HOUSING AND MANAGEMENT

Impact of increasing weaning age on pig performance and belly nosing prevalence in a commercial multisite production system

Jamil E. G. Faccin,[†] Fernanda Laskoski,[†] Luciana F. Hernig,[†] Rafael Kummer,[‡] Gustavo F. R. Lima,^{||} Uislei A. D. Orlando,^{\$} Márcio A. D. Gonçalves,^{\$} Ana Paula G. Mellagi,[†] Rafael R. Ulguim,[†] and Fernando P. Bortolozzo^{†,1}

[†]Departamento de Medicina Animal/Faculdade de Veterinária, Universidade Federal do Rio Grande do Sul, 91540-000 Porto Alegre, Rio Grande do Sul, Brazil, [‡]Master Agroindustrial, 89560-000 Videira, Santa Catarina, Brazil, ^{||}Agrocere PIC—Matrizes de suínos, 13502-741 Rio Claro, São Paulo, Brazil, ^{\$}PIC/Genus, 100 Bluegrass Commons Blvd, Ste. 2200, Hendersonville, TN 37075

¹Corresponding author: fpbortol@ufrgs.br

Abstract

The effects of increasing weaning age in a commercial production system on nursery and finishing performance were evaluated. A total of 1,176 pigs (PIC 337 × Camborough) were used in a 136-d growth trial with 14 and 10 replications/weaning age on the nursery and finishing phases, respectively. Treatments included weaning litters at 19, 22, 25, or 28 d of age. In the nursery, as weaning age increased, initial (5.04, 5.70, 6.52, and 7.26 kg) and final body weight (BW) (18.2, 19.8, 23.0, and 25.1 kg) increased (linear, $P < 0.001$). Increasing the weaning age reduced (linear, $P < 0.001$) the prevalence of pigs exhibiting belly nosing (27.6%, 15.0%, 6.5%, and 1.4%) during the first 3 wk. The percentage of pigs losing weight during the first week after weaning (35.1%, 28.7%, 12.4%, and 9.2%) decreased (linear, $P < 0.001$) as weaning age increased. Average daily gain (ADG; 295, 320, 374, 406 g/d) and average daily feed intake (493, 534, 619, 661 g/d) increased (linear, $P < 0.001$), while feed efficiency (G:F) (596, 599, 604, and 615) tended to increase (linear, $P = 0.081$) with weaning age. Removal rate (8.01%, 3.79%, 2.29%, and 1.65%) declined (linear, $P = 0.001$) as weaning age increased, while there was no evidence of difference ($P = 0.463$) in mortality rate (0.71%, 0.36%, 0.96%, 1.04%). In the finishing period, BW at 136 d post-weaning (114.9, 117.8, 124.7, and 126.5 kg) and ADG (1.02, 1.04, 1.08, and 1.07 kg/d) improved (linear, $P < 0.001$). There was no evidence of differences ($P > 0.24$) in removal (1.5%, 2.4%, 1.0%, and 0.0%) or mortality rates (0.9%, 1.0%, 1.0%, and 1.4%) with changes in weaning age. When performance was analyzed at a common day of life (164 d of age), no effects of weaning age ($P > 0.25$) were found for BW (125.2, 124.4, 128.0, and 126.5 kg) and lifetime ADG (growth rate from birth to market) (754, 751, 774, and 762 g/d). The BW sold per pig weaned increased (linear, $P < 0.001$) with weaning age. Even though the slope indicated a linear response, the magnitude of improvement was high until 25 d, before exhibiting diminishing returns from 25 to 28 d. Thus, the study suggests that increasing the weaning age can be an effective strategy to improve the overall performance in a commercial system. Although lifetime performance was not affected by the weaning age range studied, the consistent effect in the nursery and the increment in the number of pigs reaching the market facilitated by the improvement in the removal rate in the nursery phase imply that 25 d is the optimal weaning age.

Key words: belly nosing, growth performance, nursery piglets, swine, weaning age

Abbreviations

ADFI	average daily feed intake
ADG	average daily gain
BW	body weight
CP	crude protein
CV	coefficient of variation
ME	metabolizable energy
SID	standardized ileal digestible

Introduction

Weaning age is a topic that is constantly discussed across the global swine industry. In nature, weaning in pigs is a gradual process that occurs around 10 to 12 wk of age, coinciding with the near complete maturation of the gastrointestinal tract (Moeser et al., 2017). However, in commercial pig production, weaning is abrupt, occurring at around 2 to 4 wk of age. The stress suffered by weaned pigs in commercial conditions has been widely described in several studies, mainly concerning about the separation from the sow, vaccination, mixing, fighting, and switches in the environment, diet, local microbiota, and structure of the nursery (Pluske et al., 1997; Moeser et al., 2017; Faccin et al., 2019). In relation, the combination of these stressors accompanied by a period of declining passive immunity from sow milk (Pluske et al., 1997) contributes to a reduction in feed intake and growth performance, and an increase in susceptibility to infections (Moeser et al., 2007). The present global pig production scenario of antibiotic reduction and increased concerns about welfare accords with the need for a better understanding of the relationship between current commercial weaning ages and post-weaning resilience to stress.

Through some abnormal behaviors during the first weeks in the nursery, it is possible to ascertain the level of stress experienced by pigs after weaning (Bryant, 1972; Gonyou et al., 1998; Main et al., 2005a). Belly or flank nosing is an abnormal behavior that is mainly triggered by the deprivation of their natural habits, such as contact with the sow (Metz and Gonyou, 1990). The behavior is similar to the motor pattern used when pigs massage the sow udder and is usually observed as a response to early weaning (Fraser, 1978). The origins of such behavior have only been hypothesized, although many theories regard belly nosing as a sign of post-weaning stress (Main et al., 2005a). Moreover, pigs that express nosing behavior have been deemed to be failing to adapt to a new environment (Straw and Bartlett, 2001). Such maladaptation associated with high stress levels can lead to poor performance. Main et al. (2005a) have reported that the pig age at weaning is closely related to the prevalence of nosing behavior in the nursery, which is in turn strongly associated with a lower growth rate in the initial 42 d post-weaning. However, no previous weaning age dose-response study has assessed belly nosing behavior at older ages than those in the study conducted by Main et al.

It has been established that the growth rate, feed intake, and morbidity in the nursery phase are highly dependent on the weaning age (Smith et al., 2008). Moreover, recent studies have shown that the weaning weight and the growth rate in the first week in the nursery play an important role in the subsequent performance (Collins et al., 2017; Faccin et al., 2020). However, the question remains regarding how much weaning age influences performance in the first weeks after weaning.

More than a decade ago, a study conducted by Main et al. (2004) assessed the impact of weaning age on performance in a commercial system with a significant number of pigs evaluated throughout the nursery and finishing phases. The weaning

ages used in that work ranged from 12 to 21.5 d, very applicable to swine production at that time. Thus, there is a need for studies regarding weaning age with the current scenario of pig production. Furthermore, Main et al.'s (2004) findings exhibited linear improvements in body weight (BW), growth rate, mortality, and weight sold per pig weaned, increasing the relevance of studying a higher set of weaning ages. Furthermore, as pressure to reduce antibiotic use increases, a renewed look at weaning age appears to be necessary for production systems (Tokach and Vier, 2017). Thus, the main objectives of this study were to evaluate the effects of increasing the weaning age in a range of days practiced in current production systems on pig performance in the nursery and finishing phases. Moreover, to determine the incidence of belly nosing behavior and the percentage of pigs losing weight in the first week post-weaning as indicators of post-weaning stress.

Materials and Methods

The protocol used in this study was approved by the Ethics Committee of Animal Utilization (CEUA) of the Federal University of Rio Grande do Sul (UFRGS), under process no. 35420.

Animals, housing, and procedures

The study was conducted in a pig farm with 5,000 sows and a nursery, and in two finishing barns in the Midwestern part of Santa Catarina State, Brazil. The trial took place between September 2017 and May 2018, which corresponds to spring, summer, and early fall in the southern hemisphere. The average, minimum, and maximum temperatures in the region during this period were 20.7, 8.8, and 35.8 °C, respectively, and the average relative humidity was 82.9%.

Treatments included weaning litters of pigs at 19, 22, 25, or 28 d of age. A total of 1,176 weaned pigs (PIC 337 × Camborough, Pig Improvement Company, Hendersonville, TN) were individually weighed and placed in nursery pens. Each pen contained an equal number of intact males and females with the same weaning age. Pigs were allotted to pens in order to ensure a normal weight distribution of males and females weaned within each age group. Litters within the same weaning age were mixed at weaning. Each of the 28 pens contained 22 and 20 pigs in weaning batches one and two, respectively, resulting in 56 mixed-sex nursery pens in the trial and 14 replicates per weaning age. The nursery pens' dimensions were 1.6 × 4.0 m with a solid concrete floor along the entire length of the feeder and slatted plastic flooring in the remaining area. Stainless steel feeders each with four feeder holes 17 cm wide were used in the nursery. The pens had two nipple drinkers. The pens provided 0.29 m² of area per pig, 5.5 pigs per feeder hole, and 11 pigs per drinker in batch one, and 0.32 m² of area per pig, 5 pigs per feeder hole, and 10 pigs per drinker in batch two.

Diets were corn- and soybean-meal-based, and a three-phase feeding program was formulated according to meet National Research Council (2012) requirement estimates. All diets were manufactured at the on-farm feed mill and were fed in meal form. The feed budget was 1 kg per pig of phase 1 diet (3.6 Mcal of metabolizable energy [ME]/kg, 21.9% crude protein [CP], 17.0% lactose, 1.46% standardized ileal digestible [SID] lysine, and 180 ppm of colistin), 4 kg per pig of phase 2 diet (3.6 Mcal of ME/kg, 21.4% CP, 13.0% lactose, 1.42% SID lysine, and 180 ppm of colistin and 300 ppm of amoxicillin), followed by a phase 3 diet (3.5 Mcal of ME/kg, 20.1% CP, 1.30% SID lysine, and 5 ppm of florfenicol), with approximately 17 kg fed per pig until the end

of the nursery period (42 d post-weaning). In the finishing phase, a five-phase feeding regimen was implemented: 15 d of diet 1 (3.4 Mcal of ME/kg, 18.7% CP, 1.26% SID lysine, and 450 ppm of amoxicillin), 20 d of diet 2 (3.4 Mcal of ME/kg, 18.8% CP, and 1.24% SID lysine), 25 d of diet 3 (3.4 Mcal of ME/kg, 17.2% CP, 1.14% SID lysine, and 22 ppm of tylosin), 20 d of diet 4 (3.4 Mcal of ME/kg, 15.7% CP, 1.03% SID lysine, and 11 ppm of tylosin), and approximately 15 d of diet 5 (3.4 Mcal of ME/kg, 17.8% CP, 1.18% SID lysine, and 11 ppm of tylosin).

At the finishing sites, equal numbers of intact males and females were allotted in separate pens in the same barn. Due to the limited space capacity of both barns, 456 pigs from the first weaning batch and 368 pigs from the second were randomly selected. The barns that received weaning batches one and two had 24 pens and 19 pigs per pen, and 16 pens with 23 pigs per pen, respectively. A total of 40 finisher pens were used in the trial, resulting in 10 replicates per weaning age. The pens' dimensions were 4.0 × 4.8 m, with slatted concrete flooring. The feeder was stainless steel, each with three feeding holes 35 cm wide, and each pen had two nipple drinkers. These finishing pens provided 1.0 m² of area per pig, 6.3 pigs per feeder hole, and 9.5 pigs per drinker in batch one, and 0.8 m² of area per pig, 7.7 pigs per feeder hole, and 11.5 pigs per drinker in batch two. At 14 and 18 wk of age, the intact males were immunocastrated.

The pigs and the barn environments were managed according to production system standard operating procedures. Nursery and finishing barns were double curtain-sided. The criteria to remove a pig from the study were 1) pigs not responding to at least two antibiotic injectable treatments or 2) losing weight for two consecutive weeks. In the nursery, both criteria were implemented, while in the finishing phase just the antibiotic criterion was used.

Experimental design

The study was conducted in a randomized complete block design, with the four weaning age treatments used in two weaning batches. The second batch was weaned 60 d after the first. In total, pigs from 16 litters per weaning age within each batch were ear-tagged and ear-tattooed, and sex recorded at birth. A total of 128 litters were used in the study. Sows' parity of litters was balanced based on three parity categories (second, third to fifth, and sixth or greater) across weaning age treatments. Each batch saw the four weaning age treatments weaned on the same day and moved to the same nursery room (day 0). In addition, sows of the same batch were maintained in the same farrowing room from farrowing until weaning day.

At day 42 after weaning, intact males from every two nursery pens of the same weaning age were randomly selected and mixed. The same was done with females. The first batch comprised three pens of each sex per weaning age, whereas the second had two pens of each sex.

Measurements

To assess the prevalence of pigs presenting belly nosing, observations were made using the methodology described by Main et al. (2005a), with each pen observed from the back aisle for 15 min. Observations occurred on days 8, 15, and 22 post-weaning in a random sequence of pens. To be considered a "noser" pig, belly nosing behavior had to last at least 10 s. Overall prevalence was calculated as the mean percentage of pigs demonstrating belly nosing behavior per pen over the three observation days. A single trained person performed all observations.

Pigs were weighed weekly on a pen basis and individually on days 0, 7, and 42 post-weaning to obtain the coefficient of variation (CV) of each pen in the nursery, as well as to calculate the percentage of pigs that lost any amount of BW in the first week in the nursery. Pigs were fed ad libitum, and feed delivery was recorded on a pen basis throughout the nursery period. Average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G:F) were calculated using weight and feed disappearance.

In the finishing phase, pigs were weighed on days 40, 80, and 94 after placement and at the 164th day of life. The weight in a common day of life facilitated the recovery of the advantage afforded the older weaning ages, with extra days in the finishing phase. This meant that piglets from 25, 22, and 19 d of weaning age were also weighed on days 97, 100, and 103 after placement in the finishing phase, respectively. Feed delivery was not recorded in the finishing phase. Thus, BW, ADG, and mortality and removal rates were assessed.

Through combining the growth rate and the percentage of losses during the nursery and finishing periods, the weight sold per pig weaned was calculated. The formula was performed by multiplying the number of pigs that reached market day (164 d of age) per finisher pen by the final weight of the pen and dividing by the number of weaned pigs required to fill one finishing pen with the capacity for 19 or 23 pigs. This enabled calculation of the weight sold per pig weaned in three scenarios of marketing: fixed time, fixed age, and fixed weight. Fixed time was at 94 d after placement into the finisher; fixed age was considered when all pigs reached 164 d of age; and fixed weight was established when all pens achieved an average of 135 kg of market weight using the ADG of the period 80 to 94 d to calculate the number of days necessary to achieve such weight.

Statistical analysis

Statistical Analysis System software version 9.3 (SAS Inst. Inc., Cary, NC) was used to perform the statistical analysis. All models included weaning ages as the fixed effect. The two weaning batches were considered as blocks and were included as a random effect. Polynomial contrasts were used to evaluate the linear and quadratic effects of the dose-response (increasing weaning age).

In the nursery phase, the following variables were analyzed using the GLIMMIX procedure: BW, ADG, ADFI, G:F, CV, mortality rate, removal rate, weight sold per pig weaned, belly nosing prevalence, and the percentage of pigs that lost weight in the first week in the nursery. For CV, beta distribution was used. For mortality and removal rates, belly nosing prevalence, and percentage of pigs that lost weight in the first week of the nursery, a binomial distribution was fitted to the data. In the finishing phase, BW, ADG, CV, and mortality and removal rates were analyzed in the same way as in the nursery. All variables expressing a linear response were able to be estimated based on their rate of change (slope) observed for each day change in weaning age using PROC REG of SAS. The results were considered significant at $P \leq 0.05$, with a marginal effect at $0.05 < P \leq 0.10$. In all instances, pen was the experimental unit.

Results

Belly nosing and weight loss in the first week in the nursery

Increasing the weaning age reduced (linear, $P < 0.003$) the prevalence of pigs exhibiting belly nosing behavior at days 8, 15, and 22 post-weaning (Table 1). In addition, the mean percentage

Table 1. Influence of weaning age on belly nosing behavior prevalence at days 8, 15, and 22 post-weaning, and percentage of pigs that lost weight in the first week in the nursery¹

Item	Weaning age, d				SEM	Probability, P-value <	
	19	22	25	28		Linear	Quadratic
Belly nosing prevalence, %							
Day 8	16.0	5.8	1.7	0.3	0.09	0.001	0.667
Day 15	12.2	8.2	1.1	0.5	0.11	0.001	0.157
Day 22	6.1	3.1	2.0	0.7	0.08	0.003	0.676
Overall	27.6	15.0	6.5	1.4	0.61	0.001	0.163
Pigs that lost weight in the first week, %	35.1	28.7	12.4	9.2	0.62	0.001	0.888

¹A total of 1,176 pigs weaned at 19, 22, 25, and 28 d of age were used in a 42-d period in the nursery. Pens were allotted with 50% intact males and 50% gilts, and 14 replications per treatment were used across 56 pens.

(overall prevalence) of pigs demonstrating belly nosing behavior over the three observation periods decreased (linear, $P < 0.001$) as weaning age increased. No association ($P > 0.05$) with sex was found between weaning ages.

An effect of weaning age on the percentage of pigs that lost weight during the first week was found (Table 1). As the weaning age increased, the number of pigs that were lighter on day 7 than at weaning decreased (linear, $P < 0.001$).

Nursery performance

At weaning, the greater the weaning age, the greater (linear, $P < 0.001$) the BW (Table 2). During all weeks in the nursery, this pattern of difference was maintained, and by the end of the phase (42 d), BW increased (linear, $P < 0.001$) as weaning age increased from 19 to 28 d. A similar result was found for ADG and ADFI, whereby older pigs at weaning resulted in a greater (linear, $P < 0.001$) growth rate and feed intake. From days 0 to 14 and days 36 to 42, no evidence of differences was found in G:F between weaning ages. However, from days 15 to 35, an improvement (linear, $P < 0.043$) in G:F was found as weaning age increased. Overall (days 0 to 42), G:F tended to increase (linear, $P = 0.081$) as weaning age increased from 19 to 28 d. The CV of BW within pens was a treatment effect (quadratic, $P = 0.004$) on day 0, but no effect was found at the end of the nursery period ($P = 0.181$). The removal rate over the nursery period presented an association with weaning age that diminished (linear, $P = 0.001$) as weaning age increased, and no evidence of differences ($P = 0.463$) in mortality rate was found at the end of the nursery phase.

Growing-finishing performance

In the finishing phase (Table 3), increasing the weaning age augmented (linear, $P < 0.001$) BW at 40, 80, and 94 d after allotment. In addition, an increase (linear, $P < 0.017$) in the ADG from allotment to day 40 and from days 41 to 80 was found. However, from days 81 to 94 in the finishing phase, no evidence of differences ($P = 0.402$) was detected, and the overall ADG after 94 d of allotment was improved (linear, $P = 0.001$) by increasing the weaning age. The final (94 d) CV of BW within the pens was similar across treatments ($P = 0.959$). When pigs were compared at the same age (164 d of age), no difference was observed among the weaning ages tested for BW ($P = 0.277$) and ADG from birth to market ($P = 0.250$). There was no evidence of differences ($P > 0.242$) in the removal and mortality rates, either. Furthermore, as weaning age increased, pigs required fewer days (linear, $P = 0.001$) to achieve the fixed market weight (135 kg).

Weight sold per pig weaned

Although the three different market scenarios resulted in different final weights, the results among them were similar (Table 4). With fixed time (94 d) after placement in the finishing phase, fixed age (164 d), and fixed market weight (135 kg), despite different magnitudes the weight sold per pig weaned increased (linear, $P < 0.001$) as weaning age increased from 19 to 28 d.

Rate of change per day

The linear rates of improvement (slopes) as weaning age increased from 19 to 28 d are shown in Table 5. It is possible to apply these outcomes in the production systems in order to estimate, for example, the dynamic of improvement in weaning weight and the capacity to reduce nursery losses when age is increased in 1 d. In the current study, 1 d resulted in an increase of 250 g/d in weaning weight and a decrease of 0.6% per day of nursery losses.

Discussion

This study has demonstrated that weaning age affects important performance and behavior parameters during pigs' lives, mainly during the first weeks after weaning. The linear reduction in the prevalence of belly nosing behavior and in the number of pigs that lost weight in the first week in the nursery suggests that the welfare of pigs weaned at an older age is less significantly compromised (Worobec et al., 1999). Main et al. (2005a) found a similar effect of reduced prevalence of belly nosing as weaning age increased from 12 to 21 d. Even though the response occurred in a quadratic manner, the authors concluded that this behavior is mainly driven by weaning age. Although these results were attained with pigs weaned younger than 21 d, the current study indicates that this behavior maintains a relationship with the weaning age of pigs, even in older ranges and in a linear way. Other studies (Gonyou et al., 1998; Worobec et al., 1999) have reported congruent findings, where the percentage of pigs suckling another pig's belly increased as weaning age decreased.

In addition to influencing weaning weight, besides indicates how prepared a pig gets at weaning, belly nosing can impair nursery performance (Straw and Bartlett, 2001). Main et al. (2005a) described how pigs exhibiting such behavior, regardless of weaning age, exhibited a poorer growth rate than those not classified as "nosers" in a 42 d-period post-weaning. Although initial weight did not differ between pigs that nosed and those that did not, Straw and Bartlett (2001) concluded that the pigs that nosed were likely to become the smallest pigs after 6 wk post-weaning.

Table 2. Influence of weaning age on nursery performance¹

Item	Weaning age, d				SEM	Probability, P-value <	
	19	22	25	28		Linear	Quadratic
BW, kg							
Day 0 (weaning)	5.04	5.70	6.52	7.26	0.126	<0.001	0.717
Day 7	5.19	5.96	7.15	8.14	0.091	<0.001	0.191
Day 14	6.81	7.77	9.38	10.8	0.151	<0.001	0.144
Day 21	9.01	10.1	11.8	13.6	0.26	<0.001	0.198
Day 28	11.1	12.3	14.6	16.4	0.39	<0.001	0.432
Day 35	14.3	15.8	18.5	20.5	0.55	<0.001	0.611
Day 42	18.2	19.8	23.0	25.1	0.43	<0.001	0.516
Days 0 to 7							
ADG, g	22	38	90	124	25.6	<0.001	0.167
ADFI, g	92	105	132	156	7.4	<0.001	0.447
G:F	239	371	687	794	41.5	0.132	0.280
Days 8 to 14							
ADG, g	230	257	319	377	26.5	<0.001	0.022
ADFI, g	266	304	388	440	10.4	<0.001	0.496
G:F	865	845	822	856	20.6	0.822	0.585
Days 15 to 21							
ADG, g	301	324	348	381	58.7	<0.001	0.595
ADFI, g	491	525	612	664	21.1	<0.001	0.686
G:F	613	617	569	575	9.6	0.043	0.958
Days 22 to 28							
ADG, g	287	309	389	409	69.2	<0.001	0.957
ADFI, g	570	600	682	728	21.5	<0.001	0.716
G:F	502	516	569	562	12.6	0.009	0.367
Days 29 to 35							
ADG, g	442	491	589	619	62.7	<0.001	0.534
ADFI, g	708	761	874	919	17.4	<0.001	0.806
G:F	624	645	673	674	10.8	0.016	0.456
Days 36 to 42							
ADG, g	479	511	549	586	53.7	<0.001	0.863
ADFI, g	856	921	1,034	1,066	17.4	<0.001	0.349
G:F	560	554	530	550	3.5	0.669	0.619
Overall (days 0 to 42)							
ADG, g	295	320	374	406	7.8	<0.001	0.671
ADFI, g	493	534	619	661	9.4	<0.001	0.925
G:F, g/kg	596	599	604	615	4.5	0.081	0.773
Removals, %	8.01	3.79	2.29	1.65	0.021	0.001	0.480
Mortality, %	0.71	0.36	0.96	1.04	0.012	0.463	0.634
BW CV, %							
Day 0	20.1	20.2	19.2	21.4	0.42	0.049	0.004
Day 42	19.6	19.4	18.7	18.5	1.36	0.181	0.867

¹A total of 1,176 pigs weaned at 19, 22, 25 and 28 d of age were used in a 42-day period in the nursery. Pens were allotted with 50% intact males and 50% gilts, and 14 replication pens per weaning age were used across 56 pens.

It has been reported that the first week post-weaning is an essential phase in pigs' lives, potentially having an important impact on subsequent performance (Tokach et al., 1992; Collins et al., 2017; Faccin et al., 2020). Collins et al. (2010) reported that pigs weaned at 21 d of age had twice the feed intake and weight gain in the first 11 d post-weaning than their counterparts weaned at 13 d. Pollmann (1993) suggested that if pigs at least maintain their weaning weight during the first 7 d in the nursery, they will reach marketing weight 15 d before pigs that lose weight. Such findings reinforce the importance of minimizing the percentage of pigs that lose weight in the first week. In the present study, increasing the weaning age resulted in a linear manner in more pigs gaining weight during the first week in the nursery. Faccin et al. (2020) showed that pigs of the same age that gained weight during the first week were 2.4 kg heavier on day 42 than those that

lost weight in the first week. Moreover, pigs that lost weight were more likely to be removed in the future. Wolter and Ellis (2001) reported that the weight gain in the first 7 to 10 d after weaning increased weight at 56 d regardless of weight at weaning, emphasizing the importance of an adequate start to the nursery period. Similar to belly nosing, the growth rate in the first day in the nursery is determined by the weaning age, and both express an essential point that influences early and late performance in the nursery, which may serve as an animal welfare indicator.

The impact of weaning age in growth performance was not only more evident in the nursery but also significant during the finishing phase. Studies conducted with pigs weaned younger than 21 d presented similar response pattern, and in all of them, the performance improvement was driven by the highest weaning weight provided by older weaning ages (Fangman et al., 1996;

Table 3. Influence of weaning age on finishing performance¹

Item	Weaning age, d				SEM	Probability, P-value <	
	19	22	25	28		Linear	Quadratic
BW, kg							
Day 0	18.7	20.4	23.4	25.8	0.42	<0.001	0.516
Day 40	53.0	55.2	60.2	63.5	0.64	<0.001	0.354
Day 80	94.7	97.6	105.3	107.1	1.01	<0.001	0.582
Day 94	114.9	117.8	124.7	126.5	1.33	<0.001	0.708
Day 164 of age	125.2	124.4	128.0	126.5	1.53	0.277	0.816
ADG, g							
Days 0 to 40	801	811	857	877	14.0	0.001	0.723
Days 41 to 80	1,127	1,145	1,221	1,175	19.6	0.017	0.112
Day 81 to 94	1,444	1,441	1,383	1,385	62.0	0.402	0.968
Days 0 to 94	1,024	1,036	1,077	1,072	45.6	0.001	0.479
Birth to 164 d of age	754	751	774	762	8.9	0.250	0.620
Removals, %	1.5	2.4	1.0	0.0	0.12	0.242	0.400
Mortality, %	0.9	1.0	1.0	1.4	0.12	0.677	0.765
Days in finisher to 135 kg of market weight, d	108.7	106.8	102.2	100.9	2.34	<0.001	0.800

¹A total of 824 pigs weaned at 19, 22, 25 and 28 d of age were used from the nursery to the finishing phase. A total of 10 replication pens (5 pens per sex) per weaning age were used across 40 pens.

Table 4. Influence of weaning age on the weight sold per pig weaned¹ in three market scenarios

Item	Weaning age, d				SEM	Probability, P-value <	
	19	22	25	28		Linear	Quadratic
Weight sold/pig weaned scenario							
Fixed day, kg ²	102.8	109.0	118.0	120.6	2.73	<0.001	0.266
Fixed age, kg ³	112.1	115.1	121.1	120.6	2.84	<0.001	0.286
Fixed weight, kg ⁴	121.1	125.2	128.1	129.0	1.32	<0.001	0.137

¹Weight sold per pig weaned = (final BW * final number of pigs per pen)/Number of weaned pigs needed to fill one finishing pen.

²Fixed day: the final BW at 94 d after housing in the finishing facilities.

³Fixed age: all treatments achieving 164 d of age.

⁴Fixed weight: all treatments achieving 135 kg of market BW.

Table 5. Linear rate of change observed as weaning age increased from 19 to 28 d¹

Item	Rate of linear change per day increase in weaning age	
	Change per day	SEM
Weaning weight, kg	0.250	0.024
Day 42 post-weaning, kg	0.802	0.062
Nursery losses, %	-0.63	0.184
Off-test BW, kg ²	1.38	0.203
Weight sold per pig weaned (fixed time), kg ³	2.21	0.343
Weight sold per pig weaned (fixed age), kg ⁴	1.21	0.352
Weight sold per pig weaned (fixed weight), kg ⁵	1.07	0.291
Days in finisher to 135 kg of market weight, d	-0.9	0.25

¹Magnitude of change per day increase in weaning age in the nursery and finishing performance observed as weaning age increased from 19 to 28 d.

²BW based on a market scenario of fixed time in finishing pen.

³Fixed time: 94 d after placement in finishing.

⁴Fixed age: all treatments achieving 164 d of age.

⁵Fixed weight: all treatments achieving 135 kg of market weight.

Main et al., 2004; Smith et al., 2008). In addition, weaning weight is one of the essential traits that determines lifetime growth performance (Collins et al., 2017). In an observational study, López-Vergé et al. (2019) reported a positive effect of increasing the weaning age from 18 to 22 d in BW at weaning and from 18 to 24 d in BW at slaughter in a fixed time. However, a lack of effect on the BW of pigs weaned at 25 d or more compared with those weaned younger was identified. This may have owed to merely parity 1 sows in that study having lactations longer than 22 d which may have affected the performance of those pigs weaned older. In the present study, no parity 1 sows were used, enabling the authors to hypothesize that the amplitude of the responses may have been reduced by the use of only multiple-parity sows.

Regardless of the weaning age, pigs with the same age (164 d) reached a similar weight. The weight gain in the last period of the finishing phase, despite there being no significant effect as a result of varying the weaning age, suggests that as pigs become older and heavier, their growth curve becomes slower, whereas younger pigs' growth capacity continues to increase. When comparing pigs weaned at 9 or 19 d of age, Dritz et al. (1996) found that both weaning ages reached market weight at the same age. This indicates that the percentage of losses from weaning to market should receive greater attention than growth performance when deciding to increase the weaning age of a pig production system.

Increasing the weaning age reduced the number of days required to reach the market weight established in this study. Although pigs had similar lifetime performance and weight at the same age, the advantage of the entry weight in the finishing phase should be compensated by approximately one more day per day of reduction in weaning age. A higher number of days to reach market weight were found by [Main et al. \(2005b\)](#). Within a weaning age range from 15 to 21.5 d, pigs required 1.7 d more per day of increase in weaning age to achieve 120.2 kg. This discrepancy may be explained by the ranges used in each study. The magnitude of improvement in performance rates generated by an increase of, that is, 5 d in weaning age might be greater when it changes from 15 to 20 d than from 20 to 25 d. Another point to consider is the final weight target and the growth rate of the herd in each study. [López-Vergé et al. \(2019\)](#) observed that with an increase in weaning age from 18 to 24 d, pigs required fewer days to reach market weight. However, no reduction in days to reach the same weight was found when weaning age was equal to or higher than 25 d. One important point to note in that study was that the target BW was 105 kg and the growth rate from birth to slaughter did not exceed 600 g at any weaning age, indicating a low market weight target and poor lifetime performance in comparison with the current study, as well as in contemporary pig production rates and genetic lines.

Removal and mortality within weaning age are important factors to consider when determining the optimal weaning age for individual pork operations ([Smith et al., 2008](#)). In the current study, the removal rate in the nursery phase was highly and linearly influenced by weaning age. Although the herd used in the study was Porcine reproductive and respiratory syndrome virus and Porcine epidemic diarrhea virus negative, recurrent cases of influenza, colibacillosis, and Glässer's disease were confirmed by diagnostic testing. Even with the lower weaning ages tested, [Smith et al. \(2008\)](#) reported that when weaning at 15 d, twice as many pigs were removed than at 20 d. In the study conducted by [Main et al. \(2004\)](#), despite combining the percentage of pigs that died, that were nonambulatory, or that did not respond to medical treatment, increasing the age from 12 to 21.5 d linearly reduced the percentage of losses during the nursery period. In the same study, no difference was found in the finishing phase, in accordance with the present work, which has not found any effect of weaning age on removal and mortality rates in the same period. This pattern may suggest that the challenges collectively imposed by the aforementioned stressors and low age at weaning exhibit an important effect during the nursery phase. It is important to note that in the current study, all nursery diets contained feed-grade antibiotics, and we speculate that in antibiotic-free protocols, the magnitude of the impact caused by increasing the weaning age could be greater. After overcoming the nursery stressors, there is no effect of the weaning age on the survivability of pigs that are able to be transferred to finishing barns. However, when pigs' health status is more compromised or in multisource allotments, increasing the weaning age may still affect the finishing phase.

In comparison with studies with over 1,000 pigs, ours has presented a greater percentage of losses even with greater age. [Main et al. \(2004\)](#) and [Smith et al. \(2008\)](#) found that pigs weaned at 20 to 21 d saw 0.5% and 1.6% mortality and removal rates, respectively, whereas for pigs weaned at 22 d of age in the present study presented 4.2%. Mortality and removal in a nursery are largely a function of entry and exit weights ([Smith et al. 2008](#)); hence, these differences might be explained by the weaning weights of 6.49, 6.68, and 5.70 kg in [Main et al. \(2004\)](#),

[Smith et al. \(2008\)](#), and the current study, respectively. Other contributors are the criteria used by a researcher to decide whether or not to remove a pig. Although additional factors such as the health status of the herd should be considered when weaning age is evaluated ([Dritz et al. 1996](#)), the general trend in biological performance is expected to be similar across different systems ([Main et al. 2005b](#)). In a recent review, [Moesser et al. \(2017\)](#) demonstrated that weaning stressors alter intestinal development and functions, leading to long-lasting deleterious consequences for absorption and disease susceptibility. This raises the possibility that the effects of weaning age are linked to the duration of suckling, to different age-related physiological characteristics, or to a combination of them. Further studies with physiological measurements are required to elucidate this relationship.

The weight sold per pig weaned ratio combines growth performance and percentage of losses, rendering it a valuable rate to better understand the effect of increasing weaning age and enabling it to operate as an essential source for a possible economic analysis. In the present study, a slope of 2.2 kg of improvement by each day of increase in weaning age in a fixed time scenario was found, similar to 1.8 kg/d found by [Main et al. \(2004\)](#). This small difference may have been driven by the higher magnitude of losses in the current study. However, the weight sold per pig weaned in a fixed time manner may generate biased information, as pigs weaned older, marketed at a fixed time scenario, remain older, thus heavier. When comparisons were made using an identical age or on a fixed weight basis, the rate of change fell to 1.21 and 1.07 kg, respectively. These findings support the previous statement that the percentage of losses is the main driver guiding a commercial system to decide whether to increase the weaning age. Although all three scenarios indicated linear improvements in weight sold as weaning age increased, it is important to note that the impact in terms of kg sold per pig weaned was more evident from 19 to 25 d, whereas from 25 to 28 d a diminishing return occurred.

Conclusion

Increasing the weaning age from 19 to 28 d positively affected pig performance. In the nursery, older pigs at weaning exhibited improved performance, a higher level of adaptation to the post-weaning period, and an evident improvement in the removal rate. Based on the increased BW sold per pig weaned, this study suggests that the percentage of losses represents one of the main factors that can be used to determine by how many days a system should increase the weaning age. Finally, the consistent manner in which an increase in weaning age from 19 to 25 d improves the overall performance suggests that this strategy is a reliable means of increasing productivity in commercial production systems.

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Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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