Peer reviewed **ORIGINAL RESEARCH**

Assessment of hemoglobin concentration in sows and their offspring over consecutive reproductive cycles

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Summary

Objective: Evaluate hemoglobin concentration (HbC) in sows and their offspring over consecutive parities.

Materials and methods: Twenty-three females were monitored for HbC during parities 1, 2, and 3 at 7 timepoints (30 [± 2], 60 [± 2], 90 [± 2], and 112 days of gestation, 2 and 16 [± 1] days of lactation, and 5 [± 1] days post weaning). Piglet HbC was measured within 18 hours after birth and at 16 (± 1) days of age. Pigs were classified as anemic (HbC < 10 g/dL) or nonanemic (HbC ≥ 10 g/dL) at each timepoint.

Results: On gestation day 90, 71.1% of sows were anemic across parities. In parity 1, HbC was less on lactation day 16 than all gestational timepoints ($P < .001$). In parity 2, HbC on lactation days 2 and 16 was less than all gestational timepoints ($P < .001$). In parity 3, HbC on lactation days 2 and 16 was less than gestation days 30 and 60 ($P = .015$). Piglet anemia prevalence at 1 day of age was 55.8%, 36.3%, and 46.1% for parity 1, 2, and 3, respectively ($X^2 < .001$). Piglet anemia prevalence at 16 days of age was 35.6%, 18.7%, and 15.9% for parity 1, 2, and 3, respectively ($X^2 < .001$).

Implications: Decreasing sow HbC over the reproductive cycle and lack of post-weaning recovery in parity 3 indicates iron declines with advancing parity and may impact long-term health. Piglet anemia prevalence declined with advancing parity, suggesting a need to reevaluate piglet iron supplementation in litters from younger females.

Keywords: swine, anemia, hemoglobin, sow

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Resumen - Evaluación de la concentración de hemoglobina en cerdas y sus lechones durante ciclos reproductivos consecutivos

Objetivo: Evaluar la concentración de hemoglobina (HbC) en cerdas y sus lechones en partos consecutivos.

Materiales y métodos: Veintitrés hembras fueron monitoreadas para la HbC durante los partos 1, 2 y, 3 en 7 ocasiones (30 [± 2], 60 [± 2], 90 [± 2], y 112 días de gestación, 2 y 16 [± 1] días de lactancia, y 5 [± 1] días después del destete). La HbC de los lechones se midió dentro de las 18 horas posteriores al nacimiento y a los 16 (± 1) días de edad. Los cerdos se clasificaron como anémicos (HbC < 10 g/dL) o no anémicos (HbC ≥ 10 g/dL) en cada punto de muestreo.

Resultados: En el día 90 de gestación, el 71.1% de las cerdas presentaban anemia en todas las paridades. En el parto 1, la HbC fue menor el día 16 de lactancia comparada con todos los puntos de muestreo durante la gestación ($P < .001$). En la paridad 2, la HbC en los días 2 y 16 de lactancia fue menor que en todos los momentos de muestreo durante la gestación ($P < .001$). En la paridad 3, la HbC en los días de lactancia 2 y 16 fue menor que en los días 30 y 60 de gestación ($P = .015$). La prevalencia de anemia de lechones al día 1 de edad fue de 55.8%, 36.3%, y 46.1% para las paridades 1, 2, y 3, respectivamente ($X^2 < .001$). La prevalencia de anemia de los lechones a los 16 días de edad fue de 35.6%, 18.7%, y 15.9% para el parto 1, 2, y 3, respectivamente ($X^2 < .001$).

Implicaciones: La disminución de la HbC en las cerdas a lo largo del ciclo reproductivo, y la falta de recuperación post-destete en el parto 3 indica que el hierro disminuye con el aumento de paridad y puede afectar la salud a largo plazo. La prevalencia de la anemia de los lechones disminuyó con el aumento en paridad, lo que sugiere la necesidad de reevaluar la suplementación

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Résumé - Évaluation de la concentration d'hémoglobine chez les truies et leur progéniture au cours de cycles de reproduction consécutifs

Objectif: Évaluer la concentration d'hémoglobine (HbC) chez les truies et leur progéniture au cours de parités consécutives.

Matériel et méthodes: Vingt-trois femelles ont été surveillées pour l'HbC pendant les parités 1, 2, et 3 à 7 moments (30 [± 2], 60 [± 2], 90 [± 2], et 112 jours de gestation, 2 et 16 [± 1] jours de lactation, et 5 [± 1] jours après le sevrage). L'HbC des porcelets a été mesurée dans les 18 heures suivant la naissance et à 16 (± 1) jours d'âge. Les porcelets ont été classés comme anémiques (HbC < 10 g/dL) ou non anémiques (HbC ≥ 10 g/dL) à chaque moment.

Résultats: Au jour 90 de la gestation, 71.1 % des truies étaient anémiques toutes parités confondues. À la parité 1, l'HbC était inférieure au jour 16 de la lactation qu'à tous les points de gestation ($P < .001$). À la parité 2, l'HbC aux jours 2 et 16 de la lactation était inférieure à tous les points de gestation ($P < .001$). À la parité 3, l'HbC aux jours 2 et 16 de la lactation était inférieure à celle aux jours 30 et 60 de la gestation ($P = .015$). La prévalence de l'anémie des porcelets à 1 jour d'âge était de 55.8%, 36.3%, et 46.1% pour les parités 1, 2, et 3, respectivement ($X^2 < .001$). La prévalence de l'anémie des porcelets à 16 jours d'âge était de 35.6%, 18.7%, et 15.9% pour les parités 1, 2, et 3, respectivement ($X^2 < .001$).

Implications: La diminution de l'HbC des truies au cours du cycle de reproduction et l'absence de récupération après le sevrage à la parité 3 indiquent une diminution du fer à mesure que la parité progresse et peuvent avoir un impact sur la santé à long terme. La prévalence de l'anémie des porcelets a diminué avec l'avancement de la parité, ce qui suggère la nécessité de réévaluer la supplémentation en fer des porcelets dans les portées de femelles plus jeunes.

Trace mineral nutrition has received considerably less attention than other areas (ie, amino acids and energy) of pig nutrition, and most studies to establish trace mineral requirements were conducted prior to 1980.[1] Additionally, trace mineral requirements are based on a per kg of feed basis and do not take into account the body weight of the animal, its production level (including metrics such as total piglets born), changing metabolic needs during gestation and lactation, or parity. Industry levels of iron inclusion within mineral premixes into sow diets are several times higher than the published recommendations. In a recent survey of vitamin and trace mineral levels in US swine diets, average dietary iron content (mg/kg) was 1.37-fold higher than NRC requirement estimates[1] with the 25th and 75th percentile at 1.2- and 1.48-fold higher, respectively.[1,2] The authors suggest the increased inclusion of trace minerals may be attributed, in part, to an evolving understanding that the nutritional demands of modern hyperprolific sows may differ from current recommendations. However, despite the common fortification of iron in sow diets that are above recommended levels, deficiencies may still emerge due to escalating iron demands associated with increased litter size resulting from prolific breeding.

Recent data suggests that approximately 50% of sows exhibit low hemoglobin (Hb) concentration (HbC), with a greater prevalence of anemia observed in older parity sows and during lactation[3]; however, this data is based on single point of time assessment across individuals rather than serial observations in the same females. Mahan and Newton[4] reported that with advancing parity and greater levels of productivity, sows had a greater degree of depletion of micro-mineral status. Further the relationship of sow Hb status with parity and the impact on piglet Hb with parity is not well established. This prompts the question whether the greater prevalence of anemia in older parity sows also results in a decline in iron status of the offspring and whether the decline can be attributed to an escalation in the sow's iron requirements and a subsequent deficiency over time.

In response to these observations and the expected increase in reproductive capacity of sows, our study employed a longitudinal approach to track blood HbC, an indicator of anemia, across consecutive reproductive cycles in female pigs. We assessed sow HbC at 4 gestational, 2 lactational, and 1 post-weaning timepoints. This study aimed to address the current knowledge gap concerning the timeline of anemia onset in sows. Additionally, we explored the impact of parity and sow HbC on the Hb status and anemia prevalence of suckling piglets.

Animal care and use

All procedures used in this study were approved by the South Dakota State University (SDSU) Institutional Animal Care and Use Committee (IACUC No. 2209-051) and adhered to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (4th edition, 2020). Animals used in this experiment were raised and managed in the sow barn at SDSU Swine Education and Research Facility, located in Brookings, South Dakota. This study was conducted between September 2022 and October 2023.

Materials and methods

Animals, experimental design, and feeding

A total of 23 female pigs (PIC Camborough 42) with a mean (SD) age of 250 (21) days at first breeding were monitored across reproductive parities 1 to 3. The mean (SD) wean-to-estrus interval among the sows across parities was 5 (1) days. Blood HbC measurements were conducted at seven timepoints (30 [± 2], 60 [± 2], 90 [± 2], and 112 days of gestation, 2 and 16 [± 1] days of lactation, and 5 [± 1] days post weaning). Females were housed in gestation stalls from breeding until pregnancy confirmation at 28 to 30 days after breeding, after which they were moved to group housing. Around day 110 of gestation, females were relocated to farrowing crates until weaning. The study spanned 3 complete reproductive cycles, with 12 females monitored in parities 1, 2, and 3; 7 females monitored in parities 1 and 2; and 4 females monitored in parities 2 and 3.

Diets were formulated to meet or exceed NRC nutrient requirement estimates for pregnant and lactating gilts[1] based on an expected litter size of 14 piglets (Table 1). Females were provided the standard SDSU gestation diet to maintain body condition score 2.5 to 3 in each parity. Electronic sow feeders (Gestal 3G, Jyga Technologies Inc) were used to provide daily feed allotment in gestation group housing. Daily feed allotment in lactation followed a step-up program according to the standard SDSU feed curve using an electronic feeding system (Gestal Solo, Jyga Technologies Inc) starting with a target of 2.7 kg on day 1 post farrowing and to achieve *ad libitum* intake

Table 1: Composition of gestation and lactation diets (as-fed basis)

Item	Gestation	Lactation
Ingredient, %		
Ground corn	81.33	66.19
Soybean meal	14.62	29.85
Calcium carbonate	1.36	1.22
Monocalcium phosphate, 21%	1.84	1.76
Salt	0.50	0.50
Swine trace mineral premix*	0.15	0.15
Swine sow vitamin premix†	0.05	0.05
Swine toxin binder‡	0.15	0.15
Larvicide§	0.13	0.13
Calculated composition		
Dry matter, %	89.5	89.6
Metabolizable energy, kcal/kg	3403.4	3269.2
Crude protein, %	13.5	19.4
Calcium, %	0.91	0.89
Phosphorus-total, %	0.75	0.76
Phosphorus-dig, %	0.41	0.42
Standardized ileal digestibility of amino acid, %		
Lysine	0.55	0.97
Threonine	0.42	0.62
Methionine	0.21	0.28
Tryptophan	0.12	0.20
Isoleucine	0.47	0.72
Valine	0.56	0.80
Arginine	0.73	1.17
Histidine	0.33	0.47
Leucine	1.2	1.55
Phenylalanine	0.59	0.85
Analyzed composition		
Crude protein, %	14.90	18.53
Crude fat, %	3.11	1.94
Crude fiber, %	3.19	2.44
Ash, %	5.52	4.60
Iron, mean (SD), ppm¶	283.8 (28.8)	318.4 (29.8)

* Minimum provided the following per kg of diet: Copper 20 mg, Iodine 0.36 mg, Iron (ferrous sulfate) 165 mg, Manganese 40 mg, Selenium 0.3 mg, Zinc 170 mg (J & R Distributing Inc).

† Minimum supplied the following per kg of diets: Calcium 55 mg, Vitamin A 11,000 IU, Vitamin D3 1650 IU, Vitamin E 55 IU; Vitamin B12 0.044 mg, Menadione 4.4 mg, Biotin 0.165 mg, Folic Acid 1.1 mg, Niacin 55 mg, d-Pantothenic Acid 60.5 mg, Vitamin B16 3.3 mg, Riboflavin 9.9 mg, Thiamin 3.3 mg (J & R Distributing Inc).

‡ Algonite; blend of dried yeast cells, diatomaceous earth, and algae (Olmix NA Inc).

§ Minimum supplied the following per kg of diets: Active Ingredient: Tetrachlorovinphos 75.9 mg (Elanco US Inc).

¶ Analyzed iron represents the mean of five subsamples within a given diet.

within 5 days after parturition. Daily iron intake was determined based on daily feed intake and dietary iron content. Dietary iron content was based on the mean (SD) of 5 analyzed samples collected across the 3 gestation periods (283.8 [28.8] ppm of iron) and 5 analyzed samples across the 3 lactation periods (318.4 [29.8] ppm of iron).

Reproductive performance and body weight

Throughout each reproductive cycle, females were weighed on days 2 (± 1) and 109 (± 1) of gestation and on days 2 and 19 (± 3) of lactation. After completion of farrowing, comprehensive reproductive performance data for sows were recorded including litter size and number of mummified and stillborn piglets. Stillborn piglets were recorded based upon visual assessment (ie, no visible signs of crushing, lying near the rear of the sow or crate). Piglets born alive were weighed within 18 hours after birth and at weaning. Weaning (mean [SD]) occurred on days 18.1 (2.4), 18.5 (1.5), and 19.6 (1.8) of lactation for parity 1, 2, and 3, respectively.

Blood HbC

Blood samples were collected from an ear vein of sows and piglets by pricking with a 20-gauge, 2.5-cm needle and collecting a blood droplet into disposable microcuvettes via capillary action. Microcuvettes were analyzed using the HemoCue Hb 201+ device (HemoCue America) with the resulting HbC displayed and recorded within 60 seconds. The HemoCue is a suitable indicator of blood HbC and was determined to be within 1% of laboratory analysis of HbC when comparing blood collected at the same anatomical location (ie, arterial vein),[5] and within 4% when comparing laboratory analysis of blood collected at a different anatomical location (ie, ear vein vs jugular).[6] A total of 364 samples (52 samples per timepoint) were collected from sows over the duration of this experiment (n = 19, 17, and 16 at each timepoint in parity 1, 2, and 3, respectively). All piglets born alive for each respective parity (n = 294 for parity 1; n = 262 for parity 2; and n = 234 for parity 3) were monitored for HbC by collecting blood samples as previously described within 18 hours after birth, post colostrum intake, to allow for potential dehydration correction. Piglets received a 200 mg dose of iron (Gleptoferron, CEVA Animal Health) administered intramuscularly at 3 (1) days of age. Blood HbC was assessed in all piglets at 16 (1) days of age (n = 261 for parity 1; n = 219 for parity 2; and n = 201 for parity 3) to maintain consistency with the day of age each piglet was tested regardless of their actual weaning age.

Statistical analysis

To ensure the validity of our statistical approach, we performed checks for the assumptions of analysis of variance, including homogeneity of variances and normal distribution. Blood HbC of sows and piglets across time within each parity was analyzed as repeated measures analysis of variance using the GLIMMIX procedures of SAS 9.4 (SAS Institute Inc) where day was the repeated measure. The Proc Mixed procedure of SAS was used to compare blood HbC of sows and piglets across parity at a given timepoint and to compare sow body weight and reproductive performance across parity. Differences between parity were tested using Tukey's honest significant difference test. Sows and piglets were categorized as anemic using an HbC threshold of < 10 g/dL[1,7] and the percentage of anemic and nonanemic animals in those categories within each parity was compared using a Chi-square test. Given the decline in HbC over time and parity, the interaction between parity and reproductive day on sow HbC was evaluated using a multiple regression model and the slope-ratio analysis.[8] The statistical model used in the analysis is expressed as: $y = a + b_s x_s + e$ where y is the response criterion (sow HbC at a given timepoint); a is intercept; b_s is the slope; x_s is day (independent variable); and e is random error. An individual sow served as the experimental unit. An alpha ≤ .05 was considered significant and an alpha of .06 to .10 was considered a tendency.

Results

Reproductive performance

At breeding, females had less body weight in parity 1 than parity 2 and 3 ($P < .001$; Table 2). On day 109 of gestation, sows were heavier in parity 3 than in parity 1 ($P = .02$), with parity 2 being intermediate. Sow body weight on day 2 of lactation did not differ between parities; however, on day 19, sows were heavier in parity 3 than in parity 1 and parity 2 ($P < .001$). Sows in parity 3 had greater ($P = .007$) total piglets born than in parity 1 and 2; however, piglets born alive did not differ between parities (Table 2). Stillborn rates in parity 3 were greater ($P < .001$) than in both parity 1 and 2. In the first two parities, percentage of stillborn piglets was 4% for both anemic and nonanemic sows. In parity 3, the percentage of stillborn piglets was 11% among anemic sows compared to 7% among nonanemic sows. Individual birth weights of piglets born alive were greater in parity 2 ($P < .001$) followed by parity 3, with parity 1 born alive birth weights being the lowest. Piglet wean weights did not differ between parities. Piglet age at weaning tended to be greater ($P = .061$) in parity 3 than in parity 1 and 2. The total number of piglets weaned was greater in parity 3 ($P = .031$) than in parity 1, with parity 2 being intermediate.

Sow feed and iron intake

Daily sow feed intake during gestation did not differ by parity (Table 2). However, daily feed intake varied during lactation, with parity 3 sows having greater ($P = .002$) daily feed intake than both parity 1 and 2 sows. There was no difference in estimated daily iron intake between parities in gestation, however in lactation, parity 3 sows consumed greater ($P < .001$) iron than in parity 1 and 2.

Sow HbC within and across parity

In parity 1, HbC was less ($P = .015$) on day 16 than on day 2 of lactation, and day 16 was less than all gestational timepoints ($P < .001$). Parity 1 sows had greater HbC on day 5 post weaning than on day 16 of lactation ($P = .012$). In parity 2, both day 2 and 16 of lactation had less HbC than all gestational timepoints ($P < .001$), with greater HbC observed on day 5 postweaning than on day 16 of lactation ($P < .001$). In parity 3, sows had less HbC on days 2 and 16 of lactation than on days 30 and 60 of gestation ($P = .015$). No differences were observed between days 90 and 112 of gestation, days 2 and 16 of lactation, and day 5 post weaning in parity 3.

Comparing across parities, HbC was greater ($P = .04$) in parity 1 and 2 than in parity 3 on day 30 of gestation (Table 3). On day 60 of gestation, HbC was less ($P = .03$) in parity 2 and 3 than in parity 1. There was no difference in sow HbC on days 90 and 112 of gestation across parities.

On day 2 of lactation, parity 1 had greater ($P < .001$) HbC than both parity 2 and 3. On day 16 of lactation, mean HbC fell below the threshold considered anemic irrespective of parity, and parity 1 was greater (P = .05) than parity 2 and 3. At day 5 post weaning, sow HbC did not differ between parity 1 and 2, however, parity 3 was less (P < .001) than both parity 1 and 2.

Sow anemia prevalence by parity

During gestation, the prevalence of anemia peaked at day 112 for parity 1, 2, and 3, reaching rates of 26.3%, 29.4%, and 37.5%, respectively (X^2 < .001). The prevalence of anemia on day 2 of lactation for parity 1, 2, and 3 was 20%, 94.1%, and 87.5%, respectively (X^2 < .001). On day 16 of lactation, the prevalence of anemia for parity 1, 2, and 3 was 57.9% and 82.3%, 75.0%, respectively (X^2 < .001). The cumulative prevalence of anemia across all timepoints was 24.0% for parity 1, 37.0% for parity 2, and 47.3% for parity 3 (X^2 < .001).

Changes in sow HbC over time

Slope ratio analysis revealed a negative linear effect (P < .001) within each parity (Figure 1), indicating a decline in HbC over time where parity 2 slope tended (P = 0.105) to be greater than the slope of both parity 1 and 3.

Parity 1:
$$\text{sow HbC} = 12.4 + (-0.016 \times d),\quad R^2 = 0.17$$
Parity 2:
$$\text{sow HbC} = 12.2 + (-0.023 \times d),\quad R^2 = 0.37$$
Parity 3:
$$\text{sow HbC} = 11.3 + (-0.015 \times d),\quad R^2 = 0.37$$

Piglet HbC within and across parity

In parity 1, piglets had greater (P = .01) HbC at 16 days of age than at 1 day of age. In parity 2, there was no difference in piglet HbC between 16 and 1 days of age. In parity 3, piglets tended to have greater (P = .07) HbC at 16 than at 1 days of age. Piglet HbC was greater (P = .04) at 1 day of age in parity 3 than at 1 day of age in parity 1 only (Table 3). Additionally, HbC at 16 days of age was greater (P = .001) in parity 3 than at 16 days of age in parity 1.

Piglet anemia prevalence by parity

The prevalence of piglet anemia at 1 day of age was 55.8%, 36.3%, and 46.1%, for parity 1, 2 and 3, respectively (X^2 < .001; Table 4). The prevalence of piglet anemia at 16 days of age was 35.6%, 18.7%, and 15.9% for parity 1, 2 and 3, respectively (X^2 < .001).

Discussion

By exploring the relationship between sow HbC, reproductive stage, parity, and piglet outcomes, we gain a deeper understanding of these interrelationships

Table 2: Sow body weight, reproductive performance, feed intake, and iron intake over 3 consecutive reproductive cycles

Variable	Parity 1	Parity 2	Parity 3	SEM	P*
Total females, No.	19	17	16		
Sow body weight, kg					
Gestation d 0	161.9[a]	201.5[b]	214.4[b]	4.1	< .001
Gestation d 110	229.6[a]	238.9[ab]	245.1[b]	3.8	. 02
Lactation d 2	216.3	225.3	225.1	3.6	.12
Weaning*	201.7[a]	215.1[a]	233.8[b]	4.5	< .001
Total born, No.	16.6[a]	16.8[a]	17.5[b]	0.5	. 02
Born alive, No.	15.7	16.0	15.7	0.64	.94
Stillborn rate†, %	4.0[a]	4.0[a]	8.0[b]	0.3	< .001
Piglet birth weight, kg	1.42[a]	1.68[b]	1.58[c]	0.02	< .001
Piglet wean weight‡, kg	5.6	5.6	5.9	0.2	.49
Piglet wean age, d	17.9[x]	18.3[x]	19.6[y]	0.5	.06
Total weaned, No.	14.5[a]	14.7[ab]	15.2[b]	0.4	.03
Gestation feed intake, kg/d	2.18	2.20	2.20	0.01	.47
Gestation iron intake§, mg/d	619.1	624.6	624.1	0.09	.50
Lactation feed intake, kg/d	5.3[a]	5.5[a]	6.9[b]	1.20	.002
Lactation iron intake§, mg/d	1698.9[a]	1755.8[a]	2226.9[b]	0.1	< .001

* Weaning (mean [SD]) occurred on day 18.1 (2.4), 18.5 (1.5), and 19.6 (1.8) of lactation for parity 1, 2, and 3, respectively.

† The stillborn rate is expressed as a percentage of stillborn piglets relative to the total number of piglets born.

‡ Wean weights adjusted for lactation day as a covariate.

§ Calculated as individual feed intake × analyzed diet iron content. Analyzed iron represents the mean of five subsamples within a given phase.

a,b,c Different superscripts within the same row indicate differences at P < .05.

x,y Different superscripts within the same row indicate tendences at P > .06 to P < .10.

Table 3: Blood concentration of hemoglobin (g/dL) in sows and piglets in 3 consecutive reproductive cycles

Reproductive cycle	Parity			SEM	*P*
	1	2	3		
Females, No.	19	17	16	NA	NA
Gestation					
d 30	11.8^{aD}	11.3^{aD}	10.6^{bD}	0.28	.004
d 60	11.9^{aD}	10.9^{bD}	10.5^{bD}	0.29	.01
d 90	10.7^{DE}	10.4^{D}	10.2^{DE}	0.26	.57
d 112	11.0^{DE}	10.3^{D}	10.1^{DE}	0.34	.16
Lactation					
d 2	11.3^{aDE}	8.7^{bF}	9.0^{bE}	0.29	< .001
d 16*	9.8^{cV}	9.0^{yF}	9.1^{yE}	0.26	.08
Post wean†					
d 5	11.5^{aD}	11.5^{aD}	9.8^{bDE}	0.27	< .001
P	< .001	< .001	< .001	NA	NA
SEM	0.26	0.28	0.28	NA	NA
Piglets, No.	261	219	201	NA	NA
d 1	9.5^{aD}	9.8^{ab}	10.2^{bV}	0.26	.05
d 16	10.2^{aE}	10.2^{ab}	10.8^{bW}	0.29	.001
P	0.01	.94	.07	NA	NA
SEM	0.16	0.35	0.18	NA	NA

* Blood hemoglobin determined on 16 days of age for each piglet.

† Blood hemoglobin determined at 4 to 6 days after weaning.

a,b,c,x,y Superscripts a, b, and c represent $P < .05$ and x and y represent $P < .10$ across parity within day (within row).

D,E,F,V,W Superscripts D, E, and F represent $P < .05$ and V and W represent $P < .10$ across day within a specific parity (within the same column).

NA = not applicable.

in reproduction. Our findings highlight variations in both sow and piglet HbC and the prevalence of anemia, underscoring the influence of reproductive stage and consecutive reproductive cycles. This insight not only contributes to our understanding of sow and piglet health but also draws attention to potential heightened demands for iron that prolific sows and their piglets may encounter.

Sow anemia rates peaked on day 90 of gestation, with a high prevalence persisting during lactation for all parities, aligning with earlier research finding low HbC in sows during late gestation and lactation compared to earlier timepoints (ie, mid gestation).[9] Similar to humans, some degree of anemia may be expected in sows during critical reproductive phases such as late gestation and lactation. Physiologically, significant changes occur in blood serum volume and packed red blood cell volume in gestating and lactating sows.[10] An early study demonstrated a 25% increase in serum volume as a percentage of body weight and a 22% decrease in packed red blood cell volume during late gestation compared to early gestation, with a 9% continued decrease in serum volume during lactation.[11] The changes observed in serum and red blood cell volume are driven by natural processes as sows in late gestation prioritize the allocation of more nutrients to their developing fetuses and mammary glands for colostrum production, which is derived from circulating plasma.[12]

While a decline in HbC during a sow's reproductive cycle could be interpreted as a dilution effect of the overall Hb molecules due to decreased red blood cells and increased serum, often referred to as physiological anemia, the ramifications of this dilution effect have not been extensively evaluated in the sow. Considering the sow spends most of her life either gestating or lactating, the implications of her enduring a continual dilution of Hb remain uncertain. Additionally, the increased prevalence of anemia with advancing parity is challenging to justify solely by this potential dilution effect. While there is an increase in sow body weight as sows increase in parity, and there is likely a corresponding increase in blood volume, potentially exacerbating the dilution effect caused by pregnancy-related changes, it is important to distinguish this alteration from iron deficiency anemia.

The occurrence of anemia near farrowing may be attributed to increased iron requirements associated with enhanced fetal iron storage and the nutritional needs of newborn piglets.[13] The rise in sow anemia prevalence with greater parity is consistent with previous studies

Figure 1: Slope-ratio comparison of sow HbC values across gestation and lactation time points based on sow parity. Parity 1: sow HbC = 12.4 + (-0.016 × d), R^2 = 0.17; Parity 2: sow HbC = 12.2 + (-0.023 × d), R^2 = 0.37; Parity 3: sow HbC = 11.3 + (-0.015 × d), R^2 = 0.37.

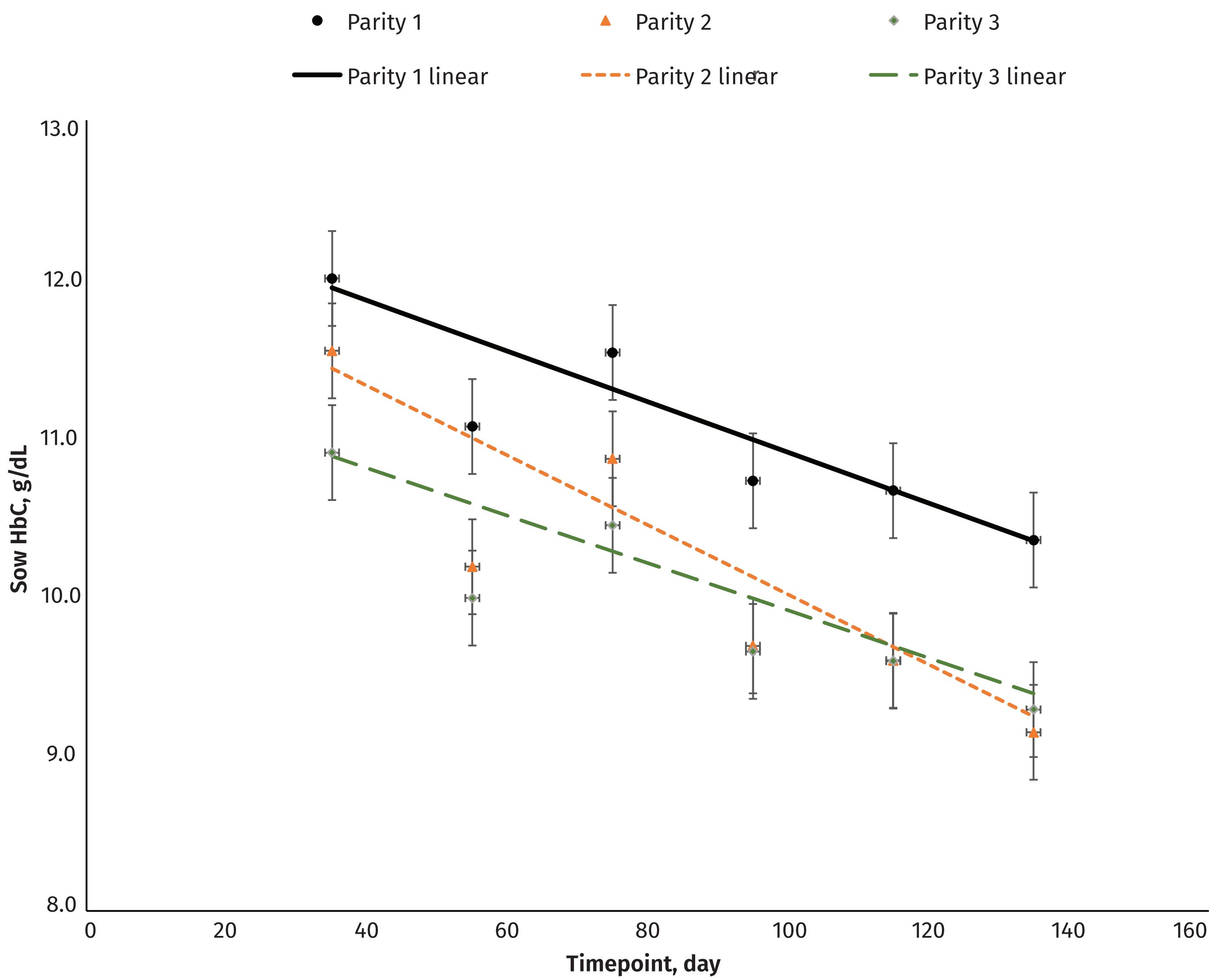

Table 4: Percent of piglets in blood hemoglobin concentration categories for each parity

	Piglet day of age					
	1			16*		
Parity	No.	HbC ≥ 10 g/dL, %	HbC < 10 g/dL, %	No.	HbC ≥ 10 g/dL, %	HbC < 10 g/dL, %
1	294	44.2	55.8	261	64.4	35.6
2	262	63.7	36.4	219	81.3	18.7
3	234	53.8	46.2	201	84.1	15.9

* Weaning occurred between 15 and 22 days of age.

that reported that sows of advanced parity have a greater prevalence of anemia.[3,14] This suggests that the decline in HbC during late gestation and lactation, potentially due to heightened iron demands, may pose challenges for sows in replenishing their iron stores after each lactation. It is speculated that the lack of recovery in HbC as sows advance in parity could be attributed to blood loss during farrowing where excessive bleeding and the loss of red blood cells exceeds the production of new red blood cells.[15] Research on blood loss during farrowing and its consequences is limited. Hemorrhaging, which is bleeding from damaged blood vessels, is a common occurrence in humans during labor often leading to exacerbated blood loss.[16] Excessive blood loss in humans can be attributed to various other factors such as prolonged, abnormal, or rapid labor, vaginal or cervical tears, or retained placental tissue.[17] The diffused nature of the sow's placenta, known as epitheliochorial placentation,[18] may potentially increase the risk of blood loss, although extensive investigation into this aspect in sows is necessary to draw definitive conclusions. Excessive blood loss in sows however may lead to difficulty in replenishing blood Hb and the potential increased iron demands post farrowing could further contribute to a decline in sow HbC over time, potentially increasing the prevalence of anemia as the sow's parity advances. If the sow enters farrowing relatively low in HbC already, experiencing blood loss could potentially worsen the degree of anemia.

Despite dietary iron at 3-fold greater than requirement estimates, iron absorbed from the diet may fall short of meeting the escalating demands across consecutive pregnancies. However, attempts to increase maternal iron supplies through oral supplementation have not shown a significant effect on hematologic variables, as indicated by previous studies.[19-21] Providing the sow with additional dietary iron (inorganic or organic sources) may not necessarily improve HbC or eliminate anemia which may suggest that the cause of low HbC is related to iron metabolism rather than dietary iron supply.

Moreover, intramuscular injection of iron to sows during gestation did not result in changes to hematologic variables in sows.[22,23] This complexity may be attributed to the intricate nature of dietary iron absorption. Additionally, the size of the sow may present challenges in providing adequate injectable iron. For piglets, the standard injectable iron dosage of 200 mg was established based on piglet iron status (circulating and stored iron) at birth and daily body weight gain.[24,25] When considering the dose of 200 mg administered to a 1.5 kg piglet near birth, the piglet receives over 130 times its body weight in iron. Applying this ratio to a 200 kg sow would result in over 26,000 mg of iron injection for a single sow. It is plausible that the sow may require a supplementation of greater injectable iron dosage in addition to dietary iron than what has been evaluated in previous research. Tailoring sow iron dosages to sow weight and daily iron needs during lactation and other critical phases, such as late gestation when iron demand is high, may be necessary. However, determining the appropriate iron dosage for the sow presents practical and economic challenges.

It is crucial to also consider the potential influence of other dietary components and the overall nutritional status of the sows. The effectiveness of iron absorption can be influenced by certain dietary factors, such as other minerals or compounds that may enhance or inhibit iron uptake. A more comprehensive evaluation of sow iron status involving measurements such as serum ferritin, serum iron, transferrin saturation, total iron-binding capacity, soluble transferrin receptor, as well as other red blood cell indices may need to be considered. This approach may offer a detailed understanding of sow iron status and absorption and help to develop strategies to address declining HbC in older parity sows. However, it must be noted that the practical implication of declining sow HbC with parity is not known. Further, the diets in this study did not include phytase. Phytases are known to enhance the release of phosphate and other minerals, including iron, from phytates,[26] potentially increasing iron absorption from cereal meals by up to 42%.[27] Considering the potential influence of phytase on iron absorption in sow diets, its inclusion could potentially enhance iron absorption, thus impacting sow HbC and overall iron status.

A potential limitation in this study is the timing of assessing piglets' initial HbC status. Colostrum intake is expected to cause a drastic increase in plasma volume during the first 12 hours of nursing without significant change to red blood cell volume.[28] This effect results in physiological anemia, similar to what was previously discussed regarding sow blood volume expansion in gestation. However, testing HbC prior to colostrum intake carries the risk to testing dehydrated piglets possibly causing HbC to appear falsely elevated due to a concentration effect. Additionally, the negative effects of HbC blood dilution due to increased plasma volume are not fully understood, particularly in conjunction with limited iron stores of approximately 50 mg mostly in the form of Hb in piglets at birth.[24]

The relationship of sow HbC to piglet HbC, which also varied across parities, indicated potential maternal influences. In contrast to sow HbC patterns, piglet HbC increased with sow parity, leading to a decrease in anemia prevalence. This observation aligns with prior research where younger parity sows were associated with a greater percentage of anemic piglets at weaning.[29] It can be speculated that there is a potential enhancement in iron transfer from sows to fetuses in utero with greater parity.[30] This speculation may contribute to understanding why sows exhibited a greater prevalence of anemia with advancing parity, suggesting a potential link to an increased iron supply to their offspring and thereby a decreased sow iron status.

Despite the reduced prevalence of anemia in piglets with increasing sow parity, the occurrence of piglet anemia near weaning raises concerns about the effectiveness of current industry standard practices for iron supplementation. Our findings correspond with previous studies suggesting an inadequacy of a standard iron injection (200 mg of Fe) administered shortly after birth to sustain optimal iron levels throughout the lactation period.[31-33] However, Chevalier et al[34] examined the effects of a second iron injection administered to suckling piglets before weaning across seven experimental stations. While additional iron injections showed some positive effects on growth and hematological measures in piglets, the response varied among different stations indicating the influence of various factors beyond iron supplementation alone. Based on the findings of this current study, sow parity could be a contributing factor causing varied response of iron supplementation in piglets. To better understand the optimal timing and dosage of iron supplementation in piglets, tailored investigations into iron dosages specific to sow parity are warranted. Addressing potential variations in iron requirements among piglets from different parity sows could optimize iron supplementation strategies and promote overall piglet health outcomes.

A potential negative consequence of the decline in sow HbC with parity may be an impact on stillborn rates. While a definitive relationship between sow HbC and stillborn piglets could not be made in this study due to limitations in sample size and the multifactorial nature of stillborn incidence,[35] low sow HbC in late gestation may have led to inadequate oxygen supply to fetuses, compromising fetal viability and resulting in elevated stillborn incidence in parity 3 sows vs parity 1 or 2. This observation aligns with findings from prior studies where the stillborn rate was greater in sows with less HbC (< 10 g/dL).[36,37] This may suggest that maternal anemia could potentially have a greater impact on fetal outcomes in later parities. However, further research is needed to elucidate the specific factors contributing to this parity-related variation in the impact of maternal anemia on fetal outcome. Additionally, while the threshold of anemia for sows is often defined as HbC < 10 g/dL, the impact of declining HbC as sows age and advance in parity requires further assessment and the current anemia threshold may need to be reevaluated based on other potential implications of anemia in older sows.

Implications

Under the conditions of this study:

- Sow HbC declines over the reproductive cycle and recovery declines with parity.
- Anemia in sows may contribute to stillborn incidence.
- Piglets from younger parity sows have greater anemia prevalence.

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Conflict of interest

None reported.

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