

**How Does the Pre-weaning Environment Affect
Gut Structure and Function, and Lifetime
Performance of the Pig?**

Hugh Geoffrey Payne

Faculty of Health Sciences

School of Veterinary and Biomedical Sciences

Murdoch University

This thesis is presented for the degree of Master of Philosophy of Murdoch University

June 2009

Declaration

I declare that this is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Hugh Geoffrey Payne

June 2009

ABSTRACT

The reduction in feed intake and growth rate that occurs following weaning is of major economic consequence to the pig industry. Currently, a range of antimicrobial products can be used to minimise the impact of weaning on piglet health and subsequent performance. However, the use of these products in pig diets is subject to increasing restriction worldwide because of perceived risks to public health and to the environment. Thus, alternative methods are required to mitigate the growth check that almost invariably occurs after weaning in most production systems.

Piglets produced outdoors are claimed to experience less of a growth check at weaning and to be able to thrive in relatively unsophisticated weaner accommodation. However, these claims have not been substantiated under Western Australian conditions, nor a scientific basis for these claims established. Consequently, a series of experiments was designed to test the general hypothesis for this thesis – *‘the gut structure and function, and lifetime performance of the weaned pig are affected by its pre- and post-weaning rearing environments’*.

Experiment 1 was conducted in two parts to quantify differences in the growth performance, health and gut structure of weaner pigs produced indoors or outdoors and reared in conventional or deep-litter pens. The weaner diet in the first part of the experiment contained 100 ppm of olaquinox and 3,000 ppm of zinc oxide (Exp1a). This experiment was repeated without using dietary antimicrobial products (Exp1b). Experiment 2 was conducted in conventional buildings to examine the effect of exposing piglets in lactation to similar substrates to those available to outdoor piglets

used in Exp1a and Exp1b in the absence of other differences in the outdoor production milieu.

Pre-weaning environments in Exp1a (indoor production (IP) and outdoor production (OP)) appeared to have little effect on gut structure and overall growth rate but significantly affected carcass composition, whereas post-weaning environments (conventional (C) or deep-litter (DL)) affected both overall growth rate and carcass composition. Although feed disappearance was similar, OP pigs grew faster than IP pigs in the first 47 d after weaning in Exp1a but not in Exp1b. Lifetime growth rate (GR), P2 backfat, feed disappearance and feed conversion ratio (FCR) were not significantly affected by the production environment in Exp1a whereas OP pigs grew slower with higher P2 backfat and FCR in Exp1b. Interestingly, OP pigs had heavier carcass weights and higher dressing percentages than IP pigs in both parts of the experiment. The effects of post-weaning environment were more consistent as DL pigs grew faster, were fatter, and had higher carcass weights and dressing percentages than C pigs.

Villus height and crypt depth of IP and OP pigs were not different at 21 (weaning) or 28 d, but villus height decreased and crypt depth increased in the week after weaning. Pigs reared in C pens had greater faecal concentrations of volatile fatty acids than pigs in DL, indicating that the latter ingested sufficient straw to alter fermentation characteristics.

In Experiment 2, there were no differences in gut structure or pre-weaning and lifetime GR of pigs offered no creep feed (NC), a commercial creep feed (CF) or an 'outdoor' mix (OM) comprising of 1 part straw, 5 parts sow feed and 25 parts of soil taken from

paddocks in which OP pigs used in Exp1a and Exp1b were farrowed. However, NC pigs grew slower in the week after weaning than the other two treatments. Backfat and feed disappearance were similar for all treatments but pigs on the OM treatment had higher carcass weights and dressing percentages than pigs on the NC and CF treatments. Villus height and crypt depth were not different between treatments and, although the piglets were weaned at 28 d, villus height decreased and crypt depth increased in the week after weaning to an extent similar to that experienced by piglets weaned at 21 d in Experiment 1.

Although all piglets received intramuscular injections of 200 mg iron (Fe) dextran when 1 to 2 days old, piglets offered the OM during lactation had higher serum iron and blood haemoglobin (Hb) levels than those offered NC or CF. Furthermore, half the piglets offered NC or CF had Hb levels indicative of chronic Fe deficiency anaemia. The average parity of sows used in this experiment was 6.3 litters, suggesting that piglets may have been born with low Fe stores, possibly because of low Fe stores in their dams due to sub-optimal mineral nutrition over successive parities.

In summary, the findings from these experiments partly supported the general hypothesis for this thesis. Under the conditions of these experiments, access to outdoor substrates in lactation had little effect on gut structure and lifetime growth rate but increased both carcass weight and dressing percentage, whereas rearing in DL pens increased feed intake, FCR, growth rate, P2 backfat, carcass weight and dressing percentage.

TABLE OF CONTENTS

Contents	Page
Declaration	i
Abstract	ii
Table of Contents	v
List of Tables	ix
List of Figures	xi
Acknowledgements	xii
Publications	xiii
Abbreviations and Definitions	xiv
General Introduction	1
1. LITERATURE REVIEW	5
1.1. Introduction	5
1.2. The use of copper, zinc and antibiotic growth promoters in pig production	7
1.3. The weaning process	9
1.4. Consequences of weaning	11
1.4.1. Decreased feed intake	11
1.4.2. Continuity of fluid intake after weaning	12
1.5. Salient features of indoor and outdoor farrowing systems	14
1.6. Salient features of conventional and deep-litter rearing system	16
1.6.1. Weaner pens	17
1.6.2. Grower/finisher accommodation	18
1.6.3. Space allowance	20
1.7. Behavioural, social and environmental consequences arising from differences between indoor and outdoor production systems	21
1.7.1. Suckling frequency	21
1.7.2. Behavioural development	25
1.7.3. Physiological effects	25
1.7.4. Gut development and ecology	26
1.7.5. Air quality	28

1.8. Environmental, behavioural and production consequences of differences between conventional and alternative post-weaning housing systems	29
1.8.1. Thermal environment	29
1.8.2. Environmental enrichment	31
1.8.3. Comparisons of pig performance in different post-weaning rearing systems	33
1.9. Creep feeding	39
1.10 Iron status	41
1.11 Conclusions	47
2. GENERAL MATERIALS AND METHODS	48
2.1. Animals	48
2.2. Housing	49
2.2.1. Pre-weaning accommodation (Experiment 1)	49
2.2.2. Weaner accommodation (Experiment 1)	50
2.2.3. Grower/finisher accommodation (Experiment 1)	51
2.2.4. Accommodation for sacrificial sacrifice cohort (Experiment 1)	52
2.2.5. Sow accommodation (Experiment 2)	52
2.2.6. Weaner pens (Experiment 2)	53
2.2.7. Grower/finisher pens (Experiment 2)	53
2.3. Slaughter procedures	54
2.4. Euthanasia and procedures for blood, gut and organ sampling	54
2.5. Carcass composition	56
2.6. Faecal sampling	56
2.7. Analytical methods	57
2.7.1. Volatile fatty acids	57
2.7.2. Haematological indices	57
3. EXPERIMENT 1	59
3.1. Introduction	59
3.2. Materials and methods	61
3.2.1. Experimental design	61
3.2.2. Animals	62

3.2.3. Housing	63
3.2.4. Nutrition	63
3.2.5. Measurements and observations	64
3.3. Statistical Analyses	65
3.4. Results	66
3.4.1. Production indices	66
3.4.1.1. Experiment 1a	66
3.4.1.2. Experiment 1b	67
3.4.1.3. Experiment 1b(IP)	68
3.4.1.4. Experiment 1b(OP)	69
3.4.1.5. Experiment 1b(IP) and 1b(OP) combined	70
3.4.2. Carcass composition of weaner piglets	72
3.4.3. Experiment 1b(IP) and 1b(OP) combined	73
3.4.4. Organ weights	75
3.4.4.1. Experiment 1a	75
3.4.4.2. Experiment 1b	75
3.4.5. Histology	77
3.4.5.1. Experiment 1b	77
3.4.6. Gut acidity (pH)	77
3.4.7. Volatile fatty acid production	78
3.4.7.1. Experiment 1a	78
3.4.7.2. Experiment 1b	82
3.4.8. Haematological indices	85
3.4.8.1. Piglets at weaning (21 d) – Experiments 1a and 1b	85
3.4.8.2. Piglets at 28 and 42 days of age (7 and 21 d post-weaning) – Experiment 1b	86
3.4.9. Health	87
3.5. Discussion	89
3.5.1. Performance indices	89
3.5.1.1. Production system effects	89
3.5.1.2. Rearing system effects	93
3.5.2. Organ weights	96
3.5.3. Volatile fatty acid production	98
3.5.4. Blood characteristics	101

3.5.5. Health	103
3.5.6. Limitations to the study	106
3.5.7. Future work	108
3.6. Conclusions	109
4. EXPERIMENT 2	111
4.1. Introduction	111
4.2. Materials and methods	113
4.2.1. Animals and experimental design	113
4.2.2. Housing, management and nutrition	114
4.2.3. Measurements and observations	116
4.2.4. Statistical analysis	119
4.3. Results	119
4.3.1. Production performance	119
4.3.2. General health	122
4.3.3. Organ weights	122
4.3.4. Morphology of the small intestine	124
4.3.5. Gut acidity values	124
4.3.6. Volatile fatty acid production	125
4.3.7. Haematological indices	128
4.4. Discussion	129
4.4.1. Pre-weaning substrate disappearance	129
4.4.2. Production indices	132
4.4.3. Organ weights	134
4.4.4. Morphology of the small intestine	135
4.4.5. Acid production	135
4.4.6. Fe status	136
4.5. Conclusions	138
5. GENERAL DISCUSSION	140
5.1. Further Work	148
6. REFERENCES	149

LIST OF TABLES

		Page
1.1	Growth performance of pigs reared in shelters (from Payne et al., 2000)	34
1.2	Performance of grower-finisher pigs in conventional or deep-litter housing systems	35
1.3	The effects of pre- and post-weaning environment and housing on pig performance	38
3.1	Calculated composition of diets used in Experiments 1a and 1b	64
3.2	Experiment 1a - Growth performance of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight	66
3.3	Performance of pigs from an indoor production system (IP) reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (Exp1b(IP))	69
3.4	Performance of pigs from an outdoor production system (OP) reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (Exp1b(OP))	70
3.5	Adjusted growth performance of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens from 5 to 105 kg live weight without dietary antimicrobial products (pooled data from Exp1b(IP) and Exp1b(OP))	71
3.6	Effect of production system on body composition (by dual energy X-ray absorptiometry) of newly-weaned, 21-day-old piglets from indoor or outdoor production systems (Exp1a)	72
3.7	Effect of age on body composition (by dual energy X-ray absorptiometry) at 21, 28 and 42 days of age of indoor-produced piglets reared in conventional pens (Exp1b(IP))	72
3.8	Effect of age on body composition (by dual energy X-ray absorptiometry) at 21, 28 and 42 days of age of outdoor-produced piglets reared in deep-litter pens (Exp1b(OP))	73
3.9	Body composition (by dual energy X-ray absorptiometry) of pigs killed at 21, 28, and 42 days of age and half-carcasses taken at 161 days of age from indoor-produced pigs reared in conventional pens (IPC) and from outdoor-produced pigs reared in deep-litter pens (OPDL) using pooled data from Exp1b(IP) and Exp1b(OP)	74
3.10	Relative weight (percentage of empty bodyweight) of visceral organs of 21 day-old newly weaned pigs from an indoor (IP) or outdoor (OP) production system (Experiment 1a)	75
3.11	Relative weight (percentage of empty bodyweight) of visceral organs at 21, 28 and 42 days of age of indoor-produced (IP) pigs reared in conventional (C) pens or from outdoor-produced (OP) pigs reared in deep-litter (DL) pens using pooled data from Exp1b(IP) and Exp1b(OP)	76

3.12	Mean villous height (μm) and crypt depth (μm) at 21, 28 and 42 days of age of pigs from an indoor production system reared in conventional (IPC) pens or from an outdoor production system reared in deep-litter (OPDL) pens using pooled data from Exp1b(IP) and Exp1b(OP)	77
3.13	Acidity (pH) of digesta at 21, 28 and 42 days of age of pigs from an indoor production system reared in conventional (IPC) pens or from an outdoor production system reared in deep-litter (OPDL) pens (Exp1b(IP) and Exp1b(OP))	78
3.14	Faecal concentrations (molar proportions) of volatile fatty acids at 33, 47, 68 and 145 days of age from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens (Experiment 1a)	81
3.15	Faecal concentration of volatile fatty acids at 35, 49, and 63 days of age of pigs from indoor (IP) or outdoor (OP) production systems reared in conventional (C) or deep-litter (DL) pens (Exp1b(IP) and Exp1b(OP))	84
3.16	Haematological indices at weaning (21 days of age) of pigs from indoor (IP) or outdoor (OP) production systems	86
3.17	Haematological indices at 28 and 42 days of age of pigs produced indoors (IP) or outdoors (OP) and reared in conventional (C) or deep-litter (DL) pens (Experiment 1b)	87
4.1	Composition of diets	117
4.2	Growth and carcass characteristics of pigs offered no creep feed (NC), creep feed (CF) or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age	121
4.3	Main effects of pre-weaning nutrition on the visceral organ weights of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM) from day 7 to weaning at 28 days of age	123
4.4	Mean villus height and crypt depth of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age	124
4.5	Main effects for acidity (pH) of digesta from 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM) from day 7 to weaning at 28 days of age	125
4.6	Total and relative concentration (% of total VFA) of VFA in digesta from the caecum and distal colon of 28 and 35 day old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM - comprised of 1 part straw, 5 parts sow feed and 25 parts soil) from day 7 to weaning at 28 days of age	127
4.7	Haematological indices of 28 and 35 d old piglets offered no creep feed (NC), creep feed (CF), or outdoor mix (OM) from day 7 to weaning at 28 days of age	128

LIST OF FIGURES

	Page
4.1 Average feed disappearance (g/pig) for pigs offered no creep (NC), creep feed (CF), or outdoor mix (OM) from day 7 to weaning at 28 days of age	120

ACKNOWLEDGEMENTS

Many organisations and people contributed to the initiation and completion of this research. My sincere thanks are due to:

- the Commonwealth of Australia for financial assistance provided under its Research Training Scheme
- Australian Pork Ltd (formerly the Pig Research and Development Corporation) for providing research funds
- the Department of Agriculture and Food Western Australia (DAFWA) for in-kind support
- Steve Lyneham, Australian Natural Pork, and Wandalup Farms for their co-operation in supplying pigs for the experiments
- Professor John Pluske for his guidance, understanding and extreme patience throughout this project
- Dr Bruce Mullan for his advice and support during the many technical and personal challenges that confronted me from the outset
- Jae Cheol Kim, Megan Trezona and Karen Moore for invaluable help with laboratory and field work
- Roland Nicholls and Stacey McCullough for expert technical assistance during the experiments
- Richard Seaward and Bob Davis and other staff at the Medina Research Station for technical support and day-to-day care of the animals
- my wife, Jan, for her endless love, encouragement and solace throughout
- finally to the pig—the gentleman who pays the rent. This intelligent, sentient creature provides unceasing reminders that reductionist science alone will not solve all the problems of pig production. A holistic approach is required to fully understand the complex interactions between the pig and its environment. Without this, efforts to improve the welfare, health, performance and productivity of the pig will not be wholly successful.

PUBLICATIONS

- Payne, H.G.**, Mullan, B.P., Nicholls, R.N., McCullough, S.M., & Pluske, J.R. (2003). Weaner pigs produced outdoors outperform counterparts produced indoors. In “Manipulating Pig Production IX”, p. 125, ed. J.E. Paterson, (Australian Pig Science Association, Werribee, Australia).
- Payne, H.G.**, Mullan, B.P., Nicholls, R.N., McCullough, S.M., Pluske, J.R., & Clark P. (2005). Haematological indices of piglets provided with parenteral iron dextran and creep feed or soil prior to weaning. In “Manipulating Pig Production X”, p. 157, ed. J.E. Paterson, (Australian Pig Science Association, Werribee, Australia).
- Payne, H.G.**, Mullan, B.P., Nicholls, R.N., McCullough, S.M., & Pluske, J.R. (2005). Piglet exposure to soil before weaning reduces the post-weaning growth check and increases carcass weight. In “Manipulating Pig Production X”, p. 158, ed. J.E. Paterson, (Australian Pig Science Association, Werribee, Australia).
- Pluske, J.R., **Payne, H.G.**, Williams, I.H., & Mullan, B.P. (2005). Early feeding for lifetime performance of pigs. *Recent Advances in Animal Nutrition in Australia* **15**:171-181.
- Pluske, J.R., Hansen, C.F., **Payne, H.G.**, Mullan, B.P., Kim, J.C., & Hampson, D.J. (2007). Gut health in the pig. In “Manipulating Pig Production X”, pp. 147-158. ed. J.E. Paterson, (Australian Pig Science Association, Werribee, Australia).
- Pluske, J.R., Durmic, Z., **Payne, H.G.**, Mansfield, J, Mullan, B.P., Hampson, D.J., & Vercoe, P.E. (2007). Microbial diversity in the large intestine of pigs born and reared in different environments. *Livestock Science* **108**:113-116.

ABBREVIATIONS AND DEFINITIONS

ADG	Average daily gain (g/d)
ANOVA	Analysis of variance
AP	Any antimicrobial product including but not limited to antibiotics, zinc, copper and acidifiers in various forms
BCR	Branch chain fatty acid ratio
C	Conventional
CF	Creep Feed
DAFWA	Department of Agriculture and Food Western Australia
DL	Deep-litter
Dressing percentage	$HSCW \div \text{Live weight at slaughter} \times 100$
DXA	Dual energy X-ray absorptiometry
FCR	Feed conversion ratio (kg : kg)
GIT	Gastrointestinal Tract
GR	Growth rate (g/d)
HSCW	Hot standard carcass weight
IP	Indoor production (piglets farrowed and suckled indoors)
OM	'Outdoor' mix comprising of: 1 part straw, 5 parts sow feed and 25 parts soil
OP	Outdoor production (piglets farrowed and suckled outdoors)
NF	No creep feed
P2	Site for subcutaneous backfat measurement (including skin) 65 mm from the dorsal midline and level with the posterior edge of the last rib
VFA	Volatile fatty acid