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Original Research Article

Post-weaning and whole-of-life performance of pigs is determined by live weight at weaning and the complexity of the diet fed after weaning☆

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ABSTRACT

The production performance and financial outcomes associated with weaner diet complexity for pigs of different weight classes at weaning were examined in this experiment. A total of 720 weaner pigs (360 entire males and 360 females) were selected at weaning (27 ± 3 d) and allocated to pens of 10 based on individual weaning weight (light weaning weight: pigs below 6.5 kg; medium weaning weight: 6.5 to 8 kg; heavy weaning weight: above 8.5 kg). Pens were then allocated in a 3 × 2 × 2 factorial arrangement of treatments with the respective factors being weaning weight (heavy, medium and light; H, M and L, respectively), weaner diet complexity (high complexity/cost, HC; low complexity/cost, LC), and gender (male and female). Common diets were fed to both treatment groups during the final 4 weeks of the weaner period (a period of 39 days). In the first 6 d after weaning, pigs offered the HC diets gained weight faster and used feed more efficiently than those offered the LC diets ($P = 0.031$). Pigs fed a HC diet after weaning tended to be heavier at the sale live weight of 123 d of age compared with pigs fed the LC diet ($P = 0.056$). There were no other main effects of the feeding program on growth performance through to slaughter. Weaning weight had a profound influence on lifetime growth performance and weight at 123 d of age, with H pigs at weaning increasing their weight advantage over the M and L pigs (101.3, 97.1, 89.6 kg respectively, $P < 0.001$). Cost-benefit analyses suggested there was a minimal benefit in terms of cost per unit live weight gain over lifetime when pigs were offered a HC feeding program to L, with a lower feed cost/kg gain. The results from this investigation confirm the impact of weaning weight on lifetime growth performance, and suggest that a HC feeding program should be focused on L weaner pigs (i.e., weaning weight less than 6.5 kg at 27 d of age) in order to maximise financial returns.

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1. Introduction

Weaning imposes abrupt and simultaneous stressors on piglets that typically causes low and variable feed consumption, sub-optimal weight gain, episodes of diarrhoea, and (or) increased morbidity and (or) mortality (Pluske et al., 1997). The post-weaning 'growth check' has detrimental impacts on lifetime growth, with Tokach et al. (1992) being amongst the first to demonstrate that pigs maintaining or losing weight in the first 7 to 10 d after weaning required an additional 10 d to reach market weight compared with pigs gaining 250 g/d in this period. As a consequence, nutrition and management after weaning is directed primarily towards encouraging rapid feed intake whilst reducing mortality and morbidity.

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Williams (2003) commented that to ensure consistently high feed intake after weaning, and hence high growth rates with concurrent minimal digestive disturbances, feeding of high-density, highly-digestible diets should be practised. Diets fed in a phase-feeding program that ease the transition from a milk liquid diet to predominately plant-based diets demonstrate how this can occur (Tokach et al., 2003). Such diets generally contain high-quality animal-based products such as lactose, fishmeal, products derived from blood, and (or) cooked cereals. Such diets are generally referred to as “complex” diets (e.g., Dunshea et al., 2002b), and in some countries, the use of more complex diets may not be as widely accepted as in others due to the lack of ability to source raw materials, the higher costs associated with securing these ingredients, and (or) different production and management factors (Pluske et al., 2006).

In this regard, there is some evidence that feeding a less-complex diet immediately after weaning, whilst initially reducing production, does not compromise long-term growth performance or carcass quality (Collins et al., 2013; Skinner et al., 2014; Whang et al., 2000). Such a strategy may also be economically advantageous over the entire wean to finish period. Furthermore, benefits associated with feeding complex diets may differ depending on the weight of the pig at weaning (Dunshea et al., 2002a,2003; Lawlor et al., 2002; Mahan and Lepine, 1991). Therefore, the aim of this experiment was to evaluate the production and financial outcomes associated with weaner diet complexity for pigs of different weight classes at weaning.

2. Materials and methods

All experimental procedures involving animals were reviewed and approved by the Animal Care and Ethics Committee (NSW Licence SPPL 111) of Rivalea Australia Pty Ltd (submitted as 08N007C). Animals were handled according to the Australian Code of Practice for the Care and Use of Animals for Scientific Purpose (NHMRC, 2013).

2.1. Animals, experimental design, diets and procedures

A total of 720 weaner pigs (360 males and 360 females; PrimeGro genetics) were selected at weaning (27 ± 3 d) over a 3-wk period (240 pigs per week) and allocated into pens of 10 based on individual weaning weight. Pigs were individually identified at selection using ear tags. Pens were then allocated in a 3 × 2 × 2 factorial arrangement of treatments with the respective factors being weaning weight (light [L]: below 6.5 kg; medium [M]: 6.5 to 8.0 kg; heavy [H]: above 8.5 kg), weaner diet complexity (high complexity/cost, HC; low complexity/cost, LC), and gender (male and female). Average weights at weaning for the L, M and H pigs were 5.5, 7.3 and 9.6 kg, respectively ($P < 0.001$). At the time of allocation, pigs were group-housed in pens of 10 of the same gender and weaning weight category. Pens were then randomly assigned within gender and weight category to either the HC or LC feeding program.

Diets were least-cost formulated on the basis of digestible energy (DE) content and standardized ileal digestible (SID) lysine using typical Australian ingredients and feed additives available for use at the time of the study. In short, in the first 14 d after weaning, the HC diets contained more cooked cereals (wheat that was steam-flaked prior to use), milk powders and soy protein concentrate (as Soycomil-P) than the LC diet, which comprised greater quantities of non-cooked wheat, soybean meal, canola meal and lupin kernels (Table 1). Thereafter, common weaner diets were offered to all pigs until d 42 following weaning (Table 2). Common commercial grower and finisher diets were then offered to all pigs in a 6-week phase-feeding program until slaughter. The composition of premixes used in the creep and weaner diets is shown in Table 3, and the calculated composition of the commercial grower and finisher diets is shown in Table 4. All diets were fed in a pelleted form. Diets and water were offered on an *ad libitum* basis throughout the experiment.

Pigs were individually weighed at weaning (d 0), 1 wk after weaning (d 6), the mid-point of the weaner phase (d 20), the end of the weaner period (d 39), the end of the grower period (d 88), and at the end of the finisher period (d 123). Feed disappearance was measured at the same time points, and average daily feed intake (ADFI), average daily gain (ADG) and feed conversion ratio (FCR) was calculated. The number of deaths and animals removed from the experiment during the weaner phase was recorded, with a reason given for removal as per standard farm practice.

Table 1
Composition and nutrient profile of experimental weaner diets offered during the first 2 weeks after weaning (g/kg, as fed basis).

Item	HC[1]		LC[1]
	Week 1	Week 2	Weeks 1 and 2
Ingredient			
Wheat		194.2	525.5
Cooked cereals	300.0		
Oat groats	184.7	299.0	2.0
Lupin kernels		25.0	60.0
Canola meal			40.0
Soybean meal		35.0	50.0
Meatmeal	32.5	31.7	69.0
Fishmeal	71.0	40.0	50.0
Bloodmeal	10.0	20.0	22.0
Skim milk powder	30.0		
Soycomil-P[2]	41.7	41.7	
Whey powder	280.0	250.0	83.5
Water	10.0	10.0	10.0
Canola oil	22.0		
Tallow		26.7	51.0
NaCl	2.0	2.0	2.0
Limestone		5.0	
Lysine HCl	2.7	3.3	3.7
DL-methionine	0.8	1.2	0.8
L-threonine	1.4	1.7	1.5
L-isoleucine		0.06	0.02
L-tryptophan	0.7	0.6	0.3
TiO_2	2.8	2.8	2.8
Creep premix[3]	3.0	3.0	1.5
Endox[4]	0.6	0.2	0.2
Formi R LHS[5]	3.0	3.0	3.0
Lysoforte[6]	0.8	0.8	0.8
Biofix Plus[7]	0.5	0.5	0.5
Adimix[8]	2.0	2.0	2.0
CTC 200[9]	2.0	2.0	2.0
Pulmotil 200[10]	2.0	2.0	2.0
Calculated composition			
Crude protein	202.3	214.8	240.7
Crude fat	52.6	60.1	75.6
Crude fibre	14.3	16.0	24.0
Digestible energy, MJ/kg	15.1	15.1	15.1
Total lysine	14.8	15.1	15.4
SID lysine	13.6	13.7	13.6
Diet cost, AU$/t	1,212	1,004	677

SID = standardized ileal digestible.
[1] HC, high complexity diet; LC, low complexity diet.
[2] Soycomil-P: Archer Daniels Midland Company, USA.
[3] Refer Table 3 for composition.
[4] Endox: Kemin Industries, Inc.
[5] Formi R LHS: Norsk Hydro a.s., Oslo, Norway.
[6] Lysoforte: Kemin Industries, Inc.
[7] Biofix Plus: BIOMIN, Australia.
[8] Adimix: Nutriad International.
[9] CTC 200: International Animal Health Products, Australia.
[10] Pulmotil 200 (tilmicosin phosphate premix): Elanco Animal Health, Australia.

Table 2
Composition and nutrient profile of weaner diets offered during weeks 3 to 6 after weaning (g/kg, as fed basis).

Item	Weeks 3 and 4	Weeks 5 and 6
Ingredient		
Wheat	517.7	425.1
Oat groats	50.0	
Mill mix		50.0
Lupin kernels	70.0	128.7
Sorghum		100.0
Canola meal	40.0	55.0
Soybean meal	40.0	47.7
Hominy		36.3
Meat meal	65.0	80.0
Fish meal	56.0	
Blood meal	22.0	20.7
Whey powder	83.3	
Water	10.0	10.0
Tallow	20.7	27.0
NaCl	2.0	2.0
Limestone		50.0
Lysine HCl	3.9	3.8
DL-methionine	0.8	1.3
L-threonine	1.6	1.3
L-isoleucine	0.3	
L-tryptophan	0.3	
Zinc oxide	2.8	1.7
Creep premix[1]	1.5	
Weaner premix[1]		1.0
Ronozyme P Liquid[2]		0.2
Porzyme[3]		0.2
Endox[4]	0.2	0.1
Adimix[5]	2.0	
Biomin SE[6]		3.0
CTC[7]	2.0	
Pulmotil 200 premix[8]	1.0	
Rumensin 100[9]	1.0	1.0
Calculated composition		
Crude protein	244.6	237.3
Crude fat	58.7	60.8
Crude fibre	24.5	33.6
Digestible energy, MJ/kg	14.8	14.5
Total lysine	15.8	14.1
SID lysine	14.0	12.0
Diet cost, AU $/t	673	512

SID = standardized ileal digestible.
[1] Refer Table 3 for composition.
[2] Ronozyme P Liquid:DSM, Australia.
[3] Porzyme: Feedworks, Australia.
[4] Endox: Kemin Industries, Inc.
[5] Adimix: Nutriad International.
[6] Biotronic SE: BIOMIN, Australia.
[7] CTC 200: International Animal Health Products, Australia.
[8] Pulmotil 200 (tilmicosin phosphate premix): Elanco Animal Health, Australia.
[9] Rumensin 100 (monensin sodium): Elanco Animal Health, Australia.

2.2. Slaughter procedures

At the desired slaughter age, pigs were transported to a commercial abattoir (Rivalea Australia Pty Ltd, Corowa, New South Wales, Australia). Pigs were held in lairage for approximately 16 h before being euthanized by CO_2, exsanguinated, and then processed according to standard abattoir procedures. Individual hot standard carcass weight (HSCW, head on, trotters on, flares in), fat depth at the P2 site (65 mm from the midline using a Hennessy Chong intrascope), was measured. Dressing percentage (carcass weight/live weight × 100) was calculated from the final live weight. Carcass weight measures were analysed on a pen basis. Slaughter data for the final 2 replicates could not be collected and included in the statistical analyses because of an outbreak of *Actinobacillus pleuropneumoniae* that occurred in the final week before their scheduled slaughter, and the subsequent withhold period on the medication.

Table 3
Composition of premixes used in creep and weaner diets (all values are per tonne of mixed feed).

Nutrient/ingredient	Diet	
	Creep	Weaner
Vitamin A, mIU[1]	10	7.5
Vitamin D_3, mIU	1.5	1
Vitamin E, g	120	100
Vitamin K, g	2	–
Niacin, g	10	10
Ca-D-pantothenate, g	5	5
Riboflavin, g	5	3
Vitamin B_6, g (pyridoxine)	2.5	2
Vitamin B_{12}, mg (cyanocobalamin)	20	10
Biotin, mg	50	–
Selenium, g	0.15	0.3
Selenium (Selplex 50), g	0.3	
Copper, g	20	20
Iron, g	100	80
Manganese, g	50	30
Zinc, g	75	75
Iodine, g	0.5	0.2
Betafin[2], g	100	–

[1] mIU; milli international units.
[2] Betafin betaine: Feedworks Australia Pty Ltd.

2.3. Cost-benefit analyses

Cost-benefit analyses (Australian dollars; current as of August 2016) were undertaken to compare the financial outcomes associated with the weaner feeding programs for the 3 weight classes of pigs. The analyses used the ADFI data for each of the treatment groups, the raw material costs of each of the weaner to finisher diets (as displayed in Tables 1, 2 and 4), and the ADG for each production period and the carcass data. The feed cost per kg of live weight gain for the entire experimental period (weaner to finisher) was used as the basis for a cost-benefit assessment of the feeding programs.

2.4. Statistical analyses

Differences in growth performance due to the effects of weaning weight and diet complexity were analysed using residual maximum likelihood (REML) mixed-model analyses (Genstat 8th edition; VSN International, Oxford UK). The model included the fixed effects of weaning weight category, diet and sex, and the random effect of replicate. The experimental unit for all analyses was the pen of animals. Where no interactions were present, the interaction term was removed and the data were reanalysed for main effects. All replicates were included in the analyses for the growth performance data to the end of the finisher period. Chi-square analysis was conducted on the mortalities and removals in the weaner phase. Data for FCR are expressed as gain:feed in the first 6 d after weaning. Statistical significance was accepted at

Table 4
Calculated nutrient profile of grower and finisher diets (g/kg, as fed basis).

Nutrient composition	Grower	Finisher
Digestible energy, MJ/kg	13.79	13.78
Crude protein	180.3	138.9
Crude fat	41.9	47.5
Crude fibre	38.3	38.0
Total lysine	11.1	8.2
SID lysine	9.7	7.2
Diet cost, AU $/t	415	400

SID = standardized ileal digestible.

$P < 0.05$, with a trend for significance being accepted at $P < 0.10$. Where appropriate, main effect means were separated using Fisher's protected least significant difference test.

3. Results

3.1. Weaner pig performance (d 0 to 39)

There were no interactions ($P > 0.05$) between feeding program and weaning weight class on performance during this period, nor were there any gender effects (data not shown). Diet complexity (HC vs. LC) influenced growth performance in the first 7 d following weaning with the pigs offered the HC diet growing faster ($P = 0.031$) and converting feed more efficiently ($P = 0.007$) during this time. There were no other significant main effects of the type of feeding program on ADG, ADFI or FCR from weaning to the end of the weaner period at d 39 (Table 5).

In contrast, weaning weight influenced ADG and ADFI from d 7 to the end of the weaner phase, with pigs classified as L, M and H at weaning, growing 442, 485 and 523 g/d, respectively ($P < 0.001$). The H pigs at weaning converted feed less efficiently between d 20 and 39 ($P = 0.006$) and in the overall weaner period than pigs either L or M at weaning ($P = 0.016$). Nevertheless, H pigs at weaning increased their weight advantage by the end of the weaner phase with weights being 30.0, 26.2 and 22.7 kg, respectively, for H, M and L pigs ($P < 0.001$; Table 5).

The influence of diet complexity and weaning weight on weaner mortality and removals is displayed in Table 6. In the first 7 d after weaning there was only 1 death, which was a sudden death in the L pigs offered the LC diet. Overall, weaner mortality over 39 d was greatest ($\chi^2 = 21.40$, $P < 0.001$) in L pigs compared with those weaned at the heaviest weight. Weaner mortality was also greater in the treatment groups offered the LC diet ($\chi^2 = 6.08$, $P = 0.014$), with the majority of these deaths occurring in the L pigs offered the LC diet.

3.2. Grower and finisher pig performance (d 39 to 123)

There were no interactions ($P > 0.05$) of diet complexity and weaning weight on performance during the grower and finisher periods (data not shown). There was no main effect of diet type fed during the 2 wk after weaning on ADG ($P = 0.250$), ADFI ($P = 0.701$) or FCR ($P = 0.349$) during the grower period. Similarly, there was no influence of weaner feeding program on finisher ADG ($P = 0.579$), ADFI ($P = 0.605$) or FCR ($P = 0.731$), although there was a trend for

Table 5
Main effect means of diet complexity and weaning weight on production measurements during the post-weaning period (d 0 to 39).

Item	Diet complexity[1]		SED[2]	Weaning weight[3]			SED[4]	*P*-value	
	HC	LC		L	M	H		Diet	Weaning weight
BW, kg									
Weaning	7.4	7.4	0.09	5.5	7.3	9.6	0.113 to 0.115	0.611	<0.001
d 39	26.4	26.2	0.30	22.7	26.2	30.0	0.370 to 0.372	0.963	<0.001
ADG, g									
d 0 to 6	74	52	9.9	70	65	54	12.1 to 12.2	0.031	0.394
d 7 to 20	428	420	10.9	363	435	473	13.3 to 13.5	0.539	<0.001
d 0 to 20	322	309	9.2	275	324	347	11.2 to 11.3	0.210	<0.001
d 21 to 39	658	664	13.2	622	655	707	16.1 to 16.2	0.517	<0.001
d 0 to 39	486	481	7.5	442	485	523	9.1 to 9.2	0.806	<0.001
ADFI, g									
d 0 to 6	130	128	7.7	131	126	130	9.3 to 9.4	0.770	0.846
d 7 to 20	494	475	14.8	425	477	551	18.1 to 18.3	0.277	<0.001
d 0 to 20	384	370	11.7	336	370	425	14.3 to 14.4	0.294	<0.001
d 21 to 39	917	886	17.4	809	889	1,007	21.3 to 21.4	0.166	<0.001
d 0 to 39	641	616	12.7	559	618	707	15.5 to 15.6	0.110	<0.001
FCR, g/g									
d 0 to 6	0.58	0.35	0.080	0.49	0.48	0.41	0.10	0.007	0.657
d 7 to 20	1.16	1.14	0.040	1.18	1.10	1.18	0.049	0.574	0.185
d 0 to 20	1.20	1.21	0.040	1.23	1.15	1.23	0.049	0.936	0.132
d 21 to 39	1.39	1.34	0.030	1.31	1.37	1.43	0.037	0.122	0.006
d 0 to 39	1.32	1.28	0.027	1.27	1.28	1.36	33.39 to 33.45	0.181	0.016

BW = body weight; ADG = Average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio.
[1] HC = high complexity diet; LC = low complexity diet.
[2] SED (standard error of the difference) for the effect of diet complexity.
[3] L = low weaning weight (below 6.5 kg); M = medium weaning weight (6.5 to 8.0 kg); H = high weaning weight (above 8.5 kg).
[4] SED for the effect of weaning weight.

Table 6
Influence of diet complexity and weaning weight on weaner mortality and removals (%).

Weaning weight[1]	Diet[2]	Number of pigs	Deaths			Removals d 0 to 20	Deaths d 20 to 39			Removals d 20 to 39	Total deaths and removals
			Unthrifty	*E. coli*	Twisted bowel	Unthrifty	Sudden death	Meningitis	Unthrifty	Unthrifty	
H	HC	120						1			1
H	LC	120					1				1
M	HC	120	1		2	1	1			1	6
M	LC	120				4	2				6
L	HC	120	1						2		3
L	LC	120	1	1		6	2			2	12

[1] L = low weaning weight (below 6.5 kg); M = medium weaning weight (6.5 to 8.0 kg); H = high weaning weight (above 8.5 kg).
[2] HC = high complexity; LC = low complexity.

pigs fed the HC diets to be heavier at slaughter than pigs fed the LC diet ($P = 0.056$) (Table 7).

Weight class at weaning continued to influence subsequent performance, with H pigs eating more feed ($P < 0.001$) and gaining weight more rapidly ($P = 0.023$) than the M and L pigs during the grower period. The ADFI continued to be greater in the H pigs during the finisher period ($P = 0.028$), although differences in ADG were not maintained ($P = 0.506$). The FCR during the grower and finisher periods were not influenced by weight at weaning ($P > 0.05$; Table 7).

During the finisher period, entire male pigs gained weight faster than females (0.91 vs. 0.85 kg/d respectively, $P = 0.011$) and were more efficient at converting feed to body gain (2.48 vs. 2.76 respectively, $P < 0.001$). As a consequence, final live weight was greater for entire male pigs than for females (97.1 vs. 94.8 kg respectively, $P = 0.012$).

There was no effect of weight class at weaning ($\chi^2 = 0.66$, $P = 0.719$; data not shown) or the type of diet fed after weaning ($\chi^2 = 0.04$, $P = 0.847$; data not shown) on grower and finisher mortality. There was no influence ($P > 0.05$) of gender on grower pig performance.

3.3. Carcass characteristics

The complexity of the diet fed after weaning had no impact on carcass weight ($P = 0.401$), carcass P2 thickness ($P = 0.408$) or dressing percentage ($P = 0.640$) (Table 7). In contrast, weight at weaning had a profound influence on carcass weight, with H pigs weighing 11.3 and 5.1 kg more at slaughter than L and M pigs, respectively ($P < 0.001$). Carcass P2 thickness was, however, similar between the 3 weight classes ($P = 0.299$), as was dressing percentage ($P = 0.563$) (Table 7).

3.4. Cost-benefit analyses

Total feed costs during the weaner period (based on ADFI and diet costs) were greater for pigs offered the HC feeding program, regardless of weaning weight (Table 8). The feed cost per kg live weight gain during this time was greater for the HC feeding program. Total live weight gain from weaning to the end of the finisher period was greatest in the L and M pigs when offered the HC feeding program, while the weaner feeding program did not appear to influence the lifetime growth performance of the H pigs. Total feed costs were however greater in all three weight categories when the pigs were offered the HC feeding program. Differences in costs per kg live weight gain were minimal across all 3 weaning weight categories (Table 8). Numerically, the cost per kg live weight gain over lifetime was lower in the L weight pigs fed the HC diet during the weaner phase. In the H and M weight pigs, the LC diet regimen was a lower cost option over the pigs' lifetime.

Table 8
Cost-benefit analyses of weaner diet complexity for light, medium and heavy weight pigs at weaning (all values in Australian dollars).

Item	L[1]		M[1]		H[1]	
	HC[2]	LC[2]	HC[2]	LC[2]	HC[2]	LC[2]
Weaner period						
Total feed cost, AU$/pig	15.83	13.85	17.13	15.49	19.89	17.23
Live weight gain, kg	17.54	16.88	18.71	19.15	20.58	20.20
Cost/kg gain, AU$/kg	0.90	0.82	0.92	0.81	0.97	0.85
Grower period						
Total feed cost, AU$/pig	30.30	29.68	33.15	32.33	33.76	34.57
Live weight gain, kg	38.15	35.75	40.52	38.50	40.08	40.71
Cost/kg gain, AU$/kg	0.79	0.83	0.81	0.84	0.84	0.85
Finisher period						
Total feed cost, AU$/pig	30.38	31.50	33.32	30.94	32.76	33.18
Live weight gain, kg	30.00	29.90	32.00	30.70	30.90	30.90
Cost/kg gain, AU$/kg	1.01	1.05	1.04	1.01	1.06	1.07
Total period, weaning to finish						
Total feed cost, AU$/kg	76.51	75.04	83.60	78.76	86.40	84.98
Live weight gain, kg	85.69	82.53	91.23	88.35	91.56	91.81
Cost/kg gain, AU$/kg	0.89	0.91	0.92	0.89	0.94	0.93

[1] L = low weaning weight (below 6.5 kg); M = medium weaning weight (6.5 to 8.0 kg); H = high weaning weight (above 8.5 kg).
[2] HC = high complexity; LC = low complexity.

4. Discussion

The improvements in ADG and FCR in the first 6 d after weaning indicated that feeding a more 'complex' diet in this time period improved growth rates and feed utilisation, although this occurred

Table 7
Main effect means of diet complexity and weaning weight on production measurements during the grower and finisher period, and carcass characteristics.

Item	Diet complexity[1]		SED[2]	Weaning weight[3]			SED[4]	*P*-value		
	HC	LC		L	M	H		Diet	Weaning weight	Sex
BW, kg										
d 88	66.0	64.5	0.87	59.7	65.7	70.4	1.07	0.121	<0.001	0.884
d 123	96.9	95.0	0.89	89.6	97.1	101.3	1.08 to 1.10	0.056	<0.001	0.012
ADG, kg										
d 39 to 88	0.80	0.78	0.019	0.75	0.80	0.82	0.0237 to 0.0239	0.250	0.023	0.933
d 89 to 123	0.89	0.87	0.024	0.86	0.89	0.88	0.0291 to 0.0295	0.579	0.506	0.011
ADFI, kg										
d 39 to 88	1.59	1.58	0.029	1.48	1.61	1.68	0.036	0.701	<0.001	0.092
d 89 to 123	2.30	2.27	0.046	2.21	2.29	2.35	0.055 to 0.056	0.605	0.028	0.134
FCR, kg/kg										
d 39 to 88	1.98	2.03	0.048	1.97	2.00	2.06	0.058 to 0.059	0.349	0.289	0.123
d 89 to 123	2.61	2.63	0.049	2.59	2.58	2.69	0.059 to 0.060	0.731	0.107	<0.001
Carcass characteristics										
Carcass weight, kg	71.2	71.0	1.35	65.3	71.5	76.6	1.53 to 1.71	0.401	<0.001	0.637
Carcass P2[5], mm	8.7	8.3	0.39	8.1	8.4	8.9	0.45 to 0.50	0.408	0.299	0.972
Dressing percentage, %	75.7	75.0	0.71	74.7	75.5	75.9	0.80 to 0.98	0.604	0.563	<0.001

BW = body weight; ADG = Average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio.
[1] HC, high complexity diet; LC, low complexity diet.
[2] SED (standard error of the difference) for the effect of diet complexity.
[3] L = low weaning weight (below 6.5 kg); M = medium weaning weight (6.5 to 8.0 kg); H = high weaning weight (above 8.5 kg).
[4] SED for the effect of weaning weight.
[5] Fat depth at the P2 site (65 mm from the midline using a Hennessy Chong Intrascope).

in the absence of stimulation of ADFI. Himmelberg et al. (1985) initially reported that feeding complex diets to pigs less than 3 wk of age and weighing less than 5.6 kg at weaning was beneficial after weaning in stimulating ADFI and ADG and improving feed conversion. Numerous other authors have reported similar outcomes, albeit with different diet formulations distinguishing 'simple' versus 'complex' diets. These findings infer a role for feeding higher-cost, more complex diets to improve production in this critical period as pigs adjust to the weaning environment, as well as to reduce mortality. However in the present study, the effects seen for the first weeks after weaning were carried through over the following weeks and by the end of the weaner phase, production measures were similar irrespective of the type of diet fed. Subsequently, the complexity of the diet fed in the first 2 wk after weaning failed to have a major impact on production measures from weaning through to slaughter.

These results concur with Whang et al. (2000) who found that the starter feeding program influenced growth performance in the period immediately after weaning but did not influence lifetime performance. In their study the authors observed a reduction in weaner performance with their low-quality starter feeding regime, but subsequent compensatory growth during the grower and finisher periods such that the feeding program did not influence protein gain for the entire growth period. A similar result was found in a more recent study by Skinner et al. (2014). These authors reported that pigs fed a 'simple' diet after weaning had reduced body weight and ADG in the nursery period compared with pigs fed a more 'complex' diet, but had no effect on overall wean-to-finish growth performance. The inclusion of in-feed antibiotics during the nursery phase induced some compensatory growth during the grower phase, however the complexity of the diet did not have any effect on performance during the grower-finisher phase.

In another study involving a $2 \times 2 \times 2$ factorial arrangement of treatments, Wolter and Ellis (2001) studied the effects of weaning weight ('heavy' vs. 'light'; 5.4 vs. 3.9 kg), post-weaning growth rate ('accelerated' vs. 'conventional'; accelerated pigs were kept in a special nursery and provided with milk liquid replacer and a dry diet whereas conventional pigs were housed in a standard nursery with a dry diet only being provided), and gender, on performance after weaning. Subsequent to the 14-d post-weaning treatment, pigs in all treatments were housed the same and fed the same dietary regimen until slaughter at 100 kg. Pigs on the 'accelerated' treatment were heavier than pigs on the 'conventional' treatment 14 d after weaning (9.2 vs. 8.1 kg) and at 56 d of age (19.6 vs. 18.3 kg). However, early growth rate had no effect on growth from d 35 of age to slaughter weight or days to reach slaughter weight. Similarly, Mahan and Lepine (1991) conducted a study involving three weaning-weight groups, namely 4.1 to 5.0 kg, 5.5 to 6.8 kg and 7.3 to 8.6 kg, and followed these through to 105 kg body weight. Production indices for the 3 weaning groups were higher as weaning weight increased during both the nursery and the growing-finishing period, however there did not seem to be a compensatory growth response for lighter-weight weanling pigs even though they were fed starter diets containing milk products. Consequently, approximately 15 fewer days were required for the heavier-weight pigs to reach a final weight of 105 kg than for the lightweight group. The medium-weight group required an intermediate number of days to reach 105 kg. In summary, these trials demonstrate that there is an interaction between diet complexity and ADG in the immediate post-weaning period. Feed intake drives growth performance in early-weaned pigs, and complex diets appear to improve ADG and primarily in the first weeks after weaning.

Data from the present study further supports studies reported previously that weight at weaning (and by inference, birth) is a major determinant of lifetime growth performance (e.g., Douglas et al., 2013; Dunshea et al., 2003; He et al., 2016; Smith et al., 2007; Wolter et al., 2002). Pigs weaned heavier at the same age were heavier at every weigh point through to slaughter, with the weight difference between the L and H pigs increasing from 4.1 kg at weaning to 11.7 kg at the end of the finisher period. These results mimic previous Australian research conducted by Dunshea et al. (2003), in which pigs heavy-for-age at weaning were 13 kg heavier at slaughter than pigs light-for-age at weaning. The results also support the work by Collins et al. (2013) in which pigs born at or below 1.2 kg grew almost 9% slower from birth to slaughter compared with their heavier born counterparts. Moreover in a study conducted by de Grau et al. (2005) using 3,736 pigs from 8 commercial farms, a greater 7-wk weight was associated with greater birth weight, greater weaning weight and, somewhat surprisingly, an earlier age at weaning. Furthermore, higher losses (mortality and culling) were observed among pigs with low weaning weights (<4.1 kg) compared with those with higher weaning weights. This is consistent with findings from the present study, where mortality was greatest in L pigs and in the treatment groups offered the LC diet.

Collectively, these data suggest that light-weight pigs at weaning are inherently more susceptible to the post-weaning challenges than heavier pigs. Both de Grau et al. (2005) and Larriestra et al. (2006) found that pigs that were lighter at weaning had higher mortality rates compared with their heavier counterparts, whilst Smith et al. (2007) and Quiniou et al. (2002) evaluated the impact of birth weight on mortality finding that the lighter the pig, the less the chance of survival. Furthermore, Collins et al. (2010) reported that weaning age (13 d of age or 21 d of age) predominately influenced growth immediately after weaning with 21-d-old pigs eating more and growing faster than their earlier-weaned counterparts.

It is possible that differences in gastrointestinal tract (GIT) structure and function contributed to the poorer performance seen after weaning in light-for-age pigs, however surprisingly little research has been conducted in this field. Michiels et al. (2013) reported that low birth weight piglets (<1 kg) showed retarded post-weaning maturation of the GIT (e.g., lower small-intestinal weight:length ratio, a higher secretory capacity in the distal jejunum, reduced oxidative capacity and a lower density of IGF-1 receptors in the proximal small intestine parallel to lower circuiting IGF-1 levels), although these changes were not related to the weaning transition as such. Similarly, Pluske et al. (2003) reported that pigs born light-for-age and weaned at either 2 or 4 wk of age (3.46 and 5.51 kg, respectively) had a less developed GIT (as assessed morphologically, histologically and enzymatically), with a post-weaning development that proceeded differently to that of pigs weaned heavier.

Dietary feeding regime during the weaner period did not influence carcass composition, supporting previous observations by Dritz et al. (1996), Lawlor et al. (2002) and Skinner et al. (2014). Lawlor et al. (2002) observed similar carcass weights and lean meat contents at commercial slaughter weights when pigs were offered different starter feeding programs, while Dritz et al. (1996) observed similar carcass compositions of pigs slaughtered at 11.9, 18.7 and 109 kg following the feeding of high, medium or low complexity starter diets. They did, however, observe that pigs weaned at 9 d of age and fed the low-complexity diet regimen had greater carcass lipid and reduced carcass protein at 109 kg, again supporting the use of high complexity weaner diets for pigs weaned at lighter weights. Wolter and Ellis (2001) found conventionally-fed pigs had 1.5 mm more backfat compared with pigs fed a more complex diet, which is in contrast to findings in the present study. However, and in support of the present study, pigs that were heavier at weaning were heavier at birth and at 56 days of age compared with lighter pigs at weaning. In addition they reached slaughter weight 8.6 days earlier. Skinner et al. (2014) observed that nursery diet complexity had no effect on meat quality, the weight of primal and retail meat cuts, with the exception of primal belly weight, or chemical body composition at market weight.

In this current study, weaning weight had a profound influence on carcass weight, with the carcasses of the L pigs at weaning being 14.4% lighter than those of the H weaning-weight pigs. Birth weight has been reported to influence carcass composition, with light birth-weight piglets producing carcasses with a greater percentage of adipose tissue than their heavier born counterparts at a given slaughter weight (Collins, 2007; Rehfeldt and Kuhn, 2006). Given the close association between birth weight and weaning weight, it is likely that L pigs at weaning would also display the same trends in carcass composition. Unfortunately the small number of animals in which the carcass data was collected in this investigation was insufficient to detect differences due to weaning weight. However previous research using the same genotype and production systems as the current study demonstrated that birth weight influenced carcass composition, with P2 back fat thickness significantly greater in light birth-weight pigs across a range of slaughter weights (Collins et al., 2013). In this regard, Rekiel et al. (2015) reviewed effects of piglet birth weight on carcass muscle, fat content and pork quality and they concluded that although their results were inconclusive, the majority of research indicates that light piglets grow slower, with a fatter carcass and the meat being of a lower quality. This would indicate that more uniform litters of a higher birth weight would be more favourable for improving carcass quality. Further investigation is required to assess management strategies to improve lifetime growth performance and carcass composition of these light birth weight animals. Practically, such strategies are likely to involve identifying pigs that are light at weaning and focusing on measures to improve their lifetime growth performance and carcass composition.

Growth performance and carcass data in the present study suggest that pigs H pigs at weaning do not benefit from the use of a HC feeding program. These results are supported by Dritz et al. (1996), in which pigs weaned at 9 or 19 d of age were offered low, medium or high complexity diets during the weaner period. The high complexity diets consisted of high levels of milk products and quality protein sources (spray dried plasma and blood meal), while the medium complexity diets contained lower concentrations of these ingredients and the low complexity diets consisted primarily of corn and soybean meal with a small amount of dried whey. These authors observed that diet complexity did not influence ADG or ADFI from 7 to 19 kg, and that growth performance from 19 to 109 kg was greater in the animals offered the medium-complexity feeding regimen regardless of age at weaning. For the animals weaned at 9 d of age, feed efficiency from 19 to 109 kg was improved when the animals were offered the medium and low cost diets.

The study by Dritz et al. (1996) did not provide any cost-benefit analyses of the feeding program based on lifetime performance and carcass returns. In the present study, non-significant differences in grower and finisher growth performance did result in a trend for the pigs offered the HC diet to be heavier at the end of the finisher period, with the differences greatest in the L and M weight pigs. Nevertheless, the cost-benefit analyses supported the use of the LC diet during the weaner period for animals weaned at 27 d of age and above 8.5 kg, and possibly for the pigs weaned above 6.5 kg. The HC feeding regime was only cost effective for piglets weaned L (below 6.5 kg weaning weight at 27 days of age).

5. Conclusions

The results from this investigation reinforce the impact of weaning weight on lifetime growth performance. The cost-benefit analyses conducted under the conditions of this production farm suggested there was no cost per kg live weight gain benefit over lifetime by offering the HC feeding program to M or H pigs (>6.5 kg) when weaned at 27 days of age. The HC feeding program only benefited L pigs at weaning (less than 6.5 kg at 27 days of age) and maximized their lifetime growth performance. However, pigs fed a HC diet post-weaning tended to be heavier at the sale live weight of 123 d of age compared with pigs fed the LC diet.

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