduced colostrum intake, also have several negative implications for the lifetime performance of GP, restricting development of muscle fibres and other tissues, limiting gastrointestinal function and resulting in lower sale weights and inferior reproductive performance in comparison to heavier, more robust piglets (Quiniou et al., 2002; Quesnel et al., 2012).

It is important to understand the physiological reasons behind why GP have reduced performance compared to sow progeny (SP) and where these performance differences occur, as this will allow producers to target management strategies to improve their overall productivity in the herd. It is also imperative to quantify the cost of the penalties associated with GP, such as through a MOFC (margin over feed cost) assessment. Therefore, the first aim of this project was to benchmark the whole-of-life performance of GP to understand the extent of the underperformance of GP in comparison to SP in commercial production systems. Segregation of GP and SP, either from weaning to slaughter or in the grower-finisher period, were evaluated as management strategies to improve the performance of GP. To gain a deeper understanding of why GP perform differently to SP, the current project explored the development of various body tissues and gastrointestinal function of GP compared to SP around birth and weaning. Differences in selected components of colostrum and milk composition and energy values between primiparous and multiparous sows were also investigated, as well as the subsequent acquisition of maternal IgG by GP and SP. Additionally, the use of feeding conjugated linoleic acid (CLA) and (or) medium-chain fatty acids (MCFA), as well as the ketogenic substance 1,3- Butanediol, in late gestation and lactation was evaluated as a strategy to improve GP performance in a commercial setting. Finally, a study was conducted comparing (i) gilts *vs* sows (parity 2-4) and (ii) a 4 mm diameter pellet of 4 mm length *vs* a 9 mm diameter pellet of 12 mm length, to ascertain whether this would impact on pre- and post-weaning growth and performance. Finally, a MOFC assessment was done comparing GP and SP.

The general hypotheses tested were that GP would be lighter and grow slower compared to SP at all stages of life, have reduced reproductive performance and have access to colostrum and milk with a lower energetic value due to lower fat, protein and lactose contents, and a lower IgG concentration. It was therefore expected that GP would be compromised in terms of the development and function of several organs and tissues (such as skeletal muscle and the gastrointestinal tract) in lactation, leading to a lower chance of lifetime survival in comparison to SP. It was further hypothesised that feeding CLA and (or) MCFA, or 1,3- Butanediol, in late gestation and lactation would improve piglet energy levels, improve colostrum and milk composition and therefore improve GP growth performance and pre-weaning survival. Feeding a larger diameter pellet to gilt litters was also hypothesised to improve both pre- and post-weaning growth and performance.

2. Objectives of the Research Project

This project set out to achieve a number of objectives regarding the performance of gilt progeny relative to sow progeny under Australian indoor commercial conditions:

1. Benchmarking of gilt performance. Gilt progeny performance was bench-marked against sow progeny performance and a mix of gilt and sow progeny at two commercial sites, representing two of the major genotypes commercially available in Australia.
2. Investigate a number of gestational, pre-lactational and lactational dietary interventions to improve gilt progeny performance.
3. Investigate a number of management and nutritional interventions in the peri-weaning period targeting an improvement in gilt progeny (with potential outcomes for all progeny).

Examine a number of targeted management interventions early in life to enhance the survival

4. and growth performance of gilt progeny.
5. Conduct a MOFC assessment of the overall impact of sow parity on progeny performance.

3. Research Methodology, Results and Discussion

[NOTE: some of the following is taken from JR Craig's PhD thesis submitted to Murdoch University, entitled: 'Understanding the early growth and development of gilt progeny to improve their lifetime performance and survival".). Included for each experiment is the abstract written for each individual paper and a reference to the full-text paper.

Theme 1. Quantifying the level of variation in gilt progeny

Experiment 1a: Gilt progeny benchmarking – Rivalea (Australia) Pty. Ltd.

Published as: Craig, J. R., C. L. Collins, K. L. Bunter, J. J. Cottrell, F. R. Dunshea, and J. R. Pluske. 2017. Poorer lifetime growth performance of gilt progeny compared with sow progeny is largely due to weight differences at birth and reduced growth in the preweaning period, and is not improved by progeny segregation after weaning. J. Anim. Sci. 95:4904-4916. doi:10.2527/jas2017.1868.

Gilt progeny (GP) are born and weaned lighter than sow progeny (SP) and have higher rates of mortality. This study aimed to quantify the performance and survival differences between GP and SP throughout the entire production cycle from birth to sale. Furthermore, the study looked at the effects of segregating GP and SP compared with comingling during rearing within common pens. It was hypothesised that GP would be lighter than SP at every age and have lower rates of survival accompanied by higher rates of medication, and that segregating GP and SP would improve the growth and survival of both groups. All progeny born to 109 gilts (parity 1) and 94 sows (parities 2 to 8) were allocated to four post-weaning treatments at birth: GP separately penned, GP mixed with SP in a common pen (GM), SP separately penned, and SP mixed with GP in a common pen (SM), with littermates split among treatments. The GM and SM pigs were penned together after weaning. Individual live weight of all progeny was recorded at birth (birth weight [BWT]), weaning (28 d; weaning weight [WWT]), 10 wk of age (10 wk weight [10WT]), and sale (22–23 wk; sale weight [SWT]). Individual HCW, backfat depth, loin depth, and dressing percentage were measured at slaughter. All post-weaning mortalities and medications were recorded.

The GP had a lighter BWT ($P = 0.032$), WWT ($P < 0.001$), 10WT ($P < 0.001$), and SWT ($P < 0.001$) than SP as well as a lower HCW ($P < 0.001$) and dressing percentage ($P = 0.012$). Post-weaning performance differences were mostly attributable to the lighter WWT of GP compared with that of SP when WWT was fitted as a covariate. The GP had a higher mortality in the immediate post-weaning period (weaning to 10 wk of age; $P = 0.028$) and from weaning to sale ($P = 0.012$) than SP, which was also attributable to lower WWT. The GP exhibited a higher incidence of mortality ($P = 0.011$) due to respiratory tract infection in the grower–finisher period, despite similar medication rates ($P = 0.83$). Segregation of GP and SP between pens presented no benefit in terms of growth and survival of both groups while requiring added labour and production considerations and, therefore, is not recommended. This study confirms that GP are lighter than SP, on average, at every stage of life from birth to slaughter and that their performance before weaning is an important determinant for whole-of-life performance.

Experiment 1b: Gilt progeny benchmarking – SunPork Solutions

Published as: Craig, J. R., R. J. E. Hewitt, T. L. Muller, J. J. Cottrell, F. R. Dunshea, and J. R. Pluske. 2019. Reduced growth performance in gilt progeny is not improved by segregation from sow progeny in the grower–finisher phase. animal:1-10. doi:10.1017/S1751731119000788.

Gilt progeny (GP) are born and weaned lighter than sow progeny (SP) and tend to have higher rates of mortality and morbidity. This study quantified the lifetime growth performance differences between GP and SP, and additionally evaluated whether segregating GP and SP in the grower-finisher period compared to mixing them within common pens reduced this variation. It was hypothesised that GP would be lighter than SP at every stage and segregation would improve growth performance of both GP and SP. All piglets born to 61 gilts (parity 1) and 47 sows (parities 2 to 7; mean 3.5 ± 0.2) were allocated to four treatments at 10 weeks of age: (i) GP housed together (GG); (ii) GP mixed (M) with SP (GM); (iii) SP housed together (SS); and (iv) SP mixed with GP (SM). The GM and SM pigs were housed together in common pens after movement into the grower-finisher facility. Individual liveweight of all progeny was recorded at birth, weaning (WWT), 10 weeks of age (10WT) and sale (SWT). Individual hot carcass weight (HCW), fat depth at the head of the last rib (P2) and dressing percentage were measured at slaughter.

Gilt progeny were lighter at birth (P = 0.038), weaning (P < 0.001) and through to sale (P = 0.001) than SP. Nursery and grower-finisher performance differences in GP were highly attributable to their lower WWT compared to SP (P < 0.001 when fitted as a covariate). Segregation of GP and SP increased grower-finisher average daily gain (ADG) in SP but decreased ADG and SWT in GP (P < 0.10). Segregated SP had increased average daily feed intake but only in males (P = 0.007); HCW (P < 0.001) and P2 fat depth (P = 0.055) were higher in mixed female GP, but there was no difference (P > 0.10) in female SP, or in males. In conclusion, GP were lighter at every stage than SP and differences after weaning were highly related to the lighter WWT of GP. Under the conditions of this study, overall segregation of GP and SP showed no consistent advantages in growth performance for both groups and differed significantly between males and females.

Experiment 1c: The MOFC impacts of progeny born to gilts or multiparous sows.

The overall impact of sow parity on progeny performance was modelled utilising the Progeny Enterprise Model (v.44) developed by SunPork Solutions (Peter Cook - CHM Alliance Pty Ltd). The two experiments (1a Rivalea Australia Pty Ltd, and 1b SunPork Farms) measured the lifetime performance of piglets born to either first parity (gilt) sows or multiparous sows (sow). Progeny were identified at birth, with performance measured at birth, weaning, 10 weeks of age, prior to final slaughter and at slaughter. The model was populated with data from Craig *et al.* (2017) – Exp 1a Rivalea and Craig *et al.* (2019) – Exp 1b SunPork, and supplementary data from experimental records. The economic values used for feed and slaughter pig value were current at the time of evaluation (June 2019) and were consistent for both datasets. The summary of the data used is presented in Tables 1 and 2 respectively.

Table 1. Performance data used for the modelling of economic performance for progeny born of different dam parity (first parity (gilt) or multiparous (sow)) housed separately or gilt and sow progeny housed as a mixed group – Experiment 1a.

	Gilt	Sow	Mixed
Weight (kg)			
Birth	1.44	1.50	1.47
Wean (28 d)	6.81	7.57	7.30
10 weeks	26.2	29.2	28.6
17 weeks	60.3	64.8	63.4
Sale	99.4	105.0	103.1
Growth performance – wean to sale			
ADG (kg/d)	0.845	0.878	0.859
ADFI (kg/d)	2.07	2.18	2.16
FCR (kg/kg)	2.45	2.49	2.52
Carcass characteristics			
HSCW (kg)	75.0	79.6	78.5
P2 fat (mm)	11.2	11.4	11.6

ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ratio; HSCW, hot standard carcase weight; P2 fat, depth of fat tissue 65 mm from the midline at the head of the last rib.

Table 2. Performance data used for the modelling of economic performance for progeny born of different dam parity (first parity (gilt) or multiparous (sow)) housed separately or gilt and sow progeny housed as a mixed group – Experiment 1b.

	Gilt	Sow	Mixed
Weight (kg)			
Birth	1.36	1.44	1.40
Wean (24 d)	6.12	6.79	6.45
10 weeks	27.5	31.3	30.1
Sale	87.6	94.3	91.3
Growth performance – wean to sale			
ADG (kg/d)	0.815	0.853	0.828
ADFI (kg/d)	1.71	1.79	1.73
FCR (kg/kg)	2.10	2.09	2.09
Carcass characteristics			
HSCW (kg)	68.7	73.5	71.1
P2 fat (mm)	8.1	9.0	8.8

ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ratio; HSCW, hot standard carcase weight; P2 fat, depth of fat tissue 65 mm from the midline at the head of the last rib.

To model real growth performance the Progeny Enterprise Model utilises a series of age response curves for liveweight, feed conversion, dressing percentage and P2 fat depth drawn from the performance data (Figure 1). These age response curves, along with slaughter payment grids, feed costs, physical space availability, etc. are then utilised to model performance. In this evaluation, all other common simulation parameters were held consistent with only the growth and carcase differences observed between the sow parity groups differing, with all pigs being slaughtered at a common age.

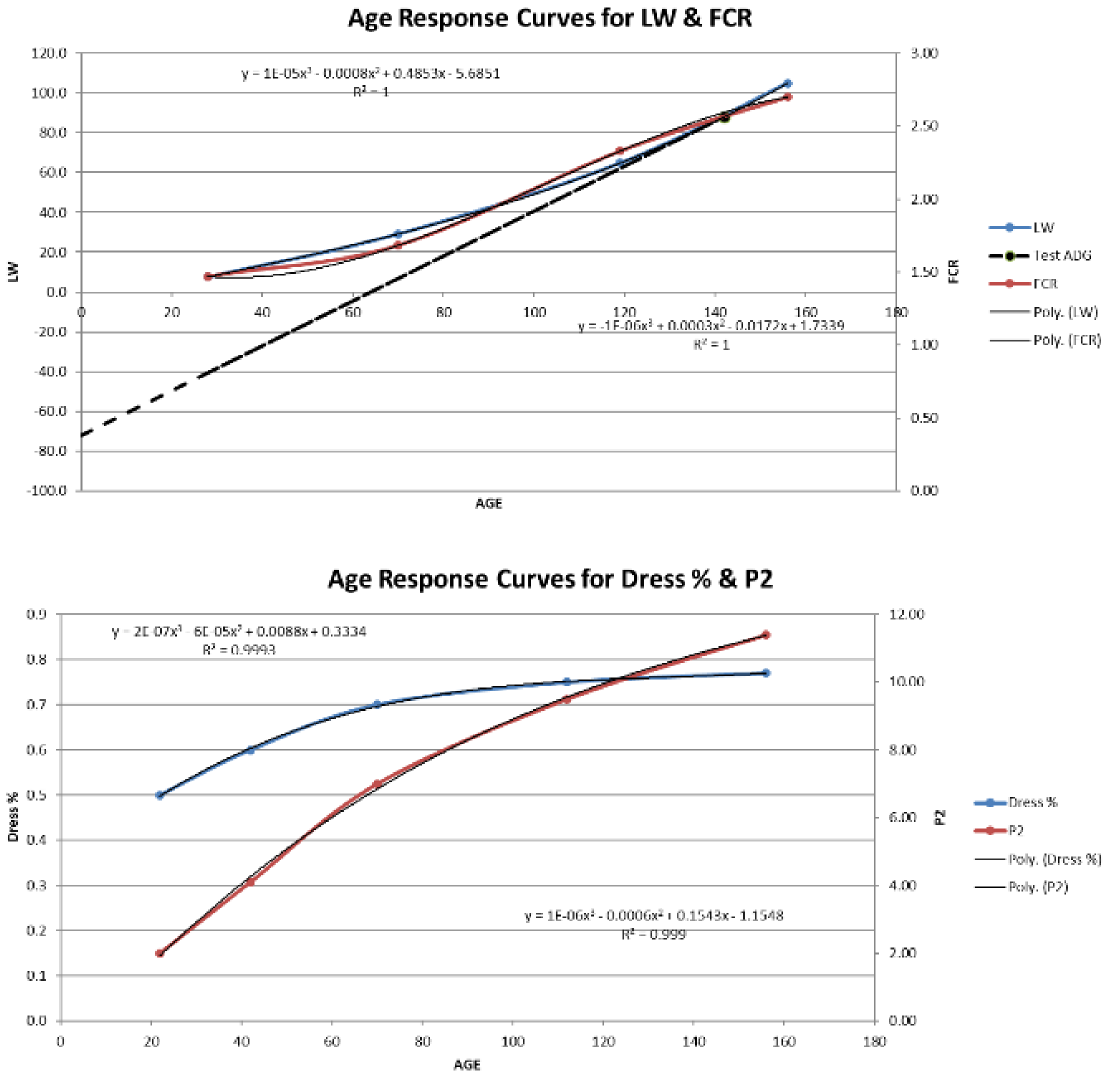

Figure 1. Example age response curves utilised for the modelling of real growth performance.

There are a range of economic indicators that are available for use in evaluating the economic efficiency of production. Feed cost per kg of gain is a long-standing measure but it is lacking in precision compared to a measure such as margin over feed cost (MOFC), which is more encompassing of changes in performance such as the time required to reach sale weight or the impact of higher weights at transfer. This analysis compared the differences in MOFC between progeny of gilt, sow or mixed parity.

The MOFC is a snapshot in time, that is dependent on the price grid that pigs are being marketed into, as well as the current feed prices, therefore providing a raw number as a result would be misleading. Consequently, the result shown below (Table 3) is the change in MOFC compared to the mixed group that would be the best reflection of 'normal' production, allowing a comparison of the differences between gilt and sow progeny and (or) their segregation. These results suggest that GP have the potential to have a large impact on the economic performance of the herd with a difference in MOFC of gilt vs sow progeny of between $5.91 and $9.71 per slaughter pig.

Table 3. The change in MOFC compared to the mixed group, of gilt and sow progeny segregated during their growth period, for Experiment 1a (Rivalea) and Experiment 1b (SunPork).

	Gilt	Sow	Mixed
Experiment 1a	-$ 2.44	$ 3.47	$ 0.00
Experiment 1b	-$ 5.33	$ 4.38	$ 0.00

If data are examined in comparison to the mixed group, that would be considered closer to 'normal' production systems, then GP housed on their own performed worse than the mixed group, had a lower MOFC, and SP performed better than the average. Whilst it would appear to be of benefit to segregate stock and capture the benefit of the increased growth performance of the SP, this must be balanced against the facilities available and health considerations around the benefits of all-in, all-out production, given the inability of the lighter gilt progeny to ever catch up.

To further investigate this difference in performance, Experiment 1a was able to track the progeny within the mixed group. The GP in the mixed group grew slower than those segregated into their own group (0.829 vs 0.845 kg/d), whilst SP held in the mixed pen grew faster than those that were segregated (0.897 vs 0.878 kg/d). This rate of gain difference obviously was reflected in worse or better, respectively, weight gain, with other characteristics also affected. As the mixed group was fed from a common feeder, no assessment of impacts on feed intake or efficiency of production were available.

If the impact on MOFC is examined (Table 4), the gap between gilt and sow progeny increases; this is compared to the average performance of these same gilt and sow progeny. A possible explanation for this is dominance/hierarchy and an ability to access food. With the mixed group, the bigger SP have less competition for feeder space as they have less pigs of their own size to deal with and hence can eat more feed, whilst the smaller GP have less access to feed as they are now competing against larger SP. This information further supports that concept of segregating gilt and sow progeny, if the health status, facilities and management practices allow it.

Table 4. The change in MOFC compared to the whole of the mixed group, of gilt and sow progeny mixed during their growth period for Experiment 1a.

	Gilt-mixed	Sow-mixed	Mixed
Experiment 1a	-$ 4.97	$ 6.90	$ 0.00

Theme 2. Quantifying the underlying biological basis for performance variation in gilt progeny

Experiment 2a: Colostrum and milk composition comparison between gilts and sows

Published as: Craig, J. R., F. R. Dunshea, J. J. Cottrell, U. A. Wijesiriwardana, and J. R. Pluske. 2019. Primiparous and Multiparous Sows Have Largely Similar Colostrum and Milk Composition Profiles Throughout Lactation. Animals 9:35. doi:10.3390/ani9020035.

It is important to understand the biological factors influencing the poorer lifetime performance of gilt progeny in comparison to sow progeny and determine whether this may be partially due to differences in lactation performance between primiparous and multiparous sows. It was hypothesised that primiparous sows would have lower levels of immunoglobulin G (IgG) in colostrum and milk compared to multiparous sows, and lower levels of other energetic components. Differences in colostrum and milk composition between ten primiparous and ten multiparous sows (parities 3 and 4) from a commercial herd were examined throughout lactation (day 0, 1, 2, 3, 7, 14, and 21).

Overall, there were no ($p \geq 0.05$) parity differences in total IgG, fat, protein, lactose, and net energy (NE) concentrations. Primiparous sows had higher lactose levels at day 2 (parity by timepoint interaction; $p = 0.036$) and lower NE at day 3 ($p = 0.091$), and multiparous sows had higher lactose levels at days 14 and 21. Results suggest that shortcomings of gilt progeny are unlikely due to insufficient nutrient levels in colostrum and milk, and more likely to reduced colostrum and milk intake and their capacity to digest and absorb each component.

Experiment 2b, Part A: A comparison of the anatomical and gastrointestinal functional development between gilt and sow progeny around birth and weaning

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Gilt progeny (GP) often have restricted growth performance and health status in comparison to sow progeny (SP) from birth, with the underlying mechanisms responsible for this yet to be fully understood. The current study aimed to compare differences in growth and development between GP and SP in the first 24 h after birth and in the peri-weaning period. Two cohorts of pigs including 36 GP and 37 SP were euthanized at 1 of 4 timepoints: a birth cohort (at birth before suckling, 0 h; and 24 h after birth, 24 h; *n* = 33) and a weaning cohort (at approximately 29 d of age; 'pre-weaning', PrW; and 24 h after weaning; 'post-weaning', PoW; *n* = 40). Pigs were individually weighed at 0 h, 24 h, PrW and PoW up until the point of euthanasia, at which time the weights of selected tissues and organs were recorded and analysed relative to BW. The length of the small intestine (SI), femur and body were also measured, and a serum sample was collected and analysed for immunoglobulin G (IgG) concentration. Samples of jejunal and ileal mucosa were collected and analysed for total protein and specific activity of lactase.

Euthanised GP were lighter ($P < 0.01$) than SP at all timepoints. At all timepoints the ratios of quadriceps weight to femur length, BW to body length, spleen to BW (all $P < 0.05$) and SI weight to length ($P < 0.10$) were lower in GP than SP. There was no difference ($P \geq 0.05$) in stomach or heart to BW ratios between GP and SP in either cohort. The brain to liver weight ratio was greater ($P = 0.044$) in GP than SP in the birth cohort, and the brain to BW ratio was greater ($P < 0.01$) in GP in both the birth and weaning cohorts. The liver to BW ratio was similar ($P = 0.35$) at birth but greater ($P = 0.014$) in GP around weaning. Total mucosal protein content in the jejunum and ileum was lower ($P = 0.007$) in GP at 24 h compared to SP, and specific activity of lactase was greater ($P = 0.022$) in GP in the birth cohort, whereas there were no differences in the weaning cohort ($P \geq 0.10$). Gilt progeny had lower ($P < 0.001$) serum IgG concentration compared to SP at 24 h, but there was no difference ($P \geq 0.10$) in the weaning cohort. Collectively, these findings suggest that the early development of GP may be delayed compared to SP, and that a number of the anatomical differences between GP and SP that exist after birth are also present at weaning.

<u>Experiment 2b, Part B: Permeability of the gastrointestinal tract of gilt and sow progeny around birth and weaning</u>

<u>*Published as: Cottrell, J. J., J. Craig, U. A. Wijesiriwardana, L. Fothergill, M. T. Ringuet, K. O'Hallorhan, D. L. Turpin, L. M. Munoz, C. L. Collins, J. B. Furness, F. R. Dunshea, and J. Pluske. 2017. The Gastrointestinal Tract of Piglets From First Parity Sows Develops More Slowly And Is More Permeable Than Piglets From Later Parity Sows. FASEB J. 31:792.*</u>

Progeny from primiparous sows (gilt) have lower birth weights, higher mortality and poorer performance than the progeny from multiparous sows. The reasons for this are complex but may involve poorer quality colostrum and impaired gastrointestinal tract (GIT) barrier function. With evidence that events early in life impact whole-of-life mortality and productivity the aim of this experiment was to investigate the influence of sow parity on piglet and GIT development at birth and weaning. The experiment comprised of 72 mixed gender Large White x Landrace piglets from parity 2–3 sows (SP) vs gilts (GP). Piglets were euthanised at birth (pre-suckle), 24 h, pre-weaning (PW, ~28 d.) and 24 h after weaning (W). After euthanasia piglets were dissected and gross anatomy quantified relative to body weight (BW) unless otherwise stated. The transepithelial resistance (TER, Ω) of the stomach, jejunum, ileum and colon and jejunum and ileum permeability to 4 kDa FITC and 150 kDa

TRITC labelled dextran (FD4 and TD150) was immediately quantified with Ussing chambers. All data was analysed using a REML (Genstat v18) for the effects of sow parity (SP v GP) and time (0 vs 24h and pre- v post- weaning). All procedures were approved by the institutional animal ethics committee.

Weights of GP were ~25 and 15% less at birth (P<0.001) and weaning (P=0.003) than SP. GP had increased brain weights at birth (P<0.001), which was consistent with lower birth weights and reduced intra-uterine growth. The body composition of GP was differed to SP, with less skeletal muscle (quadriceps:femur g/cm) at birth and weaning (P<0.05). Relative weights of the liver, heart and spleen did not differ at birth; however, enlargement of these organs was observed at weaning (P=0.012, 0.003 and 0.076). There was substantial remodelling of the gastrointestinal tract (GIT) in the first 24h, with increases >20% in SI length, >30% in stomach and SI weights (P<0.01). Concurrently stomach and colon TER reduced (P<0.001) and jenunum FD4 permeability increased (P=0.008). This likely reflects disruption of the mucosa and tight junctions accompanying introduction of enteral feeding and microbiota and was not influenced by sow parity. By weaning GP had lower small intestine (SI, g/cm) and stomach weights, indicating reduced growth of the GIT (P=0.025 and 0.056 respectively). Weaning reduced SI weight but not TER or FD4 and was not further influenced by sow parity. However, GP had increased FD4 permeability (P=0.022) overall at the weaning time point, which together with lower GIT organ weights is consistent with reduced development and barrier function. Passive uptake of maternal immunoglobulin (IgG) was assessed with TD150. Consistent with FD4 no differences in permeability between SP and GP at birth and 24 h were observed, indicating passive uptake of maternal IgG is not likely to differ between SP and GP, but does not exclude differences in active transport mechanisms.

In summary, GP are born underdeveloped compared to SP and differ in body composition by weaning. This includes enlargement of vital organs, which is linked to disease states and reduced muscle growth which will reduce productivity. Furthermore, increased GIT permeability is associated with inflammation and increased susceptibility to enteric pathogens. Collectively these differences likely underpin whole-of-life morbidity and production losses and highlight the need to develop targeted management strategies for gilts and their progeny.

<u>Experiment 2b, Part C: Characterisation of poor gastrointestinal development in gilt progeny</u>

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Progeny of primiparous sows (gilts) have poor production performance compared to those of multiparous sows. This has been attributed to underlying biological events that occur early in life. We specifically focused on the development of the gastrointestinal tract (GIT) and its function in sow vs gilt progeny (SP vs GP) reared under commercial conditions. Piglet tissues were harvested at birth, at 24h, and pre- and post-weaning (28 v 29d) and used to quantify GIT integrity. All data was analysed using Genstat V18 for the effects of parity (sow vs gilt) in birth (0 vs 24h) and weaning (pre- vs post) cohorts. GIT integrity was quantified from freshly excised tissue in Ussing chambers for transepithelial electrical resistance (TER) and macromolecule permeability (FD4; labelled 4kD dextran). Permeability was measured in stomach, colon, jejunum and ileum.

Over the 24h neonatal period, TER was significantly reduced in the stomach and colon (p=0. 048 and 0. 003 respectively) with GP having lower stomach TER than SP (p=0. 015). TER increased in the jejunum and ileum over the 24h neonatal period (p=0. 004 and 0. 002 respectively). An interactive effect of parity and time on ileum FD4 was observed (p=0. 043) where FD4 in SP ileum decreased over the 24h neonatal period and FD4 in GP ileum increased over the 24h period (p=0. 043). Jejunum FD4 was significantly higher in GP than SP over the 24h neonatal period (p=0. 048). An interactive effect of parity and time was observed in the colon over the weaning period where TER increased in SP but decreased in GP (p=0. 005). Stomach TER decreased over the weaning period in both GP and SP (p=0. 013). Jejunum and ileum TER decreased over the weaning period (p=0. 003 and 0. 057 respectively). Ileum FD4 was higher in GP than SP over the weaning period (p=0. 037). These findings reflect a reduction in GIT development in GP compared to SP and gut leakiness may be an underlying reason for poorer production performance and increased morbidity of GP.

Theme 3: Investigating gestational, pre-lactational and lactational interventions to improve gilt progeny performance

Experiment 3a: Inclusion of conjugated linoleic acid and/or medium-chain fatty acids in the late gestation and lactation diets of gilts and sows

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A number of feeding strategies have been used in attempts to improve performance of progeny born to primiparous sows, which are born lighter, grow slower, and have higher rates of mortality than progeny born to older sows. The current study examined whether feeding conjugated linoleic acid

(CLA) or a commercial medium-chain fatty acid (MCFA) product alone or in combination to primiparous and multiparous sows improved pre-weaning growth and survival of their progeny. Feeding CLA or MCFA failed to improve reproductive performance of primiparous or multiparous sows or the performance of their progeny during lactation, and there was no added benefit of feeding these products for gilt progeny. However, feeding CLA alone improved the survival of gilt and sow progeny. Further examination of the different inclusion levels and the timing of CLA feeding may be required in order for the use of this additive to be more efficacious.

Feeding conjugated linoleic acid (CLA) or medium-chain fatty acids (MCFA) to dams has been shown to improve progeny growth and survival, and hence may be particularly advantageous to gilt progeny. Primiparous (n = 129) and multiparous sows (n = 123; parities 3 and 4) were fed one of four diets from day 107 of gestation (107.3 ± 0.1 days) until weaning (day 27.2 ± 0.1 of lactation): (i) control diet; (ii) 0.5% CLA diet; (iii) 0.1% MCFA diet; and (iv) equal parts of (ii) and (iii). Progeny performance data were collected and, from a subset of sows (n = 78) and their piglets (n = 144), a colostrum (day 0), milk (day 21), and piglet serum sample (day 3) were analysed for immunoglobulin G and several selected metabolites. Liveborn pre-weaning mortality tended to be lowest (p = 0.051) in piglets from sows fed 0.5% CLA. However, sows fed the CLA diet had more (p = 0.005) stillbirths than those on the other diets. There were few effects of diet or the dam parity x diet interaction ($p \geq 0.05$) on other parameters. Overall, feeding CLA or MCFA did not improve the performance of primiparous sows, multiparous sows, or their progeny.

<u>Experiment 3b: Dietary inclusion of 1,3-butanediol in late gestation gilt and sow diets</u>

<u>*Submitted for publication as: Wijesiriwardana UA, JR Pluske, JR Craig, J Cottrell and FR Dunshea. Dietary inclusion of 1,3-Butanediol improves weight at 24-hours and pre-weaning survival in gilt and sow progeny. Submitted to Animals, June 2019.*</u>

Gilt progeny are born and weaned lighter and have poorer life-time performance than sow progeny. Low birth weights and pre-weaning mortality are highly associated and are often a result of reduced milk consumption and vigour. Glycogen stores are deposited *in utero* and are relied on heavily within the first hours of life. Because of rapid depletion of these stores, piglets must consume enough milk immediately *post-partum* for survival. Similar to glucose, ketone bodies have the ability to readily pass the placenta for the piglet to use in the neonatal period. Supplementing late gestation diets with ketogenic substances, such as 1,3-butanediol, can potentially be used by the piglet, reducing the rapid depletion of glycogen stores. This effect may be greater in improving piglet growth and survival in gilt progeny.

This study supplemented late gestation diets of both gilts and sows with 1,3-butanediol (4%) from day 90 of gestation until farrowing. Dams fed diets supplemented with 1,3-butanediol had higher plasma beta-hydroxybutyrate concentrations (β-OHB) ($p = 0.01$) and lower NEFA concentrations ($p < 0.001$). The percentage of progeny that were light-for-age (<1.1 kg) at 24 h of age was decreased by 1,3-butanediol (18.2 vs 13.5%, $p < 0.006$), particularly in gilts (24.0 vs 18.3%, $p < 0.034$). Twenty-four-hour individual and litter weights tended to be increased by the 1,3-butanediol diet ($p = 0.085$ and 0.078, respectively) although these effects were not maintained at weaning. Pre-weaning mortality was greater in gilt than in sow progeny and was not altered by dietary 1,3-butanediol. Feeding 1,3-butanediol in late gestation can improve birth weight but further work is needed to see if these effects are carried through subsequent stages of growth, particularly in gilt progeny.

Theme 4. Pre-weaning interventions targeting gilt progeny (with potential outcomes for all progeny)

Experiment 4: Creep pellet diameter effects on gilt and sow progeny performance

Submitted for publication as: Pluske, J.R., J. C. Kim, J. R. Craig, R. J. Smits, C. Braden and C.J. Brewster (in press). Feeding larger diameter pellets to piglets in lactation does not improve the weaning weight of piglets born to gilts but decreases the removal rate of pigs in the post-weaning period. Submitted to the 2019 Australasian Pig Science Association conference.

Creep feed intake of piglets during lactation is positively related to a greater interest in the feed after weaning and subsequent feed intake and performance (Bruininx et al., 2002; Pluske et al., 2007). Nevertheless, consumption of creep feed in lactation is typically low and varies considerably between and within litters. Most efforts at increasing creep feed intake in lactation have focused on feed composition, with relatively less attention paid to physical characteristics of the feed offered to piglets. Commercial pellet diameter sizes for piglet creep feed are typically 4 mm or less in line with the general thought that this size is better for chewing and swallowing and hence intake; however, there is evidence suggesting that young pigs are adaptable to a variety of pellet diameters both before and after weaning (Edge et al., 2005; van den Brand et al., 2014; Clark et al., 2016). Feeding large pellets, to 12 mm diameter, can increase feed intake of pigs during lactation and (or) in the first week in the nursery compared to feeding small pellets (van den Brand et al., 2014; Clark et al., 2016). This could be beneficial to piglets born to first-litter sows that have a lighter weaning weight. Moreover, increased feed intake after weaning irrespective of parity might reduce the number of pigs removed from the production flow. This experiment examined these two propositions.

A total of 240 mixed-parity sows (Large White x Landrace F1; Primegro™ Genetics) was used in the study, in two replicates. Sows were randomly allocated upon entry to the farrowing sheds according to a 2x2 factorial arrangement of treatments, with the factors being (1) gilts vs sows (parity 2-4) and

(2) a 4 mm diameter pellet of 4 mm length vs a 9 mm diameter pellet of 12 mm length. Diets contained ~15 MJ DE/kg and 0.87 g SID lysine/MJ. Pellets were offered on an ad libitum basis from day 3 of lactation to weaning at ~26 days of age; disappearance was recorded. After weaning, 2,070 pigs born to the gilts and sows were mixed, divided into males and females, and placed into pens (n=115) each of 18 pigs. Pigs offered the 4 mm diameter pellet or the 9 mm diameter pellet in lactation were penned together, enabling a comparison of pellet diameter on post-weaning production. Pigs were offered the same commercial diets (4 mm pellet diameter) ad libitum for 21 days after weaning. Data were analysed using the MIXED procedure of SPSS (v 25.0), with litter and pen as experimental units. Chi-square analysis (SPSS) examined the percentage of pigs removed (mortalities and illthrift) and medicated after weaning.

Total creep feed disappearance in lactation was higher (P<0.001) in litters offered the larger diameter pellet, but this did not translate to an improvement in litter weaning weight for piglets born to gilts (interaction, P>0.05). Piglets born to gilts were weaned lighter (P<0.001) than piglets born to sows. In the post-weaning period, male and female pigs offered the larger diameter pellet during lactation showed tendencies to be removed at both a lower rate (2.6 vs 3.9%, P=0.11) and receive less medications (3.3 vs 4.9%, P=0.071) than pigs offered the smaller diameter pellet during suckling. Growth rate and feed intake were both stimulated (P=0.02 and P=0.09, respectively) in pigs offered the larger diameter pellet during lactation. Offering piglets a larger diameter pellet in lactation did not improve the weaning weight of piglets born to gilts, but offered benefits to pigs in the post-weaning period in terms of a lowered removal rate and improved performance. This might be attributable to increased feed-related exploratory behaviour as evidenced by the greater disappearance of creep feed in lactation.

4. Implications & Recommendations

This work represents a thoroughly comprehensive investigation of the performance and evaluation of GP relative to SP in a number of commercial settings in Australia. It has been confirmed from these findings that GP represent a substantial loss of productivity on farm, being lighter at birth, weaning and taking substantially longer to reach market weight. Their poorer pre-weaning growth in comparison to their SP counterparts was identified as a critical factor for determining their lifetime performance and is an area where management practices should be focused to improve their overall profitability. Work from the project has also provided evidence that GP development is compromised before birth, which could determine their potential for postnatal growth. Nevertheless, some promise to improve the survival of low birthweight GP was shown with feeding 1,3 butanediol, and offering piglets, both GP and SP, a larger diameter pellet in lactation improved post-weaning production.

The key findings from the project can be summarised as follows:

1. Gilt progeny are consistently lighter than SP throughout life and are less likely to reach reproductive maturity in the breeding herd;
2. Poorer lifetime performance and MOFC of GP (slower growth rates, lower survivability after weaning) in comparison to SP is largely determined by their lighter birth weights and slower growth before weaning, and cannot be ameliorated by on-farm segregation of GP and SP;
3. Composition of fat, lactose and protein in colostrum and milk is largely similar throughout lactation between primiparous and multiparous (parity 3 and 4) sows; however, lower lactose concentration in milk from primiparous sows in late lactation (from days 14 to 21) may suggest that they suffer from catabolism resulting in reduced milk production in an extended lactation;
4. Gilt progeny have lower serum IgG concentrations early in life than SP, but not as a result of lower IgG concentrations in colostrum and milk of primiparous sows;
5. Several organs and tissues, such as the small intestine, liver, spleen and skeletal muscle (quadriceps), are less developed around birth and weaning in GP in comparison to SP;
6. Allometric growth of several of these organs differs in GP compared to SP, while similar brain development is maintained, synonymous to piglets characterised as suffering from intrauterine growth restriction (IUGR);
7. Feeding CLA and (or) MCFA to dams in late gestation and lactation does not improve the performance or energetic metabolism of GP or SP, nor does it improve the maternal transfer of IgG to either group. However, CLA supplementation increases pre-weaning survival rates of GP and SP;

8. Feeding a ketogenic substance such as 1,3-butanediol can improve 24-hour weights following parturition, although these effects were not maintained at weaning, and the compound also showed a positive effect on reducing the percentage of progeny that were light-for-age (<1.1 kg) at 24 h of age and particularly in gilts.
9. Offering piglets a larger diameter pellet (9 mm) in lactation did not improve the weaning weight of piglets born to gilts, but offered benefits to pigs in the post-weaning period in terms of a lowered removal rate and improved performance. This might be attributable to increased feed-related exploratory behavior as evidenced by the greater disappearance of creep feed in lactation.

It is suggested that future directions of research in this area should be focused on:

- Investigation of other / further nutritional interventions to improve GP prenatal development and birth weights, keeping in mind that gestating primiparous sows are likely to contribute additional digested energy to their own growth and maintenance requirements rather than foetal growth;
- Nutritional strategies to improve colostrum and milk production in primiparous sows, therefore increasing GP weaning weights and improving their overall lifetime productivity;
- Direct management strategies for improving progeny viability and energy levels before weaning, such as observation at farrowing and effective colostrum management;
- Improving sow longevity and genetic gain to reduce the need for replacement breeding stock, therefore reducing the overall number of primiparous sows and their progeny in the herd;
- Follow-up studies pertaining to increased pellet diameter (and length) for piglets both before and after weaning. Preliminary results (albeit over a large number of sows and piglets) achieved in this project appear promising, despite the lack of improvement in pre-weaning indices, because creep feed disappearance and post-weaning production were improved. Such results allow for the possibility of manipulating the composition of the pellet, e.g., to modulate aspects of the young pigs' gastrointestinal tract before weaning to impact production and performance positively after weaning.

5. Intellectual Property

There is no intellectual property associated with this project.

6. Technical Summary

As part of her laboratory analysis, JR Craig has developed a method for quantifying the macronutrient content of small volumes of colostrum and milk from pigs (see Craig *et al.,* [2019] Animals 9:35). A modified assay for total fat was developed based on the work of Forcato *et al.* (2005). Total NE (on an as-fed basis) of milk from day 3 of lactation onwards was calculated from the values for total fat, protein, and lactose according to the equation derived by Hansen *et al*. 2012. Lactose was measured based on the assay by BioVision (Catalogue #K624), and total protein was measured using the Pierce BCA Protein Assay Kit (Thermo Fisher Scientific, Scoresby Vic, Australia) after dilution of standards and samples in 2% sodium dodecyl sulfate (SDS; Invitrogen Life Technologies; Thermo Fisher Scientific). For more information please contact Jess Craig (Rivalea Australia; Ph: 02 6033 8542).

The manufacture of the larger diameter and length pellets was conducted at a commercial feed mill (Ridley).

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8. Publications Arising

<u>Refereed Journal Articles</u>

- Craig, J.R., Collins, C.L., Athorn, R.Z., Dunshea, F.R. and Pluske, J.R. 2017. Investigating the reproductive performance of gilt progeny entering the breeding herd. *Journal of Swine Health and Production* 25:230-237.
- Craig, J. R., C. L. Collins, K. L. Bunter, J. J. Cottrell, F. R. Dunshea, and J. R. Pluske. 2017. Poorer lifetime growth performance of gilt progeny compared with sow progeny is largely due to weight differences at birth and reduced growth in the preweaning period, and is not improved by progeny segregation after weaning. *Journal of Animal Science* 95:4904-4916. doi:10.2527/jas2017.1868.
- Craig, J. R., F. R. Dunshea, J. J. Cottrell, E. M. Ford, U. A. Wijesiriwardana, and J. R. Pluske. 2019. Feeding Conjugated Linoleic Acid without a Combination of Medium-Chain Fatty Acids during Late Gestation and Lactation Improves Pre-Weaning Survival Rates of Gilt and Sow Progeny. *Animals* 9:62. doi:10.3390/ani9020062.
- Craig, J. R., F. R. Dunshea, J. J. Cottrell, U. A. Wijesiriwardana, and J. R. Pluske. 2019. Primiparous and Multiparous Sows Have Largely Similar Colostrum and Milk Composition Profiles Throughout Lactation. *Animals* 9:35. doi:10.3390/ani9020035.
- Craig, J. R., R. J. E. Hewitt, T. L. Muller, J. J. Cottrell, F. R. Dunshea, and J. R. Pluske. 2019. Reduced growth performance in gilt progeny is not improved by segregation from sow progeny in the grower–finisher phase. *Animal*:1-10. doi:10.1017/S1751731119000788.
- Craig J. R., Cottrell J. J., Furness J. B., Wijesiriwardana U. A., Dunshea F. R. and Pluske J.R. (in press). A comparison of the anatomical and gastrointestinal functional development between gilt and sow progeny around birth and weaning. *Journal of Animal Science* (accepted).

<u>Conference Papers</u>

- Craig, J. R., J. J. Cottrell, U. A. Wijesiriwardana, J. B. Furness, F. R. Dunshea, and J. Pluske. 2017. Gilt progeny have lower serum immunoglobulin G (IgG) concentrations than sow progeny, but not as a result of concentrations in colostrum and milk. In: 10th International Conference on Pig Reproduction Columbia, MO. p. 42.
- Craig, J. R., F. R. Dunshea, J. J. Cottrell, E. M. Ford, U. A. Wijesiriwardana, and J. R. Pluske. 2017. Pre-weaning growth of gilt and sow progeny is not improved by feeding conjugated linoleic acid and medium chain fatty acids during gestation. Anim. Prod. Sci. 57:2452-2452.

- Craig, J. R., F. R. Dunshea, J. J. Cottrell, E. M. Ford, U. A. Wijesiriwardana, and J. R. Pluske. 2017. Effects of feeding conjugated linoleic acid (CLA) and medium chain fatty acids (MCFA) to gilts and sows on survival of their progeny. Anim. Prod. Sci. 57:2411.
- Craig, J. R., F. R. Dunshea, J. J. Cottrell, U. A. Wijesiriwardana, J. B. Furness, and J. R. Pluske. 2018. Comparison of lactose digestive capacity in the small intestine between gilt and sow progeny around birth and weaning. In: 14th International Symposium on Digestive Physiology of Pigs Brisbane, Australia.
- Cottrell, J. J., J. Craig, U. A. Wijesiriwardana, L. Fothergill, M. T. Ringuet, K. O'Hallorhan, D. L. Turpin, L. M. Munoz, C. L. Collins, J. B. Furness, F. R. Dunshea, and J. Pluske. 2017. The Gastrointestinal Tract of Piglets From First Parity Sows Develops More Slowly And Is More Permeable Than Piglets From Later Parity Sows. FASEB J. 31:792.
- Wijesiriwardana DA, Craig JR, Ringuet M, Fothergill LJ, O'Halloran K, Turpin D, Munoz L, Collins CL, Furness JB, Pluske JR, Cottrell JJ and Dunshea FR. 2019. Characterisation of poor gastrointestinal tract development in gilt progeny. Proceedings of the ASAS Midwest Section Joint Meeting. Omaha, NE. Abstract no. 193.

Submitted

- Wijesiriwardana UA, JR Pluske, JR Craig, J Cottrell and FR Dunshea. Dietary inclusion of 1,3-Butanediol improves weight at 24-hours and pre-weaning survival in gilt and sow progeny. Submitted to *Animals*, June 2019.
- Wijesiriwardana, D.A., J.R. Craig, J.R. Pluske, J.J. Cottrell and F.R. Dunshea. Dietary 1,3-Butanediol increases birth weight in both gilt and sow progeny. Submitted to the 2019 *Australasian Pig Science Association* conference.
- Pluske, J.R., J. C. Kim, J. R. Craig, R. J. Smits, C. Braden and C.J. Brewster (in press). Feeding larger diameter pellets to piglets in lactation does not improve the weaning weight of piglets born to gilts but decreases the removal rate of pigs in the post-weaning period. Submitted to the 2019 *Australasian Pig Science Association* conference.

In Preparation

- Experiment 8 (Creep feed pellet diameter) is to be written up by JR Craig as a manuscript for submission to the *Journal of Swine Health and Production* in 2019.
- JR Craig is looking to submit a version of her PhD thesis literature review as a review article to a journal such as *Livestock Science* or similar, in collaboration with JR Pluske in 2019.