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Relationship between weaning age and antibiotic usage on pig growth performance and mortality

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Abstract

A total of 2,184 pigs (DNA 600 × PIC L42) were used to evaluate the effects of weaning age and antibiotic (**AB**) use on pig performance from weaning to marketing in a commercial production system. Experimental treatments were arranged in a 3 × 2 factorial with main effects of weaning age (18.5, 21.5, or 24.5 d of age) and with the use of ABs or an antibiotic-free (**NAE**) program. At birth, pigs were ear tagged, and the date of birth and sex recorded. Pigs were weaned from a 4,000-sow farm over four consecutive weeks. Four weaning batches (one per week) of 546 pigs were used. Each weaning batch had one-third of pigs of each weaning age. Pigs were placed in pens by weaning age and then randomly assigned to an AB or NAE program. There were 14 replicate pens per treatment and 26 pigs per pen (13 barrows and 13 gilts). Pigs allocated to the AB program were fed a diet containing 441 mg/kg chlortetracycline (**CTC**) from day 8 to 21 postweaning. They were also administered 22 mg/kg of body weight (**BW**) of CTC via drinking water for five consecutive days after a porcine respiratory and reproductive syndrome outbreak during week 7 after weaning. In the first 42 d postweaning, increasing weaning age improved (linear, $P < 0.001$) BW at day 42, average daily gain (**ADG**), and average daily feed intake (**ADFI**). From weaning to 197 d of age, increasing weaning age increased (linear, $P < 0.001$) ADG and ADFI. Pigs on the AB program had greater ($P = 0.031$) ADG and ADFI compared with NAE pigs. An interaction (linear, $P = 0.005$) was observed for feed efficiency (**G:F**). When ABs were provided, increasing weaning age did not result in any change in G:F; however, in the NAE program, increasing weaning age increased G:F. Pigs on the AB program had lower ($P < 0.001$) total losses (mortality and removals) than those on the NAE program. Increasing weaning age marginally (linear, $P = 0.097$) decreased total losses. Increasing weaning age decreased (quadratic, $P < 0.001$) the number of pigs treated with an injectable AB but the AB program did not ($P = 0.238$). The weight sold (at 197 d of age) per pig weaned was increased (linear, $P = 0.050$) by increasing weaning age and by using AB in feed and water ($P = 0.019$). In summary, increasing weaning age linearly improved most of the pig performance criteria and relatively the short-term use of ABs reduced mortality and removals with both factors contributing to increased weight sold per pig weaned.

Key words: antibiotic use, antibiotic-free, growth, swine, weaning age

Abbreviations

AB	antibiotic
ADFI	average daily feed intake
ADG	average daily gain
BW	body weight
CP	crude protein
CTC	chlortetracycline
DDGS	dried distillers grains with soluble
G:F	gain-to-feed ratio
NAE	no antibiotics ever
NE	net energy
PED	porcine epidemic diarrhea
PRRS	porcine reproductive and respiratory syndrome
SID	standardized ileal digestibility
STTD	standardized total tract digestible

Introduction

The use of antibiotics (**AB**s) for maintaining animal health has come under scrutiny in recent years due to the rise of AB resistance globally (World Health Organization (WHO), 2016; Lekagul et al., 2019; Singer et al., 2019). The widespread use of ABs in human medicine and for growth promotion in livestock is being credited for the increase in AB resistance (Valentin et al., 2014; WHO, 2016; Dupont et al., 2017). As a result of this concern, the U.S. Food and Drug Administration (FDA) implemented a new drug regulation program in the Veterinary Feed Directive. With this change in policy, a reduction in the sales of medically important antimicrobials approved for use in food-producing animals in the United States occurred (FDA, 2017). From 2015 to 2017, the sales of those molecules decreased by 43%, and tetracyclines, which represent the largest volume of these sales (3,535,701 kg in 2017), decreased by 40% from 2016 to 2017 (FDA, 2017).

Chlortetracycline (**CTC**) is a broad-spectrum in-feed AB commonly used in the swine industry (Maxwell et al., 1994; Williams et al., 2018). It has been widely used because of its effect on improving pigs' growth performance, mainly in the nursery period (Dritz et al., 2002; Feldpausch et al., 2018). Recently, a study found evidence that, besides increasing growth rate, the inclusion of CTC in nursery diets increased the proportion of fecal *Escherichia coli* isolates resistant to tetracycline and ceftiofur (Williams et al., 2018). Some producers within the U.S. poultry and swine industries have eliminated AB use and have adopted a "no antibiotics ever" (**NAE**) approach to animal production (Feeks, 2019; MacDougald, 2019). One of the main reasons to adopt this mode of production is market-driven (Singer et al., 2019) because of a higher income paid by the pork processors (MacDougald, 2019). If pork producers are to adopt an NAE system, management factors, especially in the nursery at the time of weaning, may need to be reevaluated.

Main et al. (2004) conducted the first study that assessed the impact of weaning age on performance in a commercial system. The weaning ages tested (12 to 21.5 d of age) were very applicable to the swine industry at that time. This was because early weaning was shown to eliminate and successfully eradicate many pathogens (Fangman et al., 1996 and Harris and Alexander, 1999). The majority of the response criteria such as growth rate, mortality, and weight sold per pig weaned observed by Main et al. (2004) were improved linearly with increasing wean age. Recently, a study (Faccin et al., 2020b) in a commercial pig farm evaluated weaning ages varying from 19 to 28 d. It was suggested that increasing weaning age up to 25 d may be an effective management strategy to improve welfare and health quality, as well as performance settings after weaning. Maximizing the percentage of weaned pigs that reach marketing could be the primary driver to increase the weaning age in commercial production (Faccin et al., 2020b).

There is a lack of information regarding possible interactions between weaning age and the use of ABs (Faccin et al., 2020b). However, McLamb et al. (2013) observed that early-weaned pigs challenged with an F18 enterotoxigenic *E. coli* had a greater incidence of clinical disease such as diarrhea compared with later-weaned pigs. Hence, their data suggest a potential capacity to reduce AB usage as weaning age increases.

To our knowledge, there are limited data evaluating different weaning ages combined with or without the use of ABs in the wean-to-finish period. Although the NAE market is growing, controlled studies assessing the effects of raising pigs without ABs in commercial environments are scarce. Therefore, the objective of this study was to determine the effects of weaning age and AB use on pig performance in a commercial production system. Our hypothesis was that increasing weaning age would lessen the growth response to ABs and the need for AB intervention.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

Animals, housing, and procedures

A total of 2,184 barrows and gilts (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) were used in a study from weaning to market at 197 d of age. The study started in a 4,000-sow farm with four consecutive weaning batches, with an 8-d interval between batches. The litters used should meet the criteria of genetic line and birth date, aiming to achieve an exact age at weaning. Each batch had approximately 700 weaned pigs, and 546 of these were randomly selected to meet the number of pigs needed per treatment and for filling the capacity of the wean-to-finish barn with four batches. Pigs were transferred to an approximately 110 km commercial research wean-to-finish site in southern Minnesota. The interval between weaning batches resulted in a 24-d interval between the first and the fourth (last) allotment. The facility had propane heaters distributed in the barn and was double-curtain-sided. Room temperature at allotment started at 32.0 °C and was lowered to 2.0 °C per week until week 7. Pen dimensions were 3.0 × 5.5 m with completely slatted flooring and deep pits. Each pen was equipped with a three-hole stainless steel feeder and a pan waterer with two nipples to allow ad libitum access to feed and water. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of measuring and recording daily feed additions to individual pens.

Due to the sow farm's expansion just prior to trial onset, all pigs were weaned from parity 1 sows. At birth, pigs were ear-tagged with different colored tags to identify the exact age when weaned. To create three weaning age categories, litters were weaned at 18 and 19, 21 and 22, or 24 and 25 d of age to generate pigs weaned at 18.5, 21.5, and 24.5 d of age, respectively. Each pen contained an equal number of barrows and gilts. At allotment in the wean-to-finish facility, the individual pig age, weight, and gender information was used to allot pigs to pens to replicate the normal weight distribution of barrows and gilts weaned within each age group. Pens of pigs were then weighed and randomly assigned to an AB or NAE program. Thus, the experimental design consisted of a 3 × 2 factorial with the four weaning batches as a blocking factor. There were 14 replicates per treatment with 26 pigs per pen.

Pigs were fed conventional corn–soybean meal-based diets (Tables 1 and 2) with varying amounts of dried distillers grains with solubles throughout the trial, and diets were provided in meal form.

Regardless of the weaning age, all pigs were fed the diets for the same length of time to comply with the requirement to feed CTC for not more than 14 d. Pens of pigs were weighed, and feed disappearance was recorded weekly until 42 d after weaning and every 14 d after that to determine average daily gain (**ADG**), average daily feed intake (**ADFI**), and feed efficiency (**G:F**). On day 177, four pigs per pen were marketed as per standard farm protocol. Then on day 197, the remaining pigs in the pens were marketed.

Table 1. Nursery diet composition (as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3
Ingredients, %			
Corn	35.32	55.20	50.67
Whey powder	25.00	—	—
Soybean meal, 46.5% CP[2]	19.14	24.85	30.00
DDGS[2]	10.00	15.00	15.00
Soybean oil	2.50	—	—
Enzymatically treated soybean meal[3]	4.00	—	—
Calcium carbonate, 38% Ca	0.85	1.05	1.15
Monocalcium P, 21% P	0.60	1.00	1.00
Salt	0.30	0.65	0.50
L-Lysine-HCl	0.58	0.63	0.50
DL-Methionine	0.27	0.20	0.17
L-Threonine	0.21	0.23	0.18
L-Tryptophan	0.07	0.07	0.04
L-Valine	0.17	0.12	0.04
Phytase[4]	0.04	0.20	0.20
Mineral–vitamin premix[5]	0.55	0.55	0.55
Zinc oxide	0.40	0.25	—
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	1.39	1.30	1.32
Isoleucine:lysine	55	54	60
Leucine:lysine	114	126	132
Methionine:lysine	38	38	37
Methionine + cysteine:lysine	59	60	60
Threonine:lysine	63	64	64
Tryptophan:lysine	20.6	20.2	19.3
Valine:lysine	70	70	69
SID lysine:net energy, g/Mcal	5.23	5.21	5.32
Net energy, kcal/kg	2,658	2,492	2,487
Ca, %	0.72	0.70	0.75
STTD P[6], %	0.56	0.52	0.53

[1]Phases 1, 2, and 3 were fed from 5 to 6, 6 to 10, and 10 to 20, respectively. The phase 2 diet was the only diet that included 441 mg/kg of CTC for pigs on the AB treatment.
[2]CP, crude protein; DDGS, dried distillers grains with solubles.
[3]HP 300 (Hamlet Protein Inc., Findlay, OH).
[4]In phase 1, provided 5,000 phytase units FTU per gram of phytase. In phases 2 and 3, provided 1,350 phytase units FTU per gram of phytase.
[5]Provided per kilogram of premix: 35.3 g Zn, 35.3 g Fe, 3.7 g Cu, 220.5 mg I, 8.8 g Mn, 100.3 mg Se, 16,534 mg niacin, 8,818 mg pantothenic acid, 2,645 mg riboflavin, 66.1 mg biotin, 661.4 mg folic acid, 440.9 mg pyridoxin, 1,653 mg thiamin, 1,873,910 IU vitamin A, 551,150 IU vitamin D, 20,039 IU vitamin E, 992 mg vitamin K, and 11 mg vitamin B12.
[6]Standardized total tract digestible P.

Pigs assigned to the AB program had access to a diet containing 441 mg/kg CTC from day 8 to 21 after weaning. Also, after a porcine respiratory and reproductive syndrome (**PRRS**) outbreak at week 7 postweaning, pigs assigned to the AB program were medicated via drinking water for five consecutive days with CTC (22 mg/kg body weight [**BW**] per day). At least one pig per weaning age per batch was affected, thus it was considered that all pigs on test were affected. Feed samples were collected from feeders and analyzed to confirm that the CTC was indeed in the diet. The water system allowed medicating specific pens. Thus, it was possible to give access to medicated water after the PRRS outbreak just to pigs assigned to the AB program. Injectable ABs were given as needed regardless of dietary treatment, with all treatments individually recorded. Two caretakers were responsible for injectable treatments following the farm protocols without knowing which pen belonged to each AB treatment. Pigs in the NAE program that were treated with injectable ABs remained in the same pen, as pigs from this study were not marketed as NAE. Pigs identified as nonambulatory or not responding to medical treatment were removed from the trial (removals). Mortality was considered pigs with acute death. The sum of removals and mortalities was recorded as total losses.

The health status of the sow farm was considered good, as it was *Mycoplasma hyopneumoniae*, porcine epidemic diarrhea virus, and porcine respiratory and reproductive syndrome virus (PRRSv) negative. The PRRS outbreak that occurred was considered a lateral introduction as the sow farm remained PRRSV negative. The pigs were all housed in the same building, so when pigs from the second, third, and fourth weaning batch were allotted, pigs from the previous batches were already in place in the wean-to-finish facility.

Statistical analysis

Data were analyzed using generalized linear mixed models where weaning age, AB program, and their interactions were the fixed effects, with the random effect of the batch of weaning. Statistical models were fitted using the GLIMMIX procedure of SAS (v. 9.4, SAS Institute, Inc. Cary, NC). Preplanned linear and quadratic contrast statements were used to evaluate the effects of increasing weaning age as well as linear and quadratic interactions with AB program.

The BW, ADG, ADFI, G:F, and weight sold per pig weaned were evaluated, assuming a normal distribution of the response variable. The weight sold per pig weaned was calculated by multiplying the sum of pigs that reached 177 and 197 d of age by the final BW at 197 d of age and dividing by the number of weaned pigs (26) initially placed in one pen. Losses and treated pigs were fit using a binomial distribution. Pens were designated as the experimental unit in all analyses.

The PROC REG procedure of SAS was used to estimate the rate of change (slope) in wean-to-finish performance observed for each day change in weaning age.

Because pigs were weaned in four batches over 24 d and placed in the same room, an analysis of the effect of the batch order was performed. Preplanned linear and quadratic contrast statements were used. As the interval between each batch was 8 d, the fixed effect of the batch was considered as dose–response of days after the first allotment (0, 8, 16,

Table 2. Grow-finish diet composition (as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Ingredients, %						
Corn	48.33	54.45	59.93	61.29	65.34	84.73
Soybean meal, 46.5% CP[2]	18.60	12.65	7.40	6.25	7.35	13.04
DDGS[2]	30.00	30.00	30.00	30.00	25.00	—
Calcium carbonate	1.20	1.15	1.10	1.10	1.05	0.80
Monocalcium P, 21% P	0.15	0.10	—	—	—	0.15
Salt	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine-HCl	0.58	0.58	0.55	0.45	0.40	0.34
DL-Methionine	0.06	0.03	—	—	—	0.03
L-Threonine	0.12	0.11	0.09	0.06	0.06	0.13
L-Tryptophan	0.04	0.05	0.05	0.04	0.04	0.03
Phytase[3]	0.17	0.17	0.17	0.17	0.17	0.17
Mineral–vitamin premix[4]	0.20	0.20	0.20	0.15	0.10	0.10
Copper sulfate	0.03	0.03	0.03	—	—	—
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.16	1.02	0.88	0.77	0.74	0.76
Isoleucine:lysine	60	59	58	64	65	57
Leucine:lysine	154	162	176	197	195	147
Methionine:lysine	33	32	31	35	34	30
Methionine + cysteine:lysine	58	58	59	66	66	57
Threonine:lysine	62	62	62	65	66	67
Tryptophan:lysine	18.2	19.1	18.4	19.6	19.7	19.3
Valine:lysine	70	71	73	80	81	67
SID lysine:net energy, g/Mcal	4.66	4.07	3.49	3.06	2.93	2.90
Net energy, kcal/kg	2,489	2,504	2,517	2,521	2,536	2,605
Ca, %	0.60	0.55	0.50	0.49	0.47	0.40
STTD P[5], %	0.40	0.37	0.34	0.33	0.32	0.26

[1]Phases 1, 2, 3, 4, 5, and 6 were fed from 20 to 30, 30 to 45, 45 to 60, 60 to 85, 85 to 100, and 100 to 135 kg, respectively.
[2]CP, crude protein; DDGS, dried distillers grains with solubles.
[3]Provided 627 phytase units FTU per gram of phytase.
[4]Provided per kilogram of premix: 30.9 g Zn, 30.9 g Fe, 3.1 g Cu, 160.3 mg I, 3.3 g Mn, 120.2 mg Se, 14,991 mg niacin, 6,613 mg pantothenic acid, 1,984 mg riboflavin, 1,543,220 IU vitamin A, 440,920 IU vitamin D, 8,046 IU vitamin E, 881,8 mg vitamin K, and 7.9 mg vitamin B12.
[5]Standardized total tract digestible P.

and 24 d). The GLIMMIX procedure of SAS was used, and if batch order and weaning age presented interaction, it was explored. Weaning weight was used as a covariate when tested statistically different.

All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

Results

Nursery phase

No interactions were observed between weaning age and AB use for the main response variables in the nursery ($P > 0.10$). Increasing weaning age increased (linear, $P < 0.001$) ADG and ADFI resulting in an increase (linear, $P < 0.001$) in BW on day 42 (Table 3). However, increasing weaning age had no effect on G:F or on the percentage of total losses (mortalities and fall behind pigs removed from pens for welfare concerns). The percentage of pigs treated with injectable ABs in the first 42 d was reduced (quadratic, $P = 0.004$) as weaning age increased.

From weaning to 42 d, there were no differences ($P > 0.283$) in ADG or day 42 BW as a result of providing a feed-grade AB from day 8 to 21. Pigs on the AB program had greater ADFI ($P = 0.004$), thus G:F decreased ($P = 0.003$). Providing CTC in the feed did not influence the percentage of pigs requiring injectable ABs ($P = 0.626$) or total losses ($P = 0.170$).

Finishing period

From 43 d after weaning to 197 d of age (Table 4), the ADG was improved by increasing weaning age (linear, $P < 0.001$) and providing CTC in feed and water ($P = 0.020$). Interactions were found for ADFI (linear, $P = 0.045$), G:F (linear, $P = 0.005$), and for percentage of losses (quadratic, $P = 0.021$). The ADFI magnitude of improvement was higher when pigs had access to CTC combined with increasing weaning age compared with those without access to ABs. Oppositely, increasing the weaning age of pigs fed without ABs resulted in higher G:F but no effect for those with access to CTC via feed and water. The use of CTC in feed and via water reduced the percentage of losses; however, pigs weaned at 21.5 d had this effect more markedly than those weaned at 18.5 or 24.5 d. The percentage of pigs treated in the finishing period was not affected by increasing weaning age or providing ABs.

Overall period

In the overall period (from weaning to 197 d of age, Table 5), increasing weaning age improved (linear, $P < 0.001$) ADG, ADFI, and BW. Increasing weaning age resulted in a marginal

Table 3. Effects of weaning age and AB program on pig performance (day 0 to 42 post weaning)[1]

	Weaning age, d											
	18.5		21.5		24.5							
	Diet						Probability, *P*-value<					
Item	NAE	AB	NAE	AB	NAE	AB	SEM	AB	Linear age	Quadratic age	Linear age × AB	Quadratic age × AB
BW, kg												
Weaning	4.77	4.82	5.45	5.45	6.18	6.18	0.09	0.972	<0.001	0.650	0.886	0.888
Day 42	17.2	17.3	19.8	20.0	22.7	22.9	0.59	0.419	<0.001	0.976	0.793	0.942
Day 0 to 42 postweaning												
ADG, g	291	295	341	345	391	400	13.6	0.283	<0.001	0.968	0.912	0.656
ADFI, g	414	427	477	495	555	573	18.2	0.004	<0.001	0.473	0.748	0.644
G:F, g/kg	704	694	719	694	709	699	5.00	0.003	0.204	0.194	0.974	0.166
Treated, %[2]	24.1	24.7	23.1	21.2	10.0	9.1	3.70	0.626	<0.001	0.004	0.662	0.770
Losses, %[3]	1.9	2.5	1.1	1.6	1.1	1.1	1.00	0.170	0.161	0.916	0.509	0.420

[1]A total of 2,184 pigs (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) were used with 14 pens per treatment and 26 pigs (13 barrows and 13 gilts) per pen. AB program included 441 mg/kg CTC from day 8 to 21 or NAE.
[2]Percentage of pigs treated with injectable ABs.
[3]Sum of mortality and removed pigs (pigs identified as nonambulatory, not responding to medical treatment).

Table 4. Effects of weaning age and AB program on pig performance (day 43 postweaning to 197 d of age)[1]

	Weaning age, d											
	18.5		21.5		24.5							
	Diet						Probability, *P*-value<					
Item	NAE	AB	NAE	AB	NAE	AB	SEM	AB	Linear age	Quadratic age	Linear age × AB	Quadratic age × AB
BW, kg												
Day 42	17.2	17.3	19.8	20.0	22.7	22.9	0.59	0.419	<0.001	0.976	0.793	0.942
197 d of age	130.6	131.0	132.6	133.4	133.1	135.5	1.57	0.182	<0.001	0.537	0.357	0.737
Day 43 postweaning to 197 d of age												
ADG, g	927	936	959	973	986	1,009	10.0	0.020	<0.001	0.671	0.402	0.989
ADFI, g	2,223	2,205	2,259	2,309	2,295	2,377	26.8	0.058	<0.001	0.381	0.045	0.603
G:F, g/kg	418	426	424	422	429	424	10.5	0.903	0.001	0.324	0.005	0.209
Treated, %[2]	8.6	9.5	9.2	4.3	7.8	6.3	2.60	0.235	0.512	0.412	0.595	0.189
Losses, %[3]	6.9	4.9	7.7	3.5	6.8	4.8	1.08	<0.001	0.935	0.845	0.951	0.021

[1]A total of 2,184 pigs (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) were used with 14 pens per treatment and 26 pigs (13 barrows and 13 gilts) per pen. AB program included 441 mg/kg CTC from day 8 to 21 and 22 mg/kg of BW per day at week 7 postweaning via drinking water for five consecutive days or NAE.
[2]Percentage of pigs treated with injectable ABs.
[3]Sum of mortality and removed pigs (pigs identified as nonambulatory, not responding to medical treatment).

Table 5. Effects of weaning age and AB program on performance in the overall period (weaning to marketing)[1]

	Weaning age, d												
	18.5		21.5		24.5								
	Diet							Probability, P-value<					
Item	NAE	AB	NAE	AB	NAE	AB	SEM	AB	Linear age	Quadratic age	Linear age × AB	Quadratic age × AB
BW, kg												
Weaning	4.77	4.82	5.45	5.45	6.18	6.18	0.086	0.972	<0.001	0.650	0.886	0.888
197 d of age	130.6	131.0	132.6	133.4	133.1	135.5	1.57	0.182	<0.001	0.537	0.357	0.737
Birth to 197 d of age												
ADG, g	659	659	668	673	668	682	9.1	0.170	0.001	0.547	0.333	0.819
Wean to 197 d of age												
ADG, g	695	705	718	732	736	755	7.3	0.009	<0.001	0.467	0.510	0.945
ADFI, g	1,668	1,664	1,691	1,736	1,709	1,773	20.5	0.031	<0.001	0.320	0.079	0.580
G:F, g/kg	417	424	426	422	429	424	15.0	0.903	<0.001	0.324	0.005	0.209
Treated[2], %	34.4	35.4	33.1	27.0	18.0	16.1	4.42	0.238	<0.001	<0.001	0.514	0.272
Losses[3], %	8.8	7.6	8.8	5.4	7.9	5.9	1.18	<0.001	0.097	0.725	0.508	0.080
Weight sold/pig weaned[4], kg	118.5	120.9	119.9	126.1	122.0	127.2	2.86	0.019	0.050	0.481	0.535	0.540

[1]A total of 2,184 pigs (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) were used with 14 pens per treatment and 26 pigs (13 barrows and 13 gilts) per pen. The AB program included 441 mg/kg CTC from day 8 to 21 and 22 mg/kg of BW per day at week 7 postweaning via drinking water for five consecutive days (AB) or NAE.
[2]Percentage of pigs treated with injectable ABs.
[3]Sum of mortality and removed pigs (pigs identified as nonambulatory, not responding to medical treatment).
[4]Weight sold per pig weaned = (final BW * final number of pigs per pen)/number of weaned pigs needed to fill one finishing pen.

decrease of the overall losses (linear, $P = 0.097$). A decrease in the percentage of pigs treated with an injectable AB (quadratic, $P < 0.001$) was observed as weaning age increased. The weight sold (at 197 d of age) per pig weaned was increased by increasing weaning age (linear, $P = 0.050$).

The use of AB in the feed and water improved ADG ($P = 0.009$) and ADFI ($P = 0.031$). An interaction (linear, $P = 0.005$) was observed for G:F. When ABs were provided, increasing weaning age did not result in any change in G:F; however, in the NAE program, increasing weaning age linearly improved G:F. In addition, from weaning to 197 d of age, pigs with access to AB in feed and water had lower total losses ($P < 0.001$). The AB use did not influence the percentage of pigs treated with an injectable AB ($P = 0.238$). The weight sold (at 197 d of age) per pig weaned was increased by using AB in feed and water ($P = 0.019$).

Regression analysis of the response from increasing weaning age indicated that for every day of increasing weaning age (Table 6), weaning weight increased by 220 g ($P < 0.001$), and day 42 BW increased by 928 g/d ($P < 0.001$). The BW at 197 d of age was increased by 675 g for each day of change in weaning age ($P < 0.001$). The ADG and the ADFI from weaning to marketing increased ($P < 0.001$) by 11 and 14 g per day, respectively, for each day of increase in weaning age. The weight sold per pig weaned had a slope of 705 g/d as weaning age increased from 18.5 to 24.5 d ($P = 0.05$).

Table 6. Linear rate of change observed as wean age increased from 18.5 to 24.5 d of age from weaning to marketing[1]

Item	Rate of change per day	SEM
Weaning weight, kg	0.220	0.021
Day 42 postweaning, kg	0.928	0.069
BW at 197 d of age, kg	0.675	0.112
Weaning to 197 d of age ADG, kg	0.011	0.001
Weaning to 197 d of age ADFI, kg	0.014	0.001
Weight sold per pig weaned (197 d of age), kg[2]	0.705	0.212

[1]Magnitude of change per day increase in weaning age in the wean-to-finish performance observed as weaning age increased from 18.5 to 24.5 d.
[2]Weight sold per pig weaned = (final BW * final number of pigs per pen)/number of weaned pigs needed to fill one finishing pen.

Batch order of allotment

The influence of the batch order of allotment was assessed comparing each one of the four weaning batches within each weaning age (Table 7). No interactions between treatment, weaning age, and batch order were observed ($P > 0.10$). Final BW (linear, $P = 0.031$), G:F (linear, $P = 0.018$), the kilograms produced per pig weaned (linear, $P = 0.005$), and the overall ADG were reduced (quadratic, $P = 0.019$) as the batch order increased. The ADFI increased until the third batch and decreased in the fourth batch (quadratic, $P = 0.038$). The percentage of losses from weaning to marketing increased (linear, $P = 0.013$) by increasing the batch order of allotment. An interaction (linear, $P < 0.001$) was observed for the percentage of pigs requiring injectable AB treatment between batch allotment order and weaning age (Table 8). Pigs weaned at 18.5 had the highest percentage of pigs being treated in all batches with a similar percentage ($P = 0.251$) treated in all batches. However, an increase (linear, $P < 0.001$) in the percentage of pigs requiring injectable ABs was seen for pigs weaned at 21.5 d and a tendency (linear, $P = 0.096$) for an increase for pigs weaned at 24.5 d as the batch allotment order increased.

Discussion

The main hypothesis of the study was that weaning age and AB use could result in some interaction, such as greater benefits of AB in pigs weaned at younger ages. However, this was not confirmed, and both factors contributed without interacting on maximizing performance and the weight sold per pig weaned.

The use of CTC in nursery diets is a common practice in the United States (Apley et al., 2012; Agga et al., 2014). Even with recent studies showing high levels of resistance to some bacteria to this AB, improvements in growth performance in pigs provided CTC are still observed (Williams et al., 2018). In the current experiment, the low level of removals and mortality from weaning to 42 d postweaning is indicative of relatively good health status and could be the reason for small benefits in the performance of pigs fed CTC. The results from our study partially agree with the results of Feldpausch et al. (2018) and Williams et al. (2018) who observed that the addition of CTC in nursery pig diets can influence growth performance. Feldpausch et al. (2018) reported a tendency of improvements in ADG and ADFI when fed CTC per 22 nonconsecutive days. Williams et al. (2018) observed higher ADG, ADFI, and heavier pigs when fed CTC per 42 nonconsecutive days. Although the current study detected only greater feed intake, it is important to mention that the length of CTC feeding period of the present study was lower

Table 7. Wean-to-finish performance of the four weaning batches[1]

	Batch allotment order					Probability, P-value<	
Item	First	Second	Third	Fourth	SEM	Linear	Quadratic
Final BW, kg	133.7	131.1	134.9	130.0	0.75	0.031	0.109
ADG, g	719	725	727	711	4.8	0.288	0.019
ADFI, g	1,690	1,697	1,738	1,686	14.1	0.669	0.038
G:F, g/kg	425	428	419	422	9.0	0.018	0.695
Losses[2], %	6.4	6.2	8.1	10.3	1.30	0.013	0.367
Weight sold/pig weaned[3], kg	124.6	122.6	123.7	116.6	1.73	0.005	0.145

[1]A total of 2,184 pigs (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) weaned at three different ages allotted in a wean-to-finish facility following a sequence of four batches of 546 pigs each. There were 26 pigs per pen (50% barrows and 50% gilts) and 28 replications per age. Each batch was placed in the facility with an interval of 8 d.
[2]Sum of mortalities and removed pigs.
[3]Weight sold per pig weaned = (final BW * final number of pigs per pen)/number of weaned pigs needed to fill one finishing pen.

Table 8. Percentage of pigs requiring AB injectable treatment per batch within each weaning age from weaning to marketing[1]

	Batch allotment order					Probability, P-value<	
Item, %	First	Second	Third	Fourth	SEM	Linear	Quadratic
18.5 d	34.1	30.2	36.3	38.5	3.57	0.251	0.398
21.5 d	14.3	26.4	37.9	39.6	3.63	<0.001	0.057
24.5 d	16.5	12.6	19.2	23.6	3.15	0.096	0.609

[1]A total of 2,184 pigs (DNA 600, Columbus, NE × PIC L42, Hendersonville, TN) weaned at three different ages allotted in a wean-to-finish facility following a sequence of four batches of 546 pigs each. There were 26 pigs per pen (50% barrows and 50% gilts) and 28 replications per age. Each batch was placed in the facility with an interval of 8 d.

(14 d). Thus, the duration of CTC on feed may be an essential factor in the magnitude of the nursery performance response.

The use of CTC in both feed and water showed improvements in growth rate and feed intake from weaning to 197 d of age. The absence of an effect on growth rate during the nursery period, but an overall effect, might also be explained by the PRRS outbreak during the finishing period. Positive results of the use of broad-spectrum ABs, such as CTC, during the occurrence of a PRRS outbreak have been observed. In fattening pigs, the use of CTC has been shown to reduce lung lesions (Del Pozo Sacristán et al., 2012) and to improve reproductive performance in PRRS-positive sow farms (Alexopoulos et al., 2003). However, the improvements found when using CTC may be a consequence of not solely the antimicrobial effect against secondary infections but also the growth promoter effect of this molecule (Dritz et al., 2002).

Even though the caregivers were blind to treatments, NAE pigs were treated with injectable ABs at the same levels of pigs receiving AB after the challenge triggered by the PRRS outbreak. This might have contributed to higher losses of NAE pigs from day 43 postweaning to 197 d of age. The negative effect of the health challenge affected NAE pigs to a greater extent, resulting in greater losses. Similarly, in PRRS-positive herds, Dee et al. (2018) reported the negative impact that an AB-free protocol has over performance and mortalities. In the present study, clinical signs and macroscopic lesions in the necropsied pigs suggested infection by PRRSV, which were then confirmed by laboratory exams and diagnostic testing.

The interaction found for G:F from wean-to-marketing confirms the hypothesis that the use of ABs could present a bigger benefit to pigs weaned younger. However, we cannot speculate any explanation since this was the only variable presenting an interaction between AB and weaning age in the whole trial. As previously reported in other studies (Main et al., 2004; Smith et al., 2008; Faccin et al., 2020b), increasing weaning age changes important response criteria from weaning to marketing and these changes are greatest during the nursery period. Greater feed intake and growth rate suggest better postweaning adaptation. Such benefits in growth performance could be due to a shorter onset of postweaning feed intake (Laskoski et al., 2019), lower percentage of pigs presenting belly nosing behavior (Main et al., 2005; Faccin et al., 2020b), and greater weaning weight and ADG during the first week following weaning (Collins et al., 2017; Faccin et al., 2020a). Faccin et al. (2020b) also observed that increasing weaning age decreased the percentage of pigs that lost weight in the first week in the nursery. All these factors may be explained by better development of the immune system, enteric nerves, and gastrointestinal barrier when pigs are weaned at older ages (Moeser et al., 2017; Pohl et al., 2017). Weaning age influenced the growth performance, percentage of losses, and pigs treated during the nursery period, whereas the use of CTC in the phase 2 diet did not. This fact highlights the importance of weaning age in influencing postweaning performance.

In the NAE markets, pigs that receive injectable ABs lose the “AB-free” status. In the present study, most of the pigs that received an injectable AB treatment received it during the first 42 d. A total of 9.6% of pigs weaned at 24.5 d required AB administration, which was less than half of the pigs weaned at 18.5 and 21.5 d (24.5% and 22.2%, respectively). Unfortunately, other weaning age studies did not report this variable. However, these results reinforce the hypothesis that older weaning ages confer higher levels of physiologic maturation for pigs to withstand postweaning health challenges (Moeser et al., 2017).

From the weaning-to-marketing perspective, increasing weaning age followed the same response pattern as the nursery period for a lifetime and wean-to-finish growth rate, feed intake, and BW at marketing. Faccin et al. (2020b) examined the relationship between weaning age and lifetime performance but did not observe any effects due to weaning age. We speculate that the linear effect on losses during the nursery period found by Faccin et al. (2020b) may have caused an inadvertent selection of faster-growing pigs and, thus, could have increased the average BW of the remaining pigs in pens with younger weaning ages. In the present study, the rate of losses during the growing-finishing period was also higher than the percentages found by Faccin et al. (2020b). The different health conditions could help to explain the differences in lifetime performance responses between the studies. The severity of PRRS infection is age-dependent (Klinge et al., 2009), and, thus, pigs weaned younger may have been more affected. Other factors between these two studies, such as different genetic lines, parities of the sows used, and feed-grade AB protocol, may have contributed to distinct results.

Expressing weight sold on a per-pig-weaned basis allows wean-to-finish performance and percentage of losses to be quantified in a manner that directly relates to the value of the weaned pig (Main et al., 2004). Main et al. (2004) and Faccin et al. (2020b) found that the magnitude of difference in BW at marketing per pig weaned was increased by a reduction in removals and/or losses as weaning age increases. This fact highlights the strong impact of increasing weaning age in commercial pig production and how AB use, in this case mainly after a disease challenge, can improve productivity parameters.

The batch allotment order plays an important role in the health status of the herd when multiple groups are needed to fill a barn. In the current study, with 8 d intervals between each allotment, pigs from the last weaning batch were housed with pigs that were already 24 d after placement. On the other hand, the first batch was allotted into an empty barn. The efficacy and the quality of the barn cleanliness and disinfection at the reception of the pigs are strongly associated with postweaning health disorders (Madec et al., 1998). This fact allows us to infer that, in the present study, the higher the batch allotment order, the worst the hygiene of the barn at pig’s reception. Thus, health and performance variables were impaired. Younger pigs have a less effective adaptive immune response, and animals’ age strongly influences the outcome of infection (Klinge et al., 2009). Because pigs in the first batch are older than pigs in subsequent batches, regardless of weaning age, their older age when any health challenge occurred also may have explained their improved performance outcomes.

More pigs received injectable ABs as the batch order increased; however, the interaction found between weaning age and batch order shows an interesting result. The 18.5 d pigs in all batches had a high percentage of injection, and pigs weaned at 24.5 d from all batches presented a low rate with a small increase in injections as batch order increased. In contrast, even though 21.5 d pigs from the first batch had similar injection levels as 24.5 d pigs, as batch allotment order increased, pigs weaned at 21.5 d required an increasing number of injections. It could be hypothesized that the early weaning imposed more significant physiologic challenges to 18.5 d pigs regardless of health conditions, and pigs weaned at 24.5 d were old enough to overcome most of the health issues. In the conditions of the present study, the 21.5 d age may represent a threshold where only under a poorer health scenario (increasing batch order), pigs required increased intervention with injectable ABs.

In conclusion, although the use of feed-grade ABs did not significantly affect growth performance in the nursery, the use of CTC during the disease challenge contributed to relevant improvements in the overall period. Increasing weaning age from 18.5 to 24.5 d positively affected pig performance. The magnitude of responses generated by increasing weaning age in the present study, such as weight sold per pig weaned and pigs requiring injectable ABs, recommends an increase in age at weaning. The comparisons among weaning age studies and the performance of pigs from different batches highlight the relationship between weaning age and health status of the herd.

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Conflict of interest statement

The authors declare no conflict of interest.

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