Original research

Peer reviewed

Evaluating the impact of weaning weight and growth rate during the first week post weaning on overall nursery performance

Jamil E. G. Faccin, DVM, MSc; Fernanda Laskoski, DVM, MSc; Henrique S. Cemin, DVM, MSc; Ana P. G. Mellagi, DVM, PhD; Mari L. Bernardi, DVM, PhD; Rafael R. Ulguim DVM, PhD; Fernando P. Bortolozzo, DVM, PhD; Mike D. Tokach, PhD

Summary

Objective: Determine the effects of nursery pig weaning weight (WW) and first week postweaning growth rate (ADG7) on average daily gain (ADG), final weight, removals, and mortality under field conditions.

Materials and methods: In this 42-day study, 1602 pigs (mean [SD] weight: 5.42 [0.9] kg) were weaned at 19 to 21 days of age. Four successive batches of weaned pigs were moved into the same nursery room. Within each batch, pigs were allotted by WW to have approximately one-third of each class (LightWW, MediumWW, and HeavyWW) in all pens. On day 7, pigs were individually weighed and designated according to their ADG7 into four classes within their batch: NegativeADG7, LowADG7, MediumADG7, and HighADG7. An equation was developed and validated to quantify the association between WW and ADG7 with ADG.

Results: Weaning weight had no effect on ADG7 ($P = .42$), but increasing WW and ADG7 increased ($P < .001$) ADG and final weight at 42 days. Pig removal was reduced if pigs had heavy WW or gained weight in the first week after weaning (≤ 3.2%) compared to pigs that lost weight during the first week in the LightWW (20.9%) or MediumWW (10.3%) categories. Overall mortality was 1.1% with no effects of WW, ADG7, or its interaction ($P > .54$). The equation generated indicated that WW and ADG7 together had moderate accuracy ($R^2 = 0.54$; $P < .001$) to predict ADG.

Implication: The WW and ADG7 are not correlated, but they affect and partially predict the overall nursery performance.

Keywords: swine, nursery, growth rate, weaning weight, first week.

Received: February 6, 2019
Accepted: December 4, 2019

Resumen - Evaluación del impacto del peso al destete y la tasa de crecimiento durante la primera semana después del destete en el rendimiento general del destete

Objetivo: Determinar los efectos del peso al destete (WW por sus siglas en inglés) y la tasa de crecimiento post-destete de la primera semana (ADG7 por sus siglas en inglés) sobre la ganancia diaria promedio (ADG por sus siglas en inglés), el peso final, las eliminaciones y la mortalidad en condiciones de campo.

Materiales y métodos: En este estudio de 42 días, 1602 cerdos (peso medio [DE]: 5.42 [0.9] kg) fueron destetados entre los 19 y 21 días de edad. Cuatro lotes consecutivos de cerdos destetados fueron trasladados a la misma sala de cría. Dentro de cada lote, los cerdos fueron asignados por peso al destete WW para tener aproximadamente un tercio de cada clase (WWBajo, WWMedio y WWAlto) en todos los corrales. El día 7, los cerdos se pesaron individualmente y se designaron de acuerdo con su ADG7 en cuatro clases dentro de su lote: ADG7Negativo, ADG7Bajo, ADG7Medio, y ADG7Alto. Se desarrolló y validó una ecuación para cuantificar la asociación entre WW y ADG7 con ADG.

Resultados: El peso al destete no tuvo efecto sobre ADG7 ($P = .42$), pero el aumento de WW y ADG7 aumentó ($P < .001$) ADG y el peso final a los 42 días. La eliminación de los cerdos se redujo si los cerdos tuvieron un WW pesado o aumentaron de peso en la primera semana después del destete (≤ 3.2%) en comparación con los cerdos que perdieron peso durante la primera semana en las categorías WWBajo (20.9%) o WWMedio (10.3%). La mortalidad general fue del 1.1% sin efectos de WW, ADG7 o su interacción ($P > .54$). La ecuación generada indicó que WW y ADG7 juntos tenían una precisión moderada ($R^2 = 0.54$; $P < .001$) para predecir ADG.

Implicación: El peso al destete y ADG7 no están correlacionados, pero afectan y predicen parcialmente el rendimiento general del destete.

JEGF, FL, APGM, MLB, RRU, FPB: Setor de Suínos, Faculdade de Veterinária, Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil.

HSC, MDT: Department of Animal Sciences and Industry, College of Agriculture, Kansas State University, Manhattan, Kansas.

Corresponding author: Dr Fernando P. Bortolozzo, Av. Bento Gonçalves, 9090, Porto Alegre, RS, Brazil 91540–000; Tel: 55 51 3308 6132; Email: fpbortol@ufrgs.br.

This article is available online at http://www.aasv.org/shap.html.

Faccin JEG, Laskoski F, Cemin HS, Mellagi APG, Bernardi ML, Ulguim RR, Bortolozzo FP, Tokach MD. Evaluating the impact of weaning weight and growth rate during the first week post weaning on overall nursery performance. *J Swine Health Prod.* 2020;28(2):70-78.

Résumé - Évaluation de l'impact du poids au sevrage et du taux de croissance durant la première semaine post-sevrage sur les performances globales en pouponnière

Objectif: Déterminer, chez des porcelets en pouponnière, les effets du poids au sevrage (WW) et le taux de croissance durant la première semaine post-sevrage (ADG7) sur le gain quotidien moyen (ADG), le poids final, les retraits, et la mortalité dans des conditions de champ.

Matériels et méthodes: Dans cette étude d'une durée de 42 jours, 1602 porcelets (poids moyen [SD]: 5.42 [0.9] kg) furent sevrés entre 19 et 21 jours d'âge. Quatre lots successifs de porcelets sevrés furent déplacés dans la même chambre de pouponnière. Dans chacun des lots, les porcs étaient répartis par WW pour avoir approximativement un tiers de chaque catégorie (LégerWW, MédiumWW, et LourdWW) dans tous les enclos. Au jour 7, les porcs furent pesés individuellement et désignés selon leur ADG7 en quatre classes au sein de leur lot: ADG7Négatif, ADG7Faible, ADG7Moyen, et ADG7Élevé. Une équation fut développée et validée pour quantifier l'association entre WW et ADG7 et ADG.

Résultats: Le poids au sevrage n'avait aucun effet sur ADG7 ($P = .42$), mais en augmentant WW et ADG7 il y avait augmentation ($P < .001$) de l'ADG et du poids final à 42 jours. Le retrait de porcs était réduit si les porcs étaient de la classe LourdWW ou avaient pris du poids dans la première semaine après le sevrage (≤ 3.2%) comparativement aux porcs qui perdirent du poids durant la première semaine dans les catégories LégerWW (20.9%) ou MédiumWW (10.3%). La mortalité globale a été de 1.1% sans effet du WW, ADG7, ou ses interactions ($P > .54$). L'équation générée indiquait que WW et ADG7 ensemble avaient une précision modérée ($R^2 = 0.54$; $P < .001$) pour prédire ADG.

Implication: Le WW et l'ADG7 ne sont pas corrélés, mais ils affectent et prédisent partiellement la performance globale en pouponnière.

Weaning is one of the most stressful moments of a pig's life. At this transition time, piglets face changes in environmental conditions, health, hierarchy, nutrition, and other challenges.[1] These factors contribute to a dramatic reduction in feed intake. Pigs usually attain the metabolizable energy (ME) intake equivalent to the preweaning level only by the end of the second week post weaning. In addition, the ME requirements for maintenance are not fulfilled until the fifth day after weaning.[2] Stress factors may result in poor growth performance during the overall nursery phase.[3] Even with the possibility of compensatory gain after the adaptation period, pigs that are more affected by nursery stress factors can be negatively impacted for a longer period and exhibit poor performance during subsequent phases.[4]

In the past decades, numerous studies were conducted aiming to show the importance of performance immediately after weaning caused by manipulating the first postweaning diet.[5-7] Research has shown that pigs supplemented with milk preweaning[8,9] or post weaning[10,11] can reach extremely high growth rate in the nursery, sometimes exceeding 500 g/d. However, commercial conditions and challenges cause pigs to perform much more poorly immediately after weaning when they no longer have access to milk. In some studies, the effect of weaning weight was investigated in association with dietary treatments[12] or feeding durations of a starter diet,[13] and time to reach market weight was more affected by weaning weight than by feeding strategies. Recently, Collins et al[14] reinforced that the impact of weaning weight on the performance of subsequent phases was greater than diet effects.

The weight gain in the first 7 to 10 days after weaning has been shown to increase weight at 56 days for both light and heavy weaned pigs.[11] Although the growth performance until the end of the nursery period has been improved in pigs with higher early growth rate, weight at the end of the finishing phase or days to reach slaughter weight were unaffected.[11] The effect of growth rate immediately after weaning on subsequent pig growth performance has been scarcely studied, warranting investigation, especially under current pig production conditions. It would also be important to know whether growth rate immediately after weaning interacts with weaning weight to affect nursery growth performance.

The present study was performed using pigs with a small range (3 days) in weaning age to evaluate the effect of weaning weight and average daily gain (ADG) in the first 7 days post weaning on overall nursery performance (ADG and weight) as well as on removals and mortality during the 42 days post weaning. A second objective was to determine how much weaning weight and growth rate during the first week post weaning can predict overall ADG in the nursery phase in a commercial production system.

Materials and methods

The Institutional Animal Care and Use Committee of the Federal University of Rio Grande do Sul approved the protocols used in this experiment according to the process PROPESQ-UFRGS 35420.

Animals, housing, diets, and procedures

The study was conducted in a 5000-sow farm in midwestern Santa Catarina, Brazil. At weaning, 1602 barrows and gilts (PIC 337 × Camborough; Pig Improvement Company), from sows of parities 2 to 7, were identified with an ear tag and their individual weight was recorded. They had no access to creep feeding in the preweaning period. Four consecutive batches of pigs were weaned at 19 to 21 days of age and mean (SD) body weight was 5.4 (0.9) kg.

Pigs were housed in a double curtain-sided nursery room. Pens had solid concrete floor along the entire length of the feeder, and slatted plastic flooring in the remaining area. The room temperature was maintained at 28° C to 30° C in the first and second weeks after weaning, and 25° C to 26° C thereafter. Each pen had two nipple drinkers. Weaning batch 1 had 15 pigs/pen (20 pens), batch 2 had 22 (14 pens) or 23 pigs/pen (14 pens), and batch 3 had 24 pigs/pen (28 pens). Pens with 22 to 24 pigs had a feeder with four 16-cm wide feeder holes. In pens with 15 pigs, the feeder was adjusted so that pigs had access to three feeder holes. Adjustable pen gates were used to maintain a floor space allowance of 0.28 m^2/pig in all pens.

Pigs were allowed *ad libitum* access to feed and water. Diets were corn- and soybean-meal-based and a three-phase feeding program was formulated to meet the National Research Council[15] requirement estimates. All diets were manufactured at the on-farm feed mill and were fed in meal form. The feed budget was 1 kg/pig of Phase 1 diet (3.6 Mcal/kg of ME, 21.9% crude protein [CP], 1.46% standardized ileal digestible [SID] lysine, 18.0% lactose, and 180 ppm of colistin), 4 kg/pig of Phase 2 diet (3.6 Mcal/kg of ME, 21.4% CP, and 1.42% SID lysine, 12.0% lactose, 180 ppm of colistin,

and 300 ppm of amoxicillin), followed by a Phase 3 diet (3.5 Mcal/kg of ME, 20.1% CP, and 1.30% SID lysine) with approximately 17 kg/pig fed until the end of the trial.

Three weaning batches allotted in the same nursery room were used to evaluate the nursery performance and develop an equation to predict overall ADG through the nursery phase. The pigs were individually weighed on days 0, 7, and 42 (end of the study). In each pen, pigs were allotted according to weaning weight (WW) with approximately one-third of each WW class (LightWW, MediumWW, and HeavyWW) in all pens. Based on the ADG during the first week in the nursery (ADG7), four classes were created (NegativeADG7, LowADG7, MediumADG7, and HighADG7) within each batch. The NegativeADG7, LowADG7, MediumADG7, and HighADG7 classes had 22%, 26%, 26%, and 26% of the total number of pigs, respectively.

Removal reasons were pigs that were nonambulatory, pigs not responding to antibiotic treatment, and pigs that lost weight for 2 consecutive weeks (without considering the first week). Weekly, 1 veterinarian visited the nursery room to evaluate the response of the pigs to the antibiotic treatments. Also, pigs visually classified with poor growth rate were weighed for 2 consecutive weeks to confirm they were not gaining weight. Using the continuous data of WW and ADG7 from the first three batches, an equation was developed by testing the linear and quadratic terms of WW and ADG7 as predictors of overall nursery ADG.

Statistical analysis

Data were analyzed using SAS software (version 9.4; SAS Institute Inc). In all analyses, means or percentages were considered significantly different at $P \leq .05$. Pigs that died or were removed during the first week after weaning could not be classified according to ADG7, thereby 1588 of 1602 pigs were used for the analyses.

The GLIMMIX procedure was used for the analysis of weight and ADG at different timepoints in the nursery phase. The models of analysis included the fixed effects of WW classes, ADG7 classes, and their interaction. Random effects included in the models were weaning batch and pen within batch. Batch was included as a random effect to account for random error associated with variation among batches. Pen within batch was used to account for random error observed between pens within the same batch. Least squares means were compared using the Tukey-Kramer procedure, which adjusts tests on multiple comparison and unbalanced designs.[16]

According to Petrie and Watson,[17] when a categorical explanatory variable has zero cell count in one or more of its categories, the problem can be overcome by running logistic regression models after combining one or more categories of this variable. The NegativeADG7 class was grouped with LowADG7 class because there were no dead pigs in the NegativeADG7 class. The same approach was used to group MediumADG7 and HighADG7 classes within each WW class because no HighADG7 pigs belonging to HeavyWW class were removed. These groupings were performed only after using the Fisher Exact test to confirm that they were not different. Thereafter, removals and mortality were analyzed as binary responses using logistic regression models. The independence assumption for logistic regression models was checked by dividing the deviance by the degrees of freedom to confirm it was not substantially greater than one.[17]

The CORR procedure was used to obtain Pearson's correlation coefficients regarding the relationships of WW and ADG7 with variables of growth performance. Partial correlation coefficients, controlling for the effects of WW or ADG7, were also obtained. A partial correlation analysis allows examining the strength of a linear bivariate relationship while holding constant another variable in the model.[18]

The MIXED procedure of SAS was used to develop a prediction equation for overall nursery ADG using the dataset from the first three batches. The variables tested as predictor variables were the linear and quadratic terms of WW and ADG7 and the interaction between WW and ADG7. The statistical significance for inclusion of terms in the model was determined at $P \leq .05$. The single variable model with the lowest Bayesian information criterion (BIC) was selected and additional terms were added in a stepwise manual forward selection. In order to be included in the model, a reduction of at least 2 points in BIC was required.[19] The model with the lowest BIC was considered the optimal and the method of residual maximum likelihood was used to obtain the parameter estimates. Following the recommendations of Petrie and Watson,[17] the assumption of homogeneity of variance was confirmed by the random scatter of residuals with no funnel effect when the studentized residuals were plotted against the fitted values of the dependent variable. A histogram of the residuals was examined to confirm the normality assumption. A fourth batch with 526 nursery pigs was used to evaluate the accuracy of the prediction equation. The accuracy of this model was examined using the coefficient of determination (R^2), in addition to the assessment of the closeness of the points (plot of actual vs predicted values) to the straight line, ie, the line of perfect agreement.

Results

The ranges of weight and ADG for WW and ADG7 classes of each weaning batch are shown in Table 1. The different ADG7 classes started with similar ($P = .74$) weaning weight (overall mean of 5.4 kg). The weight at 7 and 42 days after weaning were affected by WW and ADG7 but there was no evidence ($P = .84$) for interaction effect (Table 2). At weaning, HeavyWW pigs were 2.1 kg heavier than LightWW pigs, and the difference between HeavyWW and LightWW pigs increased to 5 kg on day 42 (Table 2). Pigs of the HighADG7 class were 3.7 kg heavier on day 42 compared to pigs who lost weight in the first week post weaning, despite their similar weight at weaning.

The WW classes did not differ ($P = .42$) in ADG7 (Table 3). The ADG between 8 and 42 days after weaning and overall ADG were affected by WW and ADG7 classes ($P < .001$), but there was no evidence ($P = .75$) for interaction (Table 3). LightWW pigs had the lowest ADG from day 8 to 42 and for the overall nursery period. MediumWW pigs were intermediate and HeavyWW pigs had the highest ($P = .01$) growth rates at all timepoints (Table 3). For each increase in ADG7 class, ADG from day 8 to 42 increased by 19 to 25 g/d, and overall ADG increased by 26 to 34 g/d.

The percentages of removals were similar ($P = .75$) between MediumADG7 and HighADG7 for LightWW (3.57% versus 2.78%), MediumWW (2.22% versus 1.48%), and HeavyWW (0.74% versus 0.0%) classes. When MediumADG7 and HighADG7 classes were grouped, a higher odds ratio (OR) for removal ($P = .05$) was observed in LightWW (OR = 11.2) and MediumWW (OR = 4.8) than in HeavyWW pigs for the NegativeADG7 class (Table 4). Pigs that lost

Table 1: Ranges of weaning weight and average daily gain in the first week post weaning for each weaning batch by class*

	WW, kg			ADG7, g			
Batch	**LightWW**	**MediumWW**	**HeavyWW**	**NegativeADG7**	**LowADG7**	**MediumADG7**	**HighADG7**
	n = 526	n = 530	n = 532	n = 357	n = 412	n = 410	n = 409
1	3.28 to 4.77	4.79 to 5.79	5.80 to 6.90	-138 to 0	1 to 60	61 to 116	117 to 287
2	3.65 to 4.95	4.96 to 5.87	5.88 to 8.00	-228 to 0	1 to 47	49 to 91	93 to 300
3	4.09 to 5.09	5.10 to 5.85	5.86 to 8.60	-177 to 0	1 to 106	107 to 168	170 to 367

* Within weaning batch, pigs were allotted into 3 classes according to WW. Subsequently within weaning batch, pigs were allotted into 4 classes according to their ADG7.
WW = weaning weight; ADG7 = average daily gain in the first week post weaning.

Table 2: Body weight of pigs at 7 and 42 days post weaning according to weaning weight and average daily gain in the first week post weaning*

		WW classes			
Item	**ADG7 Classes**	**LightWW**	**MediumWW**	**HeavyWW**	**LS Means (SEM)**
BW at 7 d, kg	NegativeADG7	4.1	5.1	6.2	5.1 (0.19)^{d}
	LowADG7	4.6	5.6	6.8	5.7 (0.19)^{c}
	MediumADG7	5.1	6.0	7.2	6.1 (0.19)^{b}
	HighADG7	5.6	6.6	7.7	6.6 (0.19)^{a}
	LS Means (SEM)	4.8 (0.19)^{c}	5.8 (0.19)^{b}	7.0 (0.19)^{a}	
BW at 42 d, kg	NegativeADG7	15.1	17.1	20.3	17.5 (0.7)^{h}
	LowADG7	16.5	18.7	21.4	18.9 (0.7)^{g}
	MediumADG7	17.5	19.6	22.7	19.9 (0.7)^{f}
	HighADG7	19.1	20.8	23.7	21.2 (0.7)^{e}
	LS Means (SEM)	17.0 (0.7)^{g}	19.1 (0.7)^{f}	22.0 (0.7)^{e}	

* Within weaning batch, pigs were allotted into 3 classes according to WW. Subsequently within weaning batch, pigs were allotted into 4 classes according to their ADG7.
$^{a\text{-}h}$ Different superscripts within the column or the row indicate statistical difference in LS Means at 7 d ($^{a\text{-}d}$) and 42 d ($^{e\text{-}h}$), respectively ($P < .05$). Comparisons were performed using the Tukey-Kramer test.
WW = weaning weight; ADG7 = average daily gain in the first week post weaning; SEM = standard error of the mean; BW = body weight.

weight had greater odds ($P = .02$) of being removed than those that gained weight in the first week after weaning, for LightWW (OR = 8.5 and 8.1) and MediumWW classes (OR = 8.1 and 6.1). On the other hand, for HeavyWW pigs, the ADG7 classes did not differ ($P = .43$). Within the classes with weight gain, removals were not affected ($P = .10$) by WW classes. The percentages of dead pigs are shown in Table 5. Mortality was not affected by WW, ADG7 or by their interaction ($P = .54$).

The correlation coefficients of WW and ADG7 with variables regarding nursery growth performance are shown in Table 6. The ADG7 was not correlated with WW. The weight at 42 days was strongly correlated with weaning weight and moderately correlated with ADG7. The ADG from 8 to 42 days and overall ADG were weakly or moderately correlated with both WW and ADG7. All partial correlation coefficients were higher than those observed without keeping WW or ADG7 constant.

For the overall nursery ADG prediction equation, only the linear terms for WW and ADG7 were significant predictors ($P < .001$). Quadratic terms and interaction between WW and ADG7 were not significant ($P = .10$) and were removed from the model. The final prediction equation (adjusted $R^2 = 0.44$) was: overall nursery ADG = (.03161 × WW) + (.4387 × ADG7) + .1308. It is important to note that the input variables must consist of values within the ranges used to generate the prediction equation. The prediction equation generated from the first three batches was used to predict the ADG of the fourth batch. Using R^2 as a measure of goodness of fit, the ADG prediction value had a moderate accuracy ($R^2 = 0.54$, $P = .01$) caused by a relative dispersion of the dots over the line (Figure 1).

Discussion

This study investigated the impact of weaning weight and ADG7 on the overall nursery performance. Weaning weight was not correlated with ADG7, but heavier pigs at

Table 3: Average daily gain in the nursery phase according to weaning weight and average daily gain in the first week post weaning*

Item	ADG7 classes	WW classes			LS Means (SEM)
		LightWW	MediumWW	HeavyWW	
0 to 7 d, g	NegativeADG7	-34.8	-46.0	-49.5	-43.4 (15.4)[d]
	LowADG7	36.6	39.4	38.9	38.3 (15.4)[c]
	MediumADG7	99.1	97.4	100.2	98.9 (15.4)[b]
	HighADG7	174.1	173.3	177.4	174.9 (15.4)[a]
	LS Means (SEM)	68.7 (15.4)	66.0 (15.4)	66.7 (15.4)	
8 to 42 d, g	NegativeADG7	312.4	342.1	400.2	351.6 (14.3)[h]
	LowADG7	337.9	373.3	419.0	376.7 (14.2)[g]
	MediumADG7	353.5	390.2	443.5	395.7 (14.2)[f]
	HighADG7	384.2	406.9	456.6	415.9 (14.2)[e]
	LS Means (SEM)	347.0 (14.1)[g]	378.1 (14.1)[f]	429.8 (14.1)[e]	
0 to 42 d, g	NegativeADG7	254.4	279.1	323.4	286.7 (14.3)[l]
	LowADG7	287.1	316.0	354.4	320.4 (14.2)[k]
	MediumADG7	310.5	341.2	385.7	346.2 (14.2)[j]
	HighADG7	350.3	370.0	409.7	375.6 (14.2)[i]
	LS Means (SEM)	301.1 (14.2)[k]	326.3 (14.2)[j]	369.3 (14.2)[i]	

* Within weaning batch, pigs were allotted into 3 classes according to WW. Subsequently within weaning batch, pigs were allotted into 4 classes according to their ADG7.

[a-l] Different superscripts within the column or the row indicate statistical difference in LS Means within 8 to 7 d ([a-d]), 8 to 42 d ([e-h]), and 0 to 42 d ([i-l]), respectively ($P < .05$). Comparisons were performed using the Tukey-Kramer test.

WW = weaning weight; ADG7 = average daily gain in the first week post weaning; SEM = standard error of the mean.

Table 4: Number and percentage of pigs removed between 7 and 42 days of the nursery period according to weaning weight and average daily gain in the first week post-weaning*

ADG7 classes	WW classes, No. of pigs (%)		
	LightWW	MediumWW	HeavyWW
NegativeADG7	23 (20.91)[a,x]	12 (10.26)[a,x]	3 (2.31)[y]
LowADG7	4 (3.03)[b]	2 (1.40)[b]	2 (1.46)
MediumADG7 + HighADG7†	9 (3.17)[b]	5 (1.85)[b]	1 (0.38)

* Within weaning batch, pigs were allotted into 3 classes according to WW. Subsequently within weaning batch, pigs were allotted into 4 classes according to their ADG7.

† MediumADG7 and HighADG7 classes were grouped to run the logistic regression analysis because no pigs were removed in HighADG7 class within HeavyWW class. Grouping was performed only after confirmation, using the Fisher Exact test, that these two ADG7 classes were not different.

[a,b and x,y] Superscripts a and b within a column and x and y within a row indicate statistical difference ($P < .05$). Groups were compared using a logistic regression analysis.

WW = weaning weight; ADG7 = average daily gain in the first week post weaning.

weaning had higher ADG from 8 to 42 days post weaning. Collins et al[14] also reported the influence of weaning weight on ADG only after day 7 post weaning. These results demonstrate the unsuccessful adaptation of piglets to challenges of the critical period of weaning, which imposes simultaneous stressors, including change in nutrition, separation from mother and littermates, new environment, and mixing. These stressors lead to low and variable feed intake, hence reducing the weight gain,[20] regardless of the weight at weaning.

Increasing the weaning weight may have a greater impact on nursery performance than feeding and management strategies that aim to accelerate growth rate immediately after weaning.[5,11-13] The difference in initial weight (2.1 kg) between LightWW and HeavyWW pigs more than doubled on day 42 (5.0 kg), showing the importance of WW on subsequent performance. Wolter and Ellis[11] observed that heavy-weight pigs at weaning have higher ADG in the nursery phase, are heavier at 56 days of age, and take less time to reach market weight than light-weight pigs. Similarly, other studies show that fewer days are required for heavier-weight pigs at weaning to reach a final weight of 105 kg than for light-weight pigs at weaning, irrespective of postweaning diets or feeding programs.[12,13] Recently, Collins et al[14] confirmed the remarkable impact of weaning weight on lifetime growth performance, with a difference of 4.1 kg at weaning between light and heavy pigs increasing to 7.3 and 11.7 kg at 39 and 123 days after weaning, respectively. Nevertheless, the same study showed that more complex diets can be used for lighter pigs at weaning to maximize their lifetime growth performance.[14]

Overcoming stressors associated with weaning is a challenge to the pigs during the first week in the nursery. If stress is surpassed and the weight is at least maintained during the first week, then pigs can reach market weight 15 days before pigs that lose weight.[21] In the present study, pigs that gained more weight during the first week were 3.8 kg heavier on day 42 than those that lost weight in the first week. Kats et al[22] also observed a weight difference of 2.9 kg at 56 days post weaning in favor of pigs that gained weight during the first week. Wolter and Ellis[11] used improved environmental conditions and provided liquid milk replacer during two weeks after weaning to accelerate the growth in nursery phase. Although pigs with accelerated growth were 1.3 kg heavier at 56 days of age, the early growth rate had no effect on growth from day 35 onwards

Table 5: Number and percentage of pigs that died between 7 and 42 days of the nursery period according to weaning weight and average daily gain in the first week post weaning*

	WW classes, No. of pigs (%)			
ADG7 classes	**LightWW**	**MediumWW**	**HeavyWW**	**Total**
NegativeADG7 + LowADG7†	3 (1.24)	3 (1.15)	2 (0.75)	8 (1.04)
MediumADG7	2 (1.43)	1 (0.74)	2 (1.48)	5 (1.22)
HighADG7	3 (2.08)	1 (0.74)	1 (0.77)	5 (1.22)
Total	8 (1.52)	5 (0.94)	5 (0.94)	

* Within weaning batch, pigs were allotted into 3 classes according to WW. Subsequently within weaning batch, pigs were allotted into 4 classes according to their ADG7.
† NegativeADG7 and LowADG7 classes were grouped to run the logistic regression analysis because no pigs died in NegativeADG7 class. Grouping was performed only after confirmation, using the Fisher Exact test, that these two ADG7 classes were not different.
WW = weaning weight; ADG7 = average daily gain in the first week post weaning.

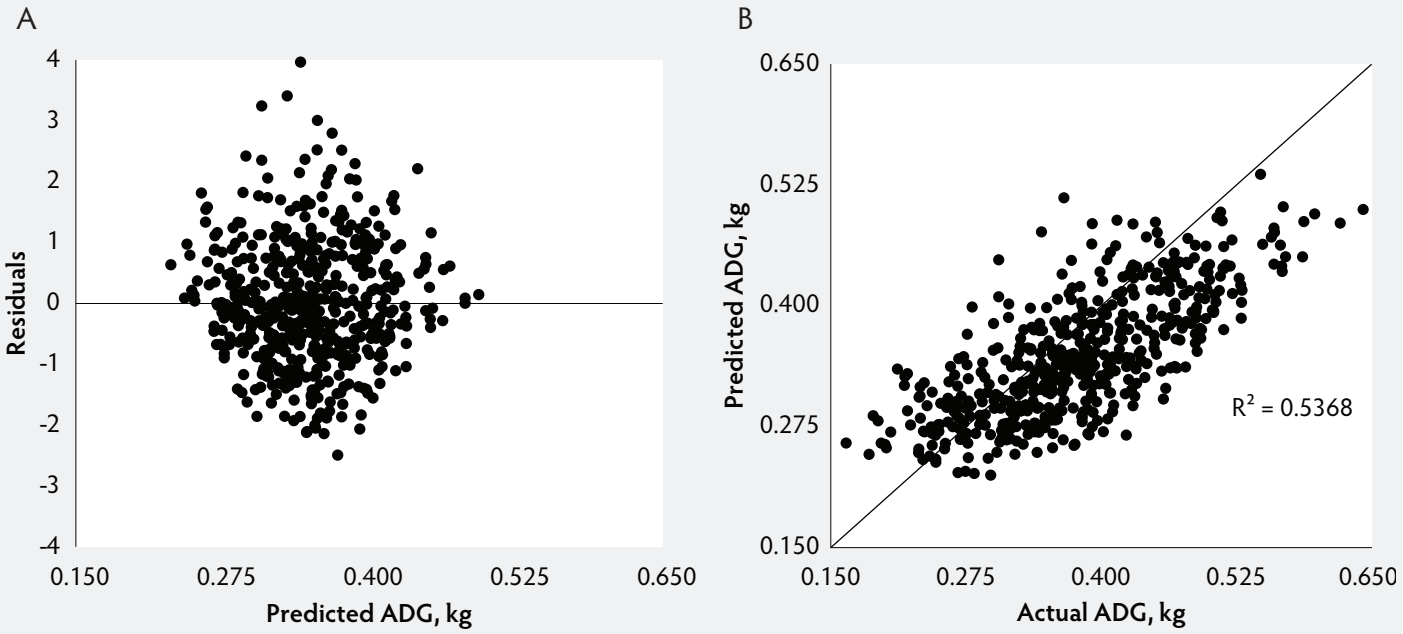
Table 6: Pearson correlation coefficients of weaning weight and average daily gain in the first week post weaning with the growth performance of nursery pigs

	ADG7	**ADG 8-42 d**	**ADG 0-42 d**	**Weight at 42 d**
WW	-0.005	0.432	0.389	0.598
P	.86	< .001	< .001	< .001
WW*	-	0.475	0.475	0.684
P		< .001	< .001	< .001
ADG7	-	0.357	0.521	0.445
P		< .001	< .001	< .001
ADG7†	-	0.411	0.579	0.580
P		< .001	< .001	< .001

* Partial correlation coefficient while controlling for the effect of ADG7.
† Partial correlation coefficient while controlling for the effect of WW.
ADG7 = average daily gain in the first week post weaning; ADG = average daily gain; WW = weaning weight.

Figure 1: A) Studentized residual plots when modeling the effect of weaning weight (WW) and average daily gain at day 7 (ADG7) values on overall nursery average daily gain (ADG) and B) plots of actual values vs predicted values relative to the line of equality. The plots for ADG are based on 526 pigs from the fourth batch. Data from the first three batches were used to develop the equation. The following equation was used for the prediction of overall ADG:

Overall nursery ADG = (0.03161 × WW) + (0.4387 × ADG7) + 0.1308.



or days to reach slaughter weight. The difference in ADG between the accelerated and conventional group was 86 g/d at the end of 14 days of treatment, which could explain why advantages in growth were not sustained to slaughter weight.[11] In the present study, despite the narrow amplitude in weaning age, the difference in ADG7 between the two extreme ADG7 classes was 218 g/d, suggesting that the advantages in growth rate would more likely be maintained until the end of the finishing phase.

Mortality was not affected by WW and ADG7. However, the combined effect of WW and ADG7 was evidenced by a drastic reduction in removals if pigs were heavier at weaning or gained weight in the first week after weaning. The lower percentage of removals observed in pigs that gained weight in the first week, regardless of their weaning weight, is probably related to enhanced postweaning feed intake preventing villous atrophy and stimulating growth.[1] Indeed, detrimental changes in gut structure and function of weaned pigs are mainly driven by inadequate feed intake.[20] Higher losses (mortality and removal) have been reported for pigs with lower weight (< 4.1 kg) on day 7 after weaning compared with those with higher weight.[23] Higher removal rates of light-weight pigs are probably also associated with the possibility of harboring more infectious pathogens.[24]

The variation in weaning age is difficult to control in nursery studies performed under field conditions. Pigs in a batch often originate from sows with a range in farrowing dates, and individual weaning age is usually unknown when they enter nursery facilities. In some studies in which the effects of WW and weight gain on nursery performance were investigated, the weaning age differences ranged from 5 to 8 days,[7,11,14,22] being a potential confounding variable for outcomes if its effect is not taken into account. The performance in the nursery is affected by the weaning age,[23,25] and for each day of increase in weaning age, overall ADG is increased by 22 g in the nursery phase.[25] Thus, individual pig age should be considered as an important variable to be recorded in nursery studies, otherwise a great variation in weaning age can be a confounding factor for growth performance evaluation. In the study by Kats et al,[22] a range of 8 days in weaning age (17 to 25 days) was used. In the current study, we tried to minimize the possible confounding effect of different weaning ages by evaluating pigs within a range as narrow as possible, ie, 3 days (19 to 21 days).

Other factors not investigated herein could also affect nursery performance. Variables such as dam parity and litter of origin can be confounding factors, but they are difficult to control in studies performed under field conditions. Sow-to-sow differences explain more of the variation in weight at 7 weeks of age than farm-to-farm differences.[23] Piglets reared by parity 1 females have increased odds of being lighter at the end of the nursery phase,[26] and those reared by mid-parity sows (parity 3 to 5) are heavier at 10 weeks of age than those reared by primiparous sows.[27] Although the individual parity number of dams was not available for analysis, we consider that the influence of dam parity was minimized because pigs reared by primiparous sows were not included in the present study. To minimize the confounding effect of litter, Wolter et al[5] equally distributed littermates to different treatments. Larriestra et al[26] confirmed the importance of including litter, which can be a source of variation related to size, weight variation, and other dam attributes, as a random effect in logistic

models for the analysis of mortality and likelihood of being light at nursery exit, but this strategy was not considered in the present study. Nursery growth performance can also be influenced by health status[23] or the use of antibiotics in the diet. Growth performance during the nursery period has been improved by antibiotic use.[7] The fact that diets used in the present study contained antibiotics may limit extrapolation of the findings to commercial units where antibiotic-free diets are used.

The conduction of on-farm research in commercial units is justified by de Grau et al[23] due to the wide variation observed in the within-farm coefficient of variation (CV) of weaning weight in 8 commercial farms (from 17.4% to 40.7%). In the present study, the within-batch CV of weaning weight varied from 16.7% to 19.1%. Large variation in within-farm (8 herds) growth rate at all stages of growth has also been reported by Magowan et al,[28] even though the same diets were offered from birth to slaughter. This denotes that several factors affect the expression of genetic potential in pigs raised under commercial conditions. Magowan et al[28] postulated that differences in pig genotype may be a significant contributor to the variable growth rate observed between pigs from different herds, even when managed in a common environment. Variation in growth rate could not be attributed to differences in genotype since a single commercial unit, with the same genotype, was evaluated in the present study.

Prediction equations have been used previously in the swine industry, especially for the estimation of farrowing weight[29] and growth performance rates.[30] Also, the precision of a predictor variable on a given outcome can be obtained through the equations. However, the use of equations requires caution to avoid generating incorrect conclusions.[31] The WW was previously considered a precise predictor of weight at 42 days, demonstrating that it was highly correlated with postweaning performance[32] and a major determinant of lifetime growth performance.[33] The fact that partial correlation coefficients did not change markedly and were not weaker than bivariate coefficients, shows that there is a direct relationship between WW or ADG7 with growth performance variables.[18] Although WW and ADG7 are important variables that positively influence nursery performance, using solely them to predict the overall nursery ADG does not explain all the variation in this variable. In a comprehensive study where a large number of factors were included in a risk factor analysis, approximately 70% of the variation in weight at the end of the nursery period (10 weeks of age) was explained by season of birth, weight at birth, weight at weaning, and weight at 6 weeks of age.[34] In the present study, 44% of the variation of nursery ADG was explained by the WW and ADG7. When the equation was validated with the dataset of the fourth batch, the coefficient of determination ($R^2 = 0.54$) suggested that 54% of the variation observed in the actual values were explained by the model-predicted values. The equation seems to underestimate the performance of the fastest growing pigs and overestimate the performance of some of the slowest growing pigs. The advantage in weight at the end of the nursery period is usually maintained until the end of growing-finishing.[35] Therefore, predicting growth rate in the nursery phase based on weaning weight and performance in the first week could help to estimate the number of days needed for pigs to reach market weight.

Increasing the weaning weight and performance during the first week post weaning may be considered a goal to improve growth performance in the nursery phase. Strategies for increasing feed intake or preventing the low feed intake problems immediately after weaning should be considered. Increasing water intake,[36] providing an ideal proportion of pigs per feeder hole,[37] improving diet digestibility,[1] and providing adequate health conditions to weaned pigs[23] may be useful strategies to support weight gain immediately after weaning as would focusing on light pigs in the earlier stages to identify those that do not exhibit feed intake or appear to lose weight.

Implications

Under the conditions of the present study:

- The ADG7 and WW were not associated.
- The overall ADG in the nursery phase was moderately predicted by WW and ADG7.
- Removals were reduced by increasing ADG7 in LightWW and MediumWW pigs.

Acknowledgments

This study was financed, in part by CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) Grant No. 430206/2018-6. The authors are grateful to Master Agroindustrial and Agroceres PIC for providing facilities and funding to perform this study. The first author was sponsored by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, Brasil.

Conflict of interest

None reported.

Disclaimer

Scientific manuscripts published in the *Journal of Swine Health and Production* are peer reviewed. However, information on medications, feed, and management techniques may be specific to the research or commercial situation presented in the manuscript. It is the responsibility of the reader to use information responsibly and in accordance with the rules and regulations governing research or the practice of veterinary medicine in their country or region.

References

1. Dong GZ, Pluske JR. The low feed intake in newly-weaned pigs: problems and possible solutions. *Asian-Aust J Anim Sci*. 2007;20:440-452.

2. Le Dividich I, Herpin P. Effects of climatic conditions on the performance, metabolism and health status of weaned piglets: a review. *Livest Prod Sci*. 1994;38:79-90.

3. King RH, Pluske JR. Nutritional management of the pig in preparation for weaning. In: Pluske JR, Le Dividich J, Verstegen MWA, eds. *Weaning the pig: concepts and consequences.* The Netherlands: Wageningen Academic Publishers. 2003:37-51.

4. Clark AB, De Jong JA, DeRouchey JM, Tokach MD, Dritz SS, Goodband RD, Woodworth JC. Effects of creep feed pellet diameter on suckling and nursery pig performance. *J Anim Sci.* 2016;94 (Suppl 2):100-101.

5. Wolter BF, Ellis M, Corrigan BP, Dedecker JM, Curtis SE, Parr EN, Webel WM. Impact of early postweaning growth rate as affected by diet complexity and space allocation on subsequent growth performance of pigs in a wean-to-finish production system. *J Anim Sci.* 2003;81:353-359.

6. Wellock IJ, Houdijk JG, Miller AC, Gill BP, Kyriazakis I. The effect of weaner diet protein content and diet quality on the long-term performance of pigs to slaughter. *J Anim Sci*. 2009;87:1261-1269.

7. Skinner LD, Levesque CL, Wey D, Rudar M, Zhu J, Hooda S, de Lange CFM. Impact of nursery feeding program on subsequent growth performance, carcass quality, meat quality, and physical and chemical body composition of growing-finishing pigs. *J Anim Sci*. 2014;92:1044-1054.

*8. Williams IH. Nutrition of the young pig in relation to body composition [PhD thesis]. Victoria, Australia: University of Melbourne; 1976.

*9. Harrell RJ, Thomas MJ, Boyd RD. Limitations of sow milk yield on baby pig growth. *Proc 1993 Cornell Nutrition Conference for Feed Manufacturers*. Rochester, NY. 1993;156-164.

10. Pluske JR, Williams IH, Aherne FX. Villous height and crypt depth in piglets in response to increases in the intake of cow's milk after weaning. *Anim Sci*. 1996;62:145-158.

11. Wolter B, Ellis M. The effects of weaning weight and rate of growth immediately after weaning on subsequent pig growth performance and carcass characteristics. *Can J Anim Sci.* 2001;81:363-369.

12. Mahan DC, Lepine AJ. Effect of pig weaning weight and associated nursery feeding programs on subsequent performance to 105 kilograms body weight. *J Anim Sci.* 1991;69:1370-1378.

13. Mahan DC, Cromwell GL, Ewan RC, Hamilton CR, Yen JT. Evaluation of the feeding duration of a phase 1 nursery diet to three-week-old pigs of two weaning weights. *J Anim Sci.* 1998;76:578-583.

14. Collins CL, Pluske JR, Morrison RS, McDonald TN, Smits RJ, Henman DJ, Stensand I, Dunshea FR. 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. *Anim Nutr*. 2017;3:372-379.

15. National Research Council. *Nutrient Requirements of Swine*. 11th ed. Washington, DC: National Academies Press; 2012.

16. Kaps M, Lamberson WR. More about blocking. In: Kaps M, Lamberson WR, eds. *Biostatistics for animal science*. Wallingford, Oxfordshire: CABI Publishing; 2004:331-341.

17. Petrie A, Watson P. Further regression analyses. In: Petrie A, Watson P, eds. *Statistics for veterinary and animal science*. 3rd ed. West Sussex, UK: Wiley-Blackwell; 2013:146-164.

18. Healey JF. Partial correlation and multiple regression and correlation. In: Healy, JF, ed. *Statistics: a tool for social research*. 9th ed. Belmont, CA: Wadsworth; 2012:433-467.

19. Kass RE, Raftery AE. Bayes factors. *J Am Stat Assoc.* 1995;90:773-795.

20. Pluske JR, Hampson DJ, Williams IH. Factors influencing the structure and function of the small intestine in the weaned pig: a review. *Livest Prod Sci*. 1997;51:215-236.

*21. Pollmann DS. Effects of nursery feeding programs on subsequent grower-finisher pig performance. *Proc 14th Western Nutrition Conf*. Edmonton, Alberta, Canada. 1993:243-254.

*22. Kats LJ, Tokach MD, Goodband RD, Nelssen JL. Influence of weaning weight and growth during the first week postweaning on subsequent pig performance. *Proc Kansas State University Swine Day*. Manhattan, KS. 1992:15-17.

23. de Grau A, Dewey C, Friendship R, de Lange K. Observational study of factors associated with nursery pig performance. *Can J Vet Res.* 2005;69:241-245.

*24. Deen J. The problem of lightweight market hogs. *Proc Allen D. Leman Swine Conference.* Minneapolis, MN. 2000;192-193.

25. Main RG, Dritz SS, Tokach MD, Goodband RD, Nelssen JL. Increasing weaning age improves pig performance in a multisite production system. *J Anim Sci.* 2004;82:1499-1507.

26. Larriestra AJ, Wattanaphansak S, Neumann EJ, Bradford J, Morrison RB, Deen J. Pig characteristics associated with mortality and light exit weight for the nursery phase. *Can Vet J*. 2006;47:560-566.

27. Huting AMS, Sakkas P, Kyriazakis I. Sows in mid parity are best foster mothers for the pre- and post-weaning performance of both light and heavy piglets. *J Anim Sci*. 2019;97:1656-1670.

28. Magowan E, McCann MEE, Beattie VE, McCracken KJ, Henry W, Smyth S, Bradford R, Gordon FJ, Mayne CS. Investigation of growth rate variation between commercial pig herds. *Animal*. 2007;1:1219-1226.

29. Mallmann AL, Oliveira GDS, Rampi JZ, Betiolo FB, Fagundes DP, Faccin JEG, Andretta I, Ulguim RR, Mellagi APG, Bortolozzo FP. Proposal of equations for predicting post-farrowing sow weight. *Acta Sci Vet*. 2018;46:1574-1582.

30. Flohr JR, Dritz SS, Tokach MD, Woodworth JC, DeRouchey JM, Goodband RD. Development of equations to predict the influence of floor space on average daily gain, average daily feed intake and gain:feed ratio of finishing pigs. *Animal*. 2018;12:1022-1029.

*31. Thomas LL, Dritz SS, Goodband RD, Tokach MD, DeRouchey JM, Woodworth JC. Generating an equation to predict post-farrow maternal weight in multiple parity sows. *Kansas Agricultural Experiment Station Research Reports*. 2016;2:8.

32. Smith AL, Stalder KJ, Serenius TV, Baas TJ, Mabry JW. Effect of piglet birth weight on weights at weaning and 42 days post weaning. *J Swine Health Prod*. 2007;15:213-218.

33. Lawlor PG, Lynch PB, Caffrey PJ, O'Doherty JV. Effect of pre- and post-weaning management on subsequent pig performance to slaughter and carcass quality. *Anim Sci*. 2002;75:245-256.

34. Paredes SP, Jansman AJM, Verstegen MWA, Awati A, Buist W, den Hartog LA, van Hees HMJ, Quiniou N, Hendriks WH, Gerrits WJJ. Analysis of factors to predict piglet body weight at the end of the nursery phase. *J Anim Sci*. 2012;90:3243-3251.

35. O'Quinn PR, Dritz SS, Goodband RD, Tokach MD, Swanson JC, Nelseen JL, Musser RE. Sorting growing-finishing pigs by weight fails to improve growth performance or weight variation. *J Swine Health Prod*. 2001;9:11-16.

36. Dybkjaer L, Jacobsen AP, Tøgersen, FA, Poulsen HD. Eating and drinking activity of newly weaned piglets: effects of individual characteristics, social mixing, and addition of extra zinc to the feed. *J Anim Sci.* 2006;84:702-711.

37. Laskoski F, Faccin JEG, Vier CM, Gonçalves MAD, Orlando U, Kummer R, Mellagi APG, Bernardi ML, Wentz I, Bortolozzo FP. Effects of pigs per feeder hole and group size on feed intake onset, growth performance, and ear and tail lesions in nursery pigs with consistent space allowance. *J Swine Health Prod*. 2019;27:12-18.

* Non-refereed references.