Title: Improving net returns in pork production by improving our management of the fallback pig: Characterizing biological and physiological differences in fallback pigs to determine optimal management and handling practices – **NPB #09-250** **revised**

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Industry summary: The last decade's unprecedented rise in litter size has resulted in an increased number of fallback pigs. Fallback pigs are those that fail to achieve performance in the barn equal to that of their contemporaries. Pigs can be born as fallbacks, in that they have a lighter birth weight. However, pigs with normal or heavy birth weights can become fallback pigs due to poor nutrition, environmental conditions, disease or other, as yet unknown, reasons. Whatever the cause, these pigs compromise barn throughput, result in weight penalties at market, and may reduce barn flow. There is little research concerning the factors that affect fallback from normal production. A better understanding of these factors may allow for the development of environmental or nutritional interventions to control their prevalence, thereby maximizing the production efficiency, throughput, and profitability of a barn. Therefore, the overall objective of this study was to develop an understanding of the underlying biology of the fallback pig, which hopefully will lead to improved management practices in the barn. The specific objectives of this experiment were to: 1) identify differences in the biology and physiology, and thus the growth and metabolism, between fallback pigs and their heavier, faster growing counterparts; 2) determine if these differences result from variations in small intestine structure or function; and 3) determine the role of blood chemistry and immune status in fallback from normal performance. To accomplish these objectives, 120 weanling pigs were utilized in growth, metabolism, and comparative slaughter experiments. Forty barrows from each of the lightest, median, and heaviest 10% pigs at weaning were placed in individual crates with slatted floors, allowing for fecal and urine collection. Eight pigs from each weaning weight category were harvested on d 5 post-weaning as the initial slaughter group. The remaining 32 pigs in each category were part of the metabolism group, and were utilized in a growth and metabolism experiment and were then slaughtered. After the completion of the live animal component of the experiment, pigs within each initial body weight (BW) category were further stratified into the slowest, median, or fastest 33% average daily gain (ADG) categories. This resulted in a total of nine treatments. Fallback pigs were designated as those belonging to the slowest ADG category from either the lightest or median BW categories. In contrast to our initial hypothesis, there was no effect of treatment on feed efficiency, which suggests that improvements in ADG were primarily driven by ADFI. Kidney and intestine weights, as well as protein and fat deposition rates were affected by both BW and ADG category, even when equalized per unit of body weight. These variations confirm that fallback pigs differ in both their biology and physiology compared to their heavier, faster growing contemporaries.

In order to further understand why these differences in carcass composition occur, the digestibility of nutrients and efficiency of energy utilization were measured and found to be maximized by pigs in the median ADG categories. While it may be more intuitive for these to be maximized by the fastest ADG categories, experiments by other researchers largely agree with our findings. Additionally, bicarbonate levels in the blood were highest in the two extreme categories: the slowest ADG, lightest BW category and the fastest ADG, heaviest BW category. Bicarbonate is a measure of acid-base balance, and the variation in its measurement is further evidence that both the poorest and highest performing pigs may have poorer physiological regulation compared to their contemporaries. These differences in nutrient digestibility, energy utilization, and blood metabolites underscore the importance of managing the entire variation of a population, and not just the poorest performers. There were no distinct patterns in differences in small intestine structure or function, nor were white blood cell or lymphocyte concentrations affected by fallback status. Thus, all pigs in the experiment, even fallback pigs, appear to have had similar health status.

Taken together, these results suggest that the underlying cause for fallback from performance lies jointly with poor feed intake and poorer utilization of absorbed nutrients. There is still little explanation as to the root cause of poorer nutrient utilization. While this experiment has made immense strides toward identifying management strategies that are more calculated and economical, the next phase of research must be undertaken in a commercial environment, in order to answer questions that could not be addressed in this experiment. Indeed, we are currently collaborating with veterinary pathologists, an Iowa pork producer, and IPPA to evaluate the broader factors affecting fallback from performance in a commercial facility. In this experiment, we have characterized the biological and physiological differences in fallback pigs and identified the underlying causes for fallback from performance. This, combined with our understanding of factors in a commercial environment, will allow us to determine management strategies that may be critical to maintaining profitability in the pork sector. For more information, contact John Patience at jfp@iastate.edu or at 515-294-5132.

Keywords: digestibility, energy, fallback, nutrition, nutrient transport, tissue accretion

Scientific abstract: The last decade's unprecedented rise in litter size has resulted in an increase in the number of fallback pigs. However, there is little peer-reviewed data available regarding the physiological differences between fallback pigs and their normal cohorts. Therefore, the objectives of this experiment were to: 1) Identify differences in the biology and physiology, and thus the growth and metabolism, between fallback pigs and their heavier counterparts; 2) determine if these differences result from variations in ileal morphology and nutrient transport capacity; and 3) determine the role of blood chemistry and immune status in fallback from normal performance. To accomplish these objectives, 120 weanling pigs (PIC C22/C29 × 337) were utilized in growth, metabolism, and comparative slaughter experiments. Forty barrows from each of the lightest, median, and heaviest 10% pigs at weaning were placed in individual metabolism crates. Eight pigs from each weaning weight category were harvested on d 5 post-weaning as the initial slaughter group. The remaining 32 pigs in each category were part of the metabolism group, and were utilized in a 27-d growth and metabolism experiment and harvested on d 32 and 33 post-weaning. After the completion of the live animal component of the experiment, pigs within each initial body weight (BW) category were further stratified into the slowest, median, or fastest 33% average daily gain (ADG) categories. This resulted in a total of nine treatments. Fallback pigs were designated as those belonging to the slowest ADG category from either the lightest or median BW categories. Data were analyzed using the GLIMMIX procedure of SAS. There was no effect ($P = 0.30$) of BW(ADG) category on feed efficiency, which suggests that ADG improvements were primarily driven by ADFI. All tissue deposition rates, which were calculated as the difference between tissue nutrient concentrations of the metabolism and initial slaughter groups, were maximized ($P < 0.0002$) by BW(ADG) category, even when equalized per unit of body weight. The apparent digestibility of dry matter, gross energy, nitrogen, and ash, as well as the related dietary energy content, were maximized ($P < 0.01$) by the median ADG categories of pigs at the end of the experiment. Interestingly, the energy efficiency for both protein and lipid deposition were not altered ($P > 0.87$) by BW(ADG) category. There was no effect ($P > 0.16$) of BW(ADG)

category on active ileal glucose, lysine, or glutamine transport. Meanwhile, measures of ileal morphology were highly affected ($P < 0.0001$) by BW(ADG) category, but not in a consistent manner. Among the measures in a standard blood chemistry panel, bicarbonate, creatinine, and albumin concentrations were significantly affected ($P < 0.03$) by BW(ADG) category, which may indicate poor physiological regulation among fallback pigs, and is an area that warrants further exploration. Pigs from the slowest ADG, heaviest BW category had the lowest ($P < 0.05$) hemoglobin concentration compared to pigs from the fastest ADG categories, which may indicate anemia. No other measures, including white blood cell or lymphocyte concentrations, were affected ($P > 0.10$), suggesting that pigs had similar health status. In summary, this report confirms that biological and physiological differences exist among pigs with varying weaning weight and ADG during the early nursery period. These data suggest that the underlying cause for fallback from performance lies jointly with poor feed intake and poorer utilization of absorbed nutrients. There is still little explanation as to the root cause of poorer nutrient utilization. While this experiment has made immense strides toward identifying management strategies that are more calculated and economical, the next phase of research must be undertaken in a commercial environment, in order to answer questions that could not be addressed in this experiment. Indeed, we are currently collaborating with veterinary pathologists, an Iowa pork producer, and IPPA to evaluate the broader factors affecting fallback from performance in a commercial facility. In this experiment, we have characterized the biological and physiological differences in fallback pigs and identified the underlying causes for fallback from performance. This, combined with our understanding of factors in a commercial environment, will allow us to determine management strategies that may be critical to maintaining profitability in the pork sector.

Introduction: The last decade's unprecedented rise in litter size has resulted in an increasing number of pigs with light birth weights, and an associated rise in the number of fallback pigs. Fallback pigs are those that fail to achieve performance in the barn equal to that of their contemporaries. Pigs can be born as fallbacks, in that they have a lighter birth weight, and thus diminished capacity for postnatal growth due to intrauterine growth retardation. However, pigs with normal or heavy birth weights can become fallback pigs due to poor nutrition, management, environmental conditions, or disease. There are many causes for this underachievement, many of which remain undetermined or undefined.

Whatever the cause, these pigs compromise barn throughput, result in weight penalties at market, reduce barn flow, and may disrupt overall herd health. While these are generally accepted principles in the field, there is little peer-reviewed data available regarding the physiological differences between fallback pigs and their normal cohorts. Some of these physiological differences may include variations in intestinal architecture, thus affecting nutrient absorption. Other physiological changes may cause differences in nutrient digestibility and utilization, causing nutrients to be repartitioned in a less efficient manner. As a result, the pig may have a higher maintenance cost, instigating it to fallback in performance. If this is the case, environmental or nutritional interventions may help control the prevalence of fallback in pigs, thereby maximizing the production efficiency, throughput, and profitability of a barn.

Objectives: 1) Identify differences in the biology and physiology, and thus the growth and metabolism, between fallback pigs and their heavier counterparts; 2) determine if these differences result from variations in ileal morphology and nutrient transport capacity; and 3) determine the role of blood chemistry and immune status in fallback from normal performance.

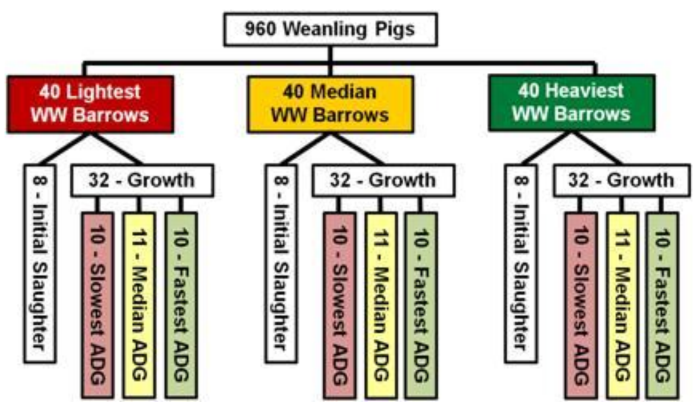
Materials & Methods: A total of 120 weanling pigs (PIC C22/C29 × 337) were utilized in growth, metabolism, and comparative slaughter experiments. Care from birth to weaning was carried out according to routine procedures on the source farm. At 19-22 days of age, 960 pigs were weaned and transported to the Iowa State University Swine Nutrition Farm. Upon arrival (d -5), pigs (5.73 ± 1.06 kg) were weighed and tagged with an individual identification number. Weaning weights of pigs were sorted by sex, and all weights of viable barrows that did not exhibit outward signs of lameness or ruptures (5.66 ± 1.09 kg) were retained for experimental animal selection. Forty barrows from each of the lightest, median, and heaviest 10% of these weaning weights were selected as experimental units and placed individually in 0.53 × 0.71 m stainless steel metabolism crates located in one room. Crates had fully slatted floors and were outfitted with separate trays for fecal and urine collection to allow for separate but total collection. A single-hole self-feeder and one nipple waterer fitted with a cup in each metabolism crate allowed for *ad libitum* access to feed and water during acclimation and the metabolism and growth trials. Feeders and waterers were checked daily to ensure adequate flow and prevent wastage. Pigs were allowed a 5-d acclimation period to adjust to weaning and environmental changes.

Eight pigs from each weaning weight category were harvested on d 5 post-weaning as the initial slaughter group. The remaining 32 pigs in each category were part of the metabolism group, and were utilized in a 27-d growth and metabolism experiment. Pigs were fed common diets from a standard commercial nursery phase-feeding program. To allow for the determination of nutrient digestibility, diets at the beginning and end of the growth trial included 0.40% titanium dioxide. Additionally, total urine and fecal grab samples were collected twice daily during 3-d collection periods during this time.

After blood samples were collected, pigs in the metabolism group were harvested on d 32 and 33 post-weaning. For both initial slaughter group and metabolism group harvest procedures, pigs were humanely euthanized by captive bolt stunning and exsanguination. All blood was collected, weighed, and retained. Organs were weighed individually, and ileal samples were taken for histology and Ussing Chamber analyses. Carcasses (including head and feet), blood, and organs were frozen, ground, homogenized, and subsampled.

After the completion of the live animal component of the experiment, pigs within each initial body weight (BW) category were further stratified into the slowest, median, or fastest 33% average daily gain (ADG) categories. This resulted in a total of nine treatments. *Fallback pigs were designated as those belonging to the slowest ADG category from either the lightest or median BW categories.*

The experimental design is shown below:



Data were analyzed using the GLIMMIX procedure of SAS. Responses of pigs in the initial slaughter group were tested against the single fixed effect of BW category because ADG category was dependent upon pigs' performance during the metabolism period, which occurred after the initial harvest. Responses of pigs in the metabolism group were tested against the single fixed effect of BW(ADG), in which ADG category was nested within BW category. The random effects were replicate and pen. Treatments were compared using the SLICE and SLICEDIFF procedures of SAS. Tukey-Kramer corrections were utilized to adjust for multiple comparisons among treatments.

Results: Final body weight and average daily feed intake (ADFI) were maximized ($P < 0.0001$) by BW(ADG) category (Table 1). In fact, fallback pigs had significantly poorer ($P < 0.05$) start weight, final weight, ADG, and ADFI compared to all other categories. However, there was no effect (*P* = 0.30) of BW(ADG) category on feed efficiency (G:F).

Differences in BW category resulted in very few effects on the physical body composition of pigs in the initial slaughter group (Table 2). However, BW(ADG) category greatly affected pigs in the metabolism group (Table 3). All actual body weights were maximized (*P* < 0.0001) by BW(ADG) category. When equalized per unit of body weight, BW(ADG) category still greatly affected (*P* < 0.02) eviscerated carcass, organ, and metabolic body weights, but not (*P* = 0.28) empty body weight. Similarly, all actual organ weights were maximized (*P* < 0.0001) by BW(ADG) category. However, blood, intestine, and kidney weights remained different (*P* < 0.01) even when equalized per unit of body weight.

The chemical body composition of pigs in the initial slaughter group did not vary considerably (Table 4). However, the percentage water contained within the carcass decreased (*P* = 0.002) with increasing BW category. This did not (*P* > 0.05) result in differences in other tissue concentrations, nor their ratios. Energy content according to gross energy increased (*P* = 0.02) with increasing BW category. These differences in water and energy content did not carry over to the metabolism outcomes (Table 5). There were no differences (*P* > 0.12) in tissue nutrient concentrations, ratios, or energy content among the BW(ADG) categories. All tissue deposition rates, which were calculated as the difference between tissue nutrient concentrations of the metabolism and initial slaughter groups, were maximized (*P* < 0.0002) by BW(ADG) category, even when equalized per unit of body weight.

Apparent digestibility of measured nutrients and dietary energy content did not vary (*P* > 0.19) with BW(ADG) category at the beginning of the metabolism experiment (Table 6). However, the apparent digestibility of dry matter, gross energy, nitrogen, and ash, as well as the related dietary energy content, were maximized (*P* < 0.01) by the median ADG categories of pigs at the end of the experiment.

Energy intake, utilization, efficiency for gain, and retention were maximized (*P* < 0.0001) by BW(ADG) category, which is to be expected due to their heavy reliance on factors such as body weight, ADG, and ADFI (Table 7). Interestingly, the energy efficiency for both protein and lipid deposition were not altered (*P* > 0.87) by BW(ADG) category, even though tissue deposition rates and energy available for growth were highly affected.

To determine if the differences between fallback pigs and their heavier contemporaries were due to intestinal physiology, ileal morphology and nutrient transport were measured. There was no effect (*P* > 0.16) of BW(ADG) category on active ion transport of tissues (Figures 1, 2, and 3). Meanwhile, measures of ileal morphology were highly affected (*P* < 0.0001) by BW(ADG) category, but not in a consistent pattern (Table 8). Fallback pigs had shorter (*P* < 0.05) villous height compared to pigs from the median ADG, lightest BW category and slowest ADG, heaviest BW category. Crypt depth was more consistently affected (*P* < 0.0001) as it was maximized by pigs in the median and fastest ADG categories.

Blood chemistry and immune status was analyzed to determine their role in fallback from normal performance. Among the measures in a standard blood chemistry panel, only bicarbonate, creatinine, and albumin concentrations were significantly affected (*P* < 0.03) by BW(ADG) category (Table 9). Bicarbonate was highest (*P* < 0.05) in the two most extreme BW(ADG) categories: the slowest ADG, lightest BW category and the fastest ADG, heaviest BW category. Additionally, fallback pigs had the lowest (*P* < 0.05) creatinine and albumin levels of all BW(ADG) categories.

Finally, there were few effects of BW(ADG) category on white blood cell differentials (Table 10). Pigs from the slowest ADG, heaviest BW category had the lowest (*P* < 0.05) hemoglobin concentration compared to pigs from the fastest ADG categories. Similar effects were seen in mean corpuscular hemoglobin concentration. No other measures, including white blood cell or lymphocyte concentrations were affected ($P > 0.10$).

Discussion: In contrast to our initial hypothesis, there was no effect of G:F, which suggests that improvements in ADG were primarily driven by ADFI. Interestingly, weights of various significant organs and tissue deposition rates remained different, even when equalized per unit of body weight. These variations in the physical and chemical carcass composition confirm that fallback pigs differ in both their biology and physiology compared to their heavier contemporaries, and identify that these differences exist in blood, intestine, and kidney development, as well as in tissue deposition rates.

In order to further understand why these differences in carcass composition occur, apparent digestibility of nutrients and energy efficiencies were measured. This study found that apparent digestibility of dry matter, gross energy, nitrogen, and ash, as well as the related energy content, intake, utilization, efficiency for gain, and retention were maximized by the median ADG categories of pigs at the end of the experiment. While it may be more intuitive for digestibilities and energy to be maximized by the fastest ADG, literature largely agrees that some variables are, indeed, maximized by the median category. This underscores the importance of managing the entire variation of a population, and not just the poorest performers.

While there were multiple differences in carcass composition, the lack of a distinct pattern among nutrient transport and morphology data yields few conclusions. However, data from this report suggest that fallback pigs do not differ dramatically from their heavier contemporaries in ileal morphology or nutrient transport.

Meanwhile, differences in bicarbonate, creatinine, and albumin concentrations may indicate poor physiological regulation among fallback pigs, which is an area that warrants further exploration. Because the body tightly regulates this equilibrium, measures of acid-base balance are rarely out of range. Bicarbonate is a measure of this balance, and the variation in its measurement is further evidence that both the poorest and highest performing pigs may have poorer physiological regulation compared to their contemporaries. Creatinine is a product of creatine phosphatase degradation, and is filtered by the kidneys. Meanwhile, albumin serves as a carrier for molecules with low water solubility. Low levels of these metabolites may indicate poor kidney function, malnutrition, or malabsorption.

Finally, low hemoglobin concentrations may indicate anemia. Correspondingly low mean corpuscular hemoglobin concentrations are thus expected, because it is a measure of hemoglobin concentration in a given volume of mean corpuscular hemoglobin concentration packed red blood cells. Because no other measures, including white blood cell or lymphocyte concentrations were affected, pigs from different BW(ADG) categories appear to have had similar health status.

Taken together, these results imply that the primary driver of fallback appears to be feed intake, but differences still exist in these pigs beyond nutrient uptake. *This suggests that the underlying cause for fallback from performance lies jointly with poor feed intake and poorer utilization of absorbed nutrients.*

There is still little explanation as to the root cause of poorer nutrient utilization. It has been hypothesized that fallback pigs have a higher maintenance cost compared to their contemporaries. While this may be true, the testing of this hypothesis requires an extensive experiment utilizing respiration chambers, which are not available in the United States. Gene expression and metabolomics may serve as a more practical method of identifying the cause of poor nutrient utilization among these pigs. Other scientific fields have found success in utilizing this "systems biology" approach to solve complex problems with a multitude of confounding factors. For instance, microarray analyses and qPCR may allow us to discover genes or pathways that are up- or down-regulated in fallback pigs compared to their contemporaries, allowing for enhanced understanding of nutrient utilization. We have an application pending with the NPB to pursue this direction of research.

Finally, these results have greatly enhanced our understanding of fallback pig physiology. While this experiment has made immense strides toward identifying management strategies that are more calculated and economical, the next phase of research must be undertaken in a commercial environment in order to answer questions that could not be addressed in this experiment. Indeed, we are currently collaborating with veterinary pathologists, an Iowa pork producer, and IPPA to evaluate the broader factors affecting fallback from performance in a commercial facility.

In summary, this report has characterized the biological and physiological differences in fallback pigs and identified the underlying causes for fallback from performance. This, combined with our understanding of factors in a commercial environment, will allow us to determine management strategies that may be critical to maintaining profitability in the pork sector.

Table 1. Effects of initial body weight (BW) and ADG category on the weekly weight and performance of weaned pigs in the metabolism group[1]

	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW				
Item	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
Start weight, kg	4.10	4.65	5.00	5.35	6.30	6.80	7.51	7.88	8.88	0.191	< 0.0001
Final weight, kg	14.30	18.23	20.36	15.57	21.93	24.90	22.20[c]	25.07	28.32	0.682	< 0.0001
ADG, g/d	378	503	569	378	579	672	543	637	719	22.9	< 0.0001
ADFI, g/d	421	601	673	455	699	845	655	758	872	37.5	< 0.0001
ADFI, % NRC[2]	47.9	59.1	62.3	48.9	63.6	74.9	59.3	68.1	81.3	3.08	< 0.0001
Gain:feed ratio, g/g	0.92	0.84	0.85	0.82	0.83	0.79	0.85	0.85	0.82	0.039	0.30

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows).

[2]Calculated by dividing the actual DE intake by the estimated DE intake using the equation by NRC, 1998: DE intake (Mcal/d) = $-1.531 + (0.4555 \times BW) - (0.00946 \times BW^2)$.

Table 2. Effects of initial body weight (BW) category on the physical body composition of weaned pigs in the initial slaughter group[1]

Item	Lightest 10% BW	Median 10% BW	Heaviest 10% BW	Pooled SEM	*P* =
Number of pigs	8	8	8		
Weight, kg					
Fasted live weight	5.1	6.2	6.8	0.50	0.07
Eviscerated carcass	4.1	4.9	5.5	0.41	0.07
Organ	0.8	0.9	0.9	0.08	0.16
EBW[2]	4.8	5.8	6.4	0.47	0.08
Metabolic BW[3]	2.3	2.8	3.4	0.03	< 0.0001
Weight, g/kg live weight					
Eviscerated carcass	804	790	804	9.9	0.28
Organ	151	150	139	7.6	0.08
EBW[2]	954	940	943	5.4	0.10
Metabolic BW[3]	497	465	526	41.3	0.58
Organ weight, g					
Blood	209	270	269	37.7	0.15
Heart	31	35	38	4.2	0.52
Intestines, empty	253	312	298	24.9	0.22
Kidneys	31	36	39	7.0	0.34
Liver	124	140	154	3.2	0.22
Lungs	67	80	79	11.4	0.22
Spleen	13	15	14	2.0	0.79
Stomach, empty	32	40	38	3.6	0.09
Organ weight, g/kg metabolic BW[3]					
Blood	89.0	95.7	79.1	13.54	0.42
Heart	13.4	12.5	11.2	1.77	0.64
Intestines, empty	108.5	110.5	87.8	9.90	0.17
Kidneys	13.3	12.9	11.5	1.21	0.54
Liver	53.2	49.6	45.3	4.43	0.46
Lungs	28.7	28.6	23.2	2.48	0.23
Spleen	5.5	5.2	4.2	0.68	0.35
Stomach, empty	13.6	14.2	11.1	1.38	0.10

[1]Data are presented as least square means. Eight pigs from each BW category were harvested as the initial slaughter group (24 total barrows) on d 5 post-weaning.
[2]EBW = empty body weight: the sum the eviscerated carcass weight (including head and feet) and organ weight (including all organs listed and blood, but not digestive contents)
[3]Calculated using the equation by Noblet et al., 1999: Metabolic BW = $BW^{0.60}$.

Table 3. Effects of initial body weight (BW) and ADG category on the physical body composition of weaned pigs in the metabolism group[1]

Item	Lightest 10% initial BW Slowest 33% ADG	Lightest 10% initial BW Median 33% ADG	Lightest 10% initial BW Fastest 33% ADG	Median 10% initial BW Slowest 33% ADG	Median 10% initial BW Median 33% ADG	Median 10% initial BW Fastest 25% ADG	Heaviest 10% initial BW Slowest 33% ADG	Heaviest 10% initial BW Median 33% ADG	Heaviest 10% initial BW Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
Weight, kg											
Fasted live weight	15.4	19.5	20.9	15.5	20.7	23.9	17.1	21.6	26.1	1.13	< 0.0001
Eviscerated carcass	12.2	15.6	16.0	12.2	16.5	19.4	13.5	17.5	21.3	0.94	< 0.0001
Organ	2.4	3.0	3.7	2.5	3.2	3.4	2.8	3.0	3.8	0.16	< 0.0001
EBW[2]	14.6	18.6	19.7	14.7	19.7	22.8	16.3	20.5	25.0	1.07	< 0.0001
Metabolic BW[3]	5.3	6.1	6.4	4.9	6.3	6.8	5.5	6.7	7.2	0.20	< 0.0001
Weight, g/kg live weight											
Eviscerated carcass	788	800	768	781	799	814	787	809	813	8.2	0.0004
Organ	159	152	175	163	153	143	168	140	144	5.3	< 0.0001
EBW[2]	947	952	943	945	951	957	952	949	957	5.9	0.28
Metabolic BW[3]	345	311	305	337	306	288	329	330	277	22.6	0.02
Organ weight, g											
Blood	611	808	1,000	703	913	972	835	890	1,053	58.9	< 0.0001
Heart	88	109	128	86	111	129	98	119	134	7.6	< 0.0001
Intestines, empty	957	1,089	1,413	937	1,153	1,220	1,028	968	1,353	78.8	< 0.0001
Kidneys	178	209	287	178	213	242	192	223	282	19.9	< 0.0001
Liver	85	109	129	89	118	130	111	120	150	7.6	< 0.0001
Lungs	367	461	510	359	455	523	409	451	553	24.0	< 0.0001
Spleen	36	46	42	31	45	54	34	48	57	3.8	< 0.0001
Stomach, empty	120	130	167	123	143	153	138	149	171	8.6	< 0.0001
Organ weight, g/kg metabolic BW[3]											
Blood	115.3	133.3	155.2	142.4	144.8	141.9	151.3	134.1	145.5	9.40	0.005
Heart	16.6	18.0	20.0	17.6	17.4	18.8	17.3	17.9	18.6	1.09	0.41
Intestines, empty	181.6	179.5	222.4	191.3	183.2	178.0	179.9	145.4	187.5	11.92	0.01
Kidneys	16.0	17.9	20.0	18.2	18.7	19.1	20.0	18.1	20.8	1.13	0.001
Liver	69.7	76.0	79.7	73.8	71.9	76.2	73.2	68.0	76.5	3.76	0.14
Lungs	33.7	34.6	44.3	37.2	33.7	35.1	34.5	33.7	38.8	3.31	0.48
Spleen	6.7	7.5	6.6	6.3	7.2	7.9	6.1	7.3	7.8	0.60	0.06
Stomach, empty	23.0	21.4	26.2	25.6	22.5	22.3	24.7	22.6	23.6	1.30	0.14

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). All pigs were harvested as the metabolism on d 32 post-weaning.

[2]EBW = empty body weight: sum of eviscerated carcass weight (including head and feet) and organ weight (including all organs and blood, but not digesta).

[3]Calculated using the equation by Noblet et al., 1999: Metabolic BW = $BW^{0.60}$.

Table 4. Effects of initial body weight (BW) on the chemical body composition of weaned pigs in the initial slaughter group[1]

Item	Lightest 10% BW	Median 10% BW	Heaviest 10% BW	Pooled SEM	*P* =
Number of pigs	8	8	8		
Empty body weight, kg[2]	4.84	5.81	6.43	0.471	0.08
Water, %	69.0	66.8	65.7	0.73	0.002
Protein %	15.1	15.7	15.6	0.35	0.46
Lipid, %	14.7	15.2	16.0	0.59	0.28
Ash, %	2.8	2.9	2.9	0.07	0.23
Lipid:protein ratio	0.98	0.97	1.03	0.050	0.69
Water:protein ratio	4.6	4.3	4.2	0.12	0.06
Ash:protein ratio	0.18	0.19	0.19	0.003	0.40
GE, Mcal/kg	5.67	5.87	5.98	0.074	0.02

[1]Data are presented as least square means. Eight pigs from each BW category were harvested as the initial slaughter group (24 total barrows) on d 5 post-weaning.
[2]EBW = empty body weight: sum of eviscerated carcass weight (including head and feet) and organ weight (including all organs and blood, but not digesta).

Table 5. Effects of initial body weight (BW) and ADG category on the chemical body composition of weaned pigs in the metabolism group[1]

	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW				
Item	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
Empty body weight, kg[2]	13.1	16.9	18.6	15.4	20.1	23.0	19.3	23.3	26.1	0.73	< 0.0001
Water, %	71.4	70.3	71.3	71.2	69.7	69.6	70.5	70.2	68.9	0.79	0.23
Protein %	15.3	15.8	14.7	15.2	15.8	15.8	15.2	15.2	15.9	0.42	0.12
Lipid, %	10.9	11.1	10.9	10.7	11.9	12.1	11.8	12.4	12.6	0.45	0.19
Ash, %	2.9	3.0	2.7	2.8	3.0	3.0	2.8	2.9	3.0	0.09	0.25
Lipid:protein ratio	0.46	0.60	0.66	0.90	0.68	0.70	0.59	0.73	0.72	0.116	0.59
Protein:water ratio	5.7	4.5	5.2	3.2	4.4	4.8	5.1	4.8	4.5	0.89	0.79
Ash:protein ratio	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.005	0.89
GE, Mcal/kg	5.86	5.84	5.91	5.89	5.91	5.94	5.77	5.98	6.02	0.070	0.19
Deposition rate, g/d											
Water	210	300	350	257	358	428	332	427	486	17.1	< 0.0001
Protein	45	69	70	51	80	94	68	89	110	4.9	< 0.0001
Lipid	25	41	46	30	53	66	43	66	79	4.4	< 0.0001
Ash	9	13	13	9	15	18	13	17	20	0.9	< 0.0001
Deposition rate, g/d/kg EBW[2]											
Water	42.1	52.6	57.3	50.3	56.1	62.1	51.4	61.7	65.4	2.63	< 0.0001
Protein	8.9	12.0	11.5	9.7	12.4	13.7	10.6	12.9	14.8	0.90	0.0002
Lipid	4.9	7.2	7.5	5.4	8.4	9.6	6.7	9.5	10.5	0.82	0.0002
Ash	1.7	2.2	2.1	1.8	2.3	2.6	1.9	2.4	2.8	0.17	0.0002

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). All pigs were harvested as the metabolism on d 32 post-weaning.

[2]EBW = empty body weight: sum of eviscerated carcass weight (including head and feet) and organ weight (including all organs and blood, but not digesta).

Table 6. Effects of initial body weight (BW) and ADG category on the apparent total tract digestibility (ATTD) of energy and nutrients of weaned pigs in the metabolism group[1]

	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW				
Item	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
d 5 post-weaning											
ATTD, %											
Dry matter[2]	73.0	75.0	76.5	74.8	75.9	77.6	75.4	74.6	76.9	1.75	0.44
Gross energy[3]	71.2	73.7	75.5	72.9	74.6	76.5	72.7	72.7	75.7	2.02	0.31
Nitrogen[3]	63.2	64.6	67.9	65.0	66.5	70.6	65.7	63.8	68.6	3.00	0.43
Crude fat[3]	65.5	67.6	71.0	64.0	66.5	68.5	62.3	62.0	70.4	3.97	0.52
ADF[3]	73.8	75.7	76.8	75.8	75.4	78.6	77.2	75.7	78.2	1.85	0.52
Ash[3]	71.0	73.8	75.7	74.1	75.3	77.0	74.6	73.1	76.0	1.84	0.30
Energy, Mcal/kg											
DE	3.18	3.29	3.37	3.25	3.33	3.41	3.24	3.24	3.38	0.090	0.31
ME[4]	2.94	3.05	3.13	2.99	3.09	3.19	3.01	3.00	3.15	0.086	0.20
NE[5]	2.39	2.37	2.34	2.55	2.21	1.96	2.10	2.25	2.25	0.019	0.50
d 32 post-weaning											
ATTD, %											
Dry matter[2]	84.1	86.4	85.9	85.1	86.2	84.6	85.8	85.9	85.4	0.72	0.003
Gross energy[3]	85.2	87.5	86.9	85.8	87.4	85.8	86.9	86.8	86.4	0.70	0.004
Nitrogen[3]	81.3	84.9	84.6	81.9	85.3	82.0	84.1	84.5	84.0	1.16	0.01
Crude fat[3]	84.0	85.5	85.4	83.5	85.2	85.9	85.4	84.6	85.6	1.45	0.55
ADF[3]	86.3	88.7	87.8	87.3	87.7	87.2	87.9	88.0	88.1	0.73	0.17
Ash[3]	97.2	97.7	97.6	97.4	97.7	97.4	97.5	97.6	97.5	0.13	0.001
Energy, Mcal/kg											
DE	3.47	3.57	3.54	3.50	3.56	3.50	3.54	3.54	3.52	0.029	0.005
ME[4]	3.28	3.38	3.36	3.29	3.38	3.31	3.36	3.36	3.34	0.031	0.002
NE[5]	2.43	2.50	2.48	2.45	2.49	2.45	2.48	2.48	2.47	0.020	0.003

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows).

[2]Calculated using the equation by Oresanya et al., 2005: DM Apparent Digestibility = 100% - [(Diet Marker Concentration ÷ Feces Marker Concentration) × 100].

[3]Calculated using the equation by Woyengo et al., 2008: Nutrient Apparent Digestibility Coefficient = 100% - {[(Diet Index Marker Concentration ÷ Feces Index Marker Concentration) × (Feces Nutrient Concentration ÷ Diet Nutrient Concentration)] × 100}.

[4]Calculated using the equation by Noblet and Perez, 1993: ME = DE × [1.003 – (0.0021 × %CP)].

[5]Calculated using the equation by Noblet et al., 1994: NE = 0.700 × DE + 1.61 × EE + 0.48 × ST - 0.91 × CP - 0.87 × ADF.

Table 7. Effects of initial body weight (BW) and ADG category on the energetic efficiency of weaned pigs in the metabolism group[1]

Item	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW			BW(ADG)	
	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	*P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
Energy intake, Mcal/d[2]											
DE	1.46	2.15	2.38	1.59	2.49	2.95	2.32	2.68	3.06	0.135	< 0.0001
ME	1.38	2.04	2.26	1.50	2.36	2.79	2.20	2.55	2.91	0.130	< 0.0001
NE	1.02	1.50	1.67	1.12	1.74	2.07	1.63	1.88	2.14	0.094	< 0.0001
NE for maintenance, Mcal[3]	0.57	0.69	0.75	0.61	0.79	0.87	0.80	0.87	0.96	0.020	< 0.0001
NE for growth, Mcal[4]	0.60	1.04	1.25	0.73	1.34	1.79	1.32	1.65	2.06	0.085	< 0.0001
NE efficiency for gain, Mcal/kg[5]	1.56	2.06	2.20	1.83	2.38	2.69	2.38	2.58	2.86	0.114	< 0.0001
NE efficiency for tissue depot, g/Mcal/d[6]											
Protein	73	66	57	71	56	55	54	54	55	11.8	0.87
Lipid	39	38	37	12	34	43	33	40	39	16.9	0.91
Energy retained tissue, kg[7]											
Protein	0.25	0.39	0.40	0.29	0.45	0.53	0.39	0.51	0.62	0.027	< 0.0001
Lipid	0.23	0.39	0.43	0.28	0.51	0.63	0.41	0.62	0.74	0.041	< 0.0001
Retained GE, Mcal/kg EBW											
Determined by bomb calorimetry	0.53	0.74	0.87	0.68	0.93	1.13	0.88	1.16	1.34	0.048	< 0.0001
Calculated by energy retained as tissue	0.49	0.78	0.83	0.57	0.96	1.16	0.80	1.13	1.36	0.065	<0.0001

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows).

[2]Calculated using the equation: Energy intake = Dietary energy × ADFI.

[3]Calculated using the equation by Just, 1982: NE required for maintenance = 0.078 Mcal × $BW^{0.75}$.

[4]Calculated using the equation: Energy for growth = Energy intake – energy required for maintenance.

[5]Calculated using the equation: Energy efficiency for gain = Energy for growth ÷ ADG.

[6]Calculated using the equation: Energy efficiency for tissue deposition = Tissue deposition ÷ energy for growth.

[7]Calculated using the equation by Ewan, 2001: Energy retained as protein = Protein deposition × 5.66; or Energy retained as lipid = Lipid deposition × 9.46.

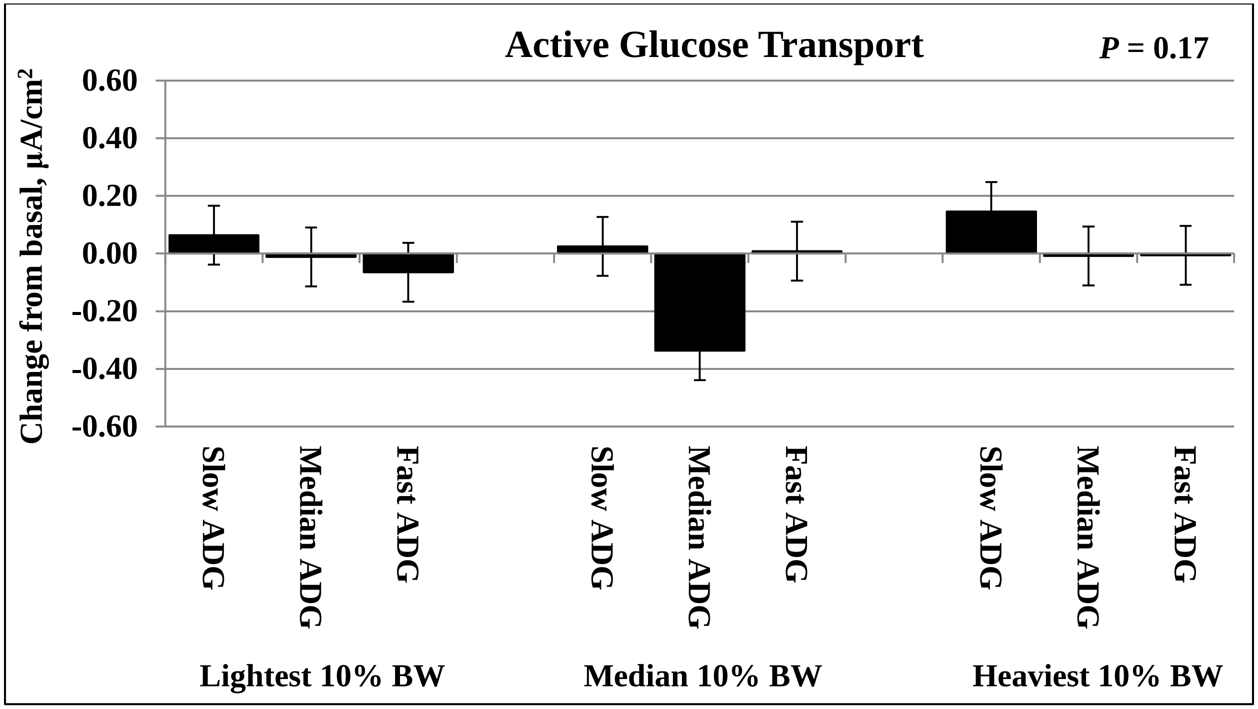


Figure 1. Effects of initial body weight (BW) and ADG category on the active glucose transport in ileal samples of weaned pigs in the metabolism group. After a 27-d growth experiment where pigs were fed a common commercial feed program, pigs were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Pigs were fasted for 12 h and harvested on d 32 post-weaning. Pooled SEM are shown.

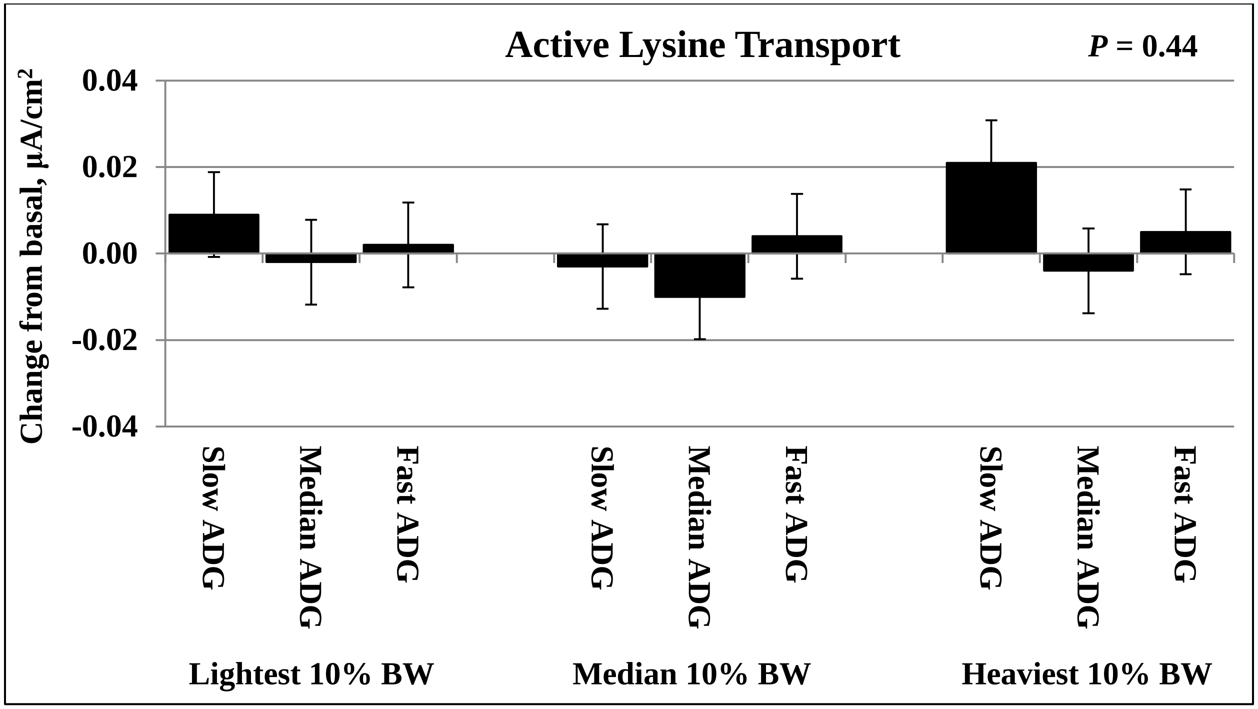


Figure 2. Effects of initial body weight (BW) and ADG category on the active lysine transport in ileal samples of weaned pigs in the metabolism group. After a 27-d growth experiment where pigs were fed a common commercial feed program, pigs were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Pigs were fasted for 12 h and harvested on d 32 post-weaning. Pooled SEM are shown.

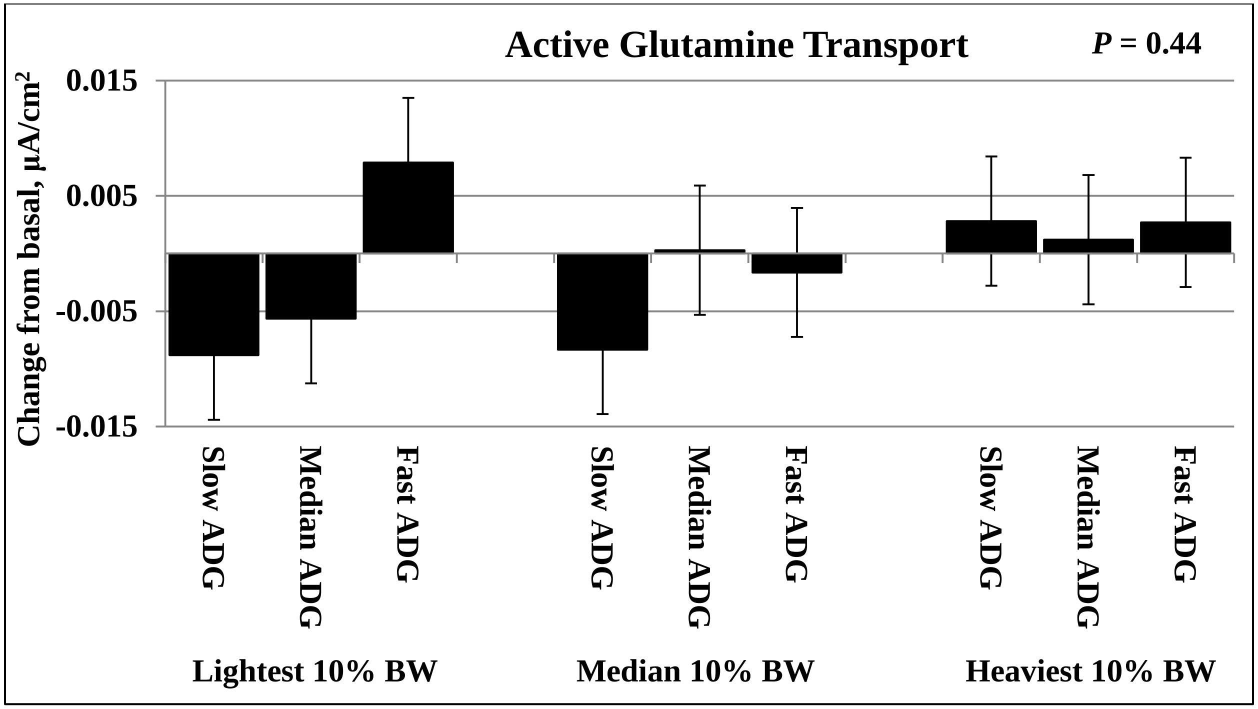


Figure 3. Effects of initial body weight (BW) and ADG category on the active glutamine transport in ileal samples of weaned pigs in the metabolism group. After a 27-d growth experiment where pigs were fed a common commercial feed program, pigs were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Pigs were fasted for 12 h and harvested on d 32 post-weaning. Pooled SEM are shown.

Table 8. Effects of initial body weight (BW) and ADG category on ileal morphology of weaned pigs in the metabolism group[1]

	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW				
Item	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	5	0	7	3	6	2	6	8		
Villous height, µm	365	418		330	323	403	437	382	390	23.9	< 0.0001
Crypt depth, µm	245	259		211	284	277	231	269	256	13.0	< 0.0001
Height:depth ratio	1.58	1.69		1.60	1.24	1.51	2.06	1.46	1.57	0.126	< 0.0001

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Pigs were harvested as the metabolism group on d 32 post-weaning. Tissues from 48 pigs were mounted, stained, and analyzed for histology by a third party that was blinded to treatment categories. Pigs were chosen at time of harvest, prior to stratification into ADG categories. Therefore, pigs were not divided evenly among BW(ADG) category.

Table 9. Effects of initial body weight (BW) and ADG category on blood chemistry concentrations of weaned pigs in the metabolism group[1]

	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW				
Item	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	BW(ADG) *P* =
Number of pigs	11	10	11	11	10	10	11	10	11		
Sodium, mEq/L	138	139	140	139	139	139	138	139	139	0.8	0.61
Potassium, mEq/L	6.9	6.7	6.7	6.7	6.9	6.5	6.9	6.8	6.4	0.30	0.75
Chloride, mEq/L	101	101	101	101	101	102	100	101	100	0.9	0.81
Bicarbonate, mEq/L	26.3	23.2	25.2	24.9	25.	24.7	22.8	24.2	26.8	1.42	0.03
Calcium, mg/dL	10.4	10.6	10.7	10.4	10.6	10.7	10.6	11.0	10.7	0.14	0.06
Phosphorus, mg/dL	11.1	11.1	11.4	10.8	11.5	10.7	11.6	11.0	10.6	0.37	0.14
Magnesium, mg/dL	2.58	2.60	2.77	2.62	2.63	2.56	2.60	2.63	2.55	0.124	0.87
BUN, mg/dL	11	12	12	10	14	11	11	10	10	1.2	0.16
Creatinine, mg/dL	1.0	1.2	1.2	1.1	1.3	1.2	1.2	1.2	1.3	0.08	0.02
Glucose, mg/dL	72	80	85	82	84	82	75	97	90	8.7	0.10
Total protein, g/dL	5.1	5.4	5.4	5.3	5.3	5.5	5.4	5.4	5.5	0.11	0.20
Albumin, g/dL	3.0	3.4	3.4	3.1	3.3	3.5	3.3	3.5	3.4	0.11	0.01
AST, IU/L[2]	56.3	69.2	52.1	68.9	55.3	49.3	83.4	60.8	70.3	9.48	0.18
Creatine Kinase, IU/L	1645	1918	1422	1330	1351	1758	3025	3123	3636	873.0	0.99
Alkaline Phosphatase, IU/L	417	367	397	394	380	378	344	342	342	24.0	0.80
GGT, IU/L[3]	49	49	54	48	61	52	55	57	49	4.8	0.27
Total Bilirubin, mg/dL	0.44	0.58	0.49	0.42	0.58	0.47	0.46	0.43	0.47	0.083	0.56
Anion Gap	18.4	21.3	20.4	19.5	19.3	19.7	22.0	20.4	18.8	1.6	0.24

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Blood was drawn from the jugular vein of pigs on d 32 post-weaning. Samples were analyzed by a third party that was blinded to treatment categories.

[2]Aspartate aminotransferase

[3]Gamma-glutamyl transpeptidase

Table 10. Effects of initial body weight (BW) and ADG category on white blood cell differential concentrations of weaned pigs in the metabolism group[1]

Item	Lightest 10% initial BW			Median 10% initial BW			Heaviest 10% initial BW			BW(ADG)	
	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 25% ADG	Slowest 33% ADG	Median 33% ADG	Fastest 33% ADG	Pooled SEM	*P* =
Number of pigs	8	7	9	9	9	8	10	7	9		
White blood cell count, × 10^3/μL	16.29	18.40	17.54	16.06	14.70	18.74	19.01	21.00	18.27	2.188	0.62
Red blood cell count, × 10^6/μL	6.40	6.59	6.67	6.29	6.59	6.88	6.58	6.95	7.14	0.261	0.32
Hemogloblin, g/dL	11.9	12.5	12.3	11.6	11.7	12.5	11.0	12.6	12.7	0.42	0.02
Hematocrit, %	36.9	39.1	38.4	36.4	36.9	38.8	35.0	39.2	39.5	1.34	0.10
Mean corpuscular volume, fl	57.7	59.4	57.9	57.9	55.9	56.7	53.3	56.3	56.0	1.17	0.28
Mean corpuscular hemoglobin, pg	18.6	18.9	18.5	18.5	17.8	18.3	16.8	18.2	17.9	0.46	0.21
Mean corpuscular hemoglobin concentration, g/dL	32.1	31.9	32.1	31.8	31.9	32.2	31.1	31.9	32.5	0.41	0.03
Platelet, × 10^3/μL	259	284	298	349	359	220	325	347	247	42.5	0.13
Neutrophil, × 10^3/μL	4.48	5.31	4.24	3.59	3.72	4.71	5.60	4.80	3.38	0.778	0.12
Lymphocyte, × 10^3/μL	10.71	11.50	12.26	11.02	9.81	12.71	12.09	14.74	13.20	1.768	0.72
Monocyte, × 10^3/μL	0.42	0.46	0.47	0.56	0.43	0.57	0.66	0.74	0.58	0.135	0.88
Eosinophil, × 10^3/μL	0.38	0.49	0.35	0.46	0.44	0.47	0.60	0.44	0.39	0.132	0.58
Basophil, × 10^3/μL	0.23	0.21	0.27	0.22	0.17	0.26	0.22	0.32	0.32	0.060	0.61

[1]Data are presented as least square means. Beginning at d 5 post-weaning, 32 pigs per BW category (96 total barrows) were allowed *ad libitum* access to commercial diets in individual metabolism crates for 27 days. One barrow from the median 10% initial BW category was taken off test due to inflamed joints. At the completion of the growth trial, barrows were divided into the 33% slowest, median, and fastest ADG, resulting in 10 or 11 barrows per BW(ADG) category (95 total barrows). Blood was drawn from the jugular vein of pigs into EDTA-coated tube on d 32 post-weaning. Up to 3 samples per category clotted, and were therefore not used in analyses. Samples were analyzed by a third party that was blinded to treatment categories.