

Effect of feeding levels with high micronutrients on the reproductive performance and plasma progesterone concentration in early gestation sows

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Abstract

This experiment investigated the effect of feeding levels with high micronutrients on the reproductive performance and plasma progesterone concentration in early gestation sows. Thirty-six first-parity sows (Landrace × Yorkshire × Duroc), with an initial average body weight of 160.85 kg, were randomly allocated to four dietary treatments during early gestation: Treatment 1) fed 1.5 kg/day (days 1-30), Treatment 2) fed 1.5 kg/day with 1.7 times the vitamins and minerals (total vitamin E 150 IU) (days 1-15) and fed 1.5 kg/day (days 16-30), Treatment 3) fed 1.5 kg/day with 1.7 times the vitamins and minerals (total vitamin E 150 IU) (days 1-30), and Treatment 4) fed 2.5 kg/day (days 1-30), with nine replicates per treatment. At day 30 of gestation, sows in Treatment 4 had the highest body weight, body condition score, and backfat thickness ($P < 0.01$). Treatment 4 had the highest litter size, but no difference between Treatments 2 and 3 ($P > 0.05$). Treatments 2 and 3 had a high litter size but lower stillborn and mummified piglets, which led to a higher number of weaned piglets than Treatments 1 and 4 ($P < 0.05$). Treatment 3 had the highest plasma progesterone concentration at 10 and 30 days of gestation ($P > 0.05$). In conclusion, low feed intake with 1.7 times the vitamins and minerals levels (treatments 2 and 3) in the early gestation stage increases litter size, similar to high feed intake that contains 1.7 times the vitamins and minerals (treatment 4). However, the plasma progesterone concentration showed no significant difference among the treatment groups.

Keywords: litter size, minerals, sow feeding strategy, swine reproduction, vitamins

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Introduction

The nature of the early gestation stage has been greatly changed due to the entry of embryos, implantation, embryo development, as well as changes in progesterone and estrogen levels. This period had high oxidative stress, resulting in high embryo loss because changes in the uterine environment during days 10-16 of gestation play a crucial role in embryonic survival following trophoblast elongation and placental attachment. The majority, about 20-30% of embryonic loss, occurs during days 10 to 30 of gestation (Geisert *et al.*, 2020). Therefore, it is essential to establish adequate uterine space to support fetal survival for a large litter. The period of rapid conceptus elongation on Day 12 of pregnancy is a selection point for regulating potential litter size in the pigs (Geisert *et al.*, 2020). Thus, the management of nutrition in the early gestation stage is very important due to its relation to progesterone concentration. Liu *et al.* (2020) found that progesterone hormone is crucial for embryo development and functions to stabilize the uterine environment, with progesterone concentration peaking on days 12-14 of gestation and linearly decreasing afterward (Hoving *et al.*, 2017).

High feed intake in the early gestation stage increases the progesterone clearance rate and may lead to a reduction in the litter size (Jindal *et al.*, 1997). However, high feed intake can support fetal growth and development and result in good reproductive performance as litter sizes today are larger than in the past (Hoving *et al.*, 2011). On the other hand, with increased feed intake, the sow will receive higher levels of vitamins and minerals compared to low feed intake; this point may support the embryo growth and reproductive performance of the sow. Vitamins and minerals are coenzymes, very crucial during the gestation stage to enhance antioxidant and hormone levels, supporting each other's function. Especially, vitamin E is the main antioxidant that eliminates oxidative stress, leading to reduced cell damage, which causes preeclampsia, miscarriage, and fetal intrauterine growth restriction (Aziz *et al.*, 2019). Nowadays, commercial swine breeding farms (Dalto and da Silva, 2020) use a higher level of vitamin E than that recommended by the National Research Council (NRC, 2012). Therefore, vitamin E levels in the swine breeder's diet may be necessary to improve reproductive performance.

This study would like to emphasize more about the different periods for providing feeding levels and micronutrient levels related to the progesterone hormone, as studies about the most important period to manage nutrition in the first 30 days of gestation are still limited and unclear. Therefore, this experiment aimed to examine the differences in supplementation duration during days 1-15 of gestation and days 1-30 of gestation in sows, as this period is significant for embryo implantation. Whether the feeding levels and micronutrient levels provided during different periods affect the reproductive performance and plasma progesterone concentration in early gestation sows.

Materials and Methods

The experimental procedures followed the Institutional Animal Care and Use Committee (IACUC) of the National Pingtung University of Science and Technology guidelines for handling animal use for scientific purposes under IACUC No. 112-055.

Experimental materials and procedures: The experiment was conducted at a dry sow house and climate chamber at the animal farm of the National Pingtung University of Science and Technology (NPUST).

Thirty-six (Landrace × Yorkshire × Duroc) first-parity sows were used. Sows were chosen from a commercial farm with an average weight of 130 kg/sow. Before mating, the initial average body weight was 160.85 kg. Sows were located in a dry sow house after being moved from a commercial farm (pre-mating period) until middle gestation (79 days of gestation). Pre-mating sows were detected with standing estrus behavior and feeding was managed at 2.2-2.6 kg/day (twice a day), according to body size to ensure all sows had the same body size before mating: skinny size (BCS less than 3) provided 2.6 kg/day; moderate size (BCS at 3) provided 2.4 kg/day; obese size (BCS more than 3) provided 2.2 kg/day. In the process of synchronizing the sows, after the second estrus behavior, the sows received Regumate® Porcine (MSD Animal Health, Rue de Lyons, Igoville, France) at 5 mL by oral administration provided at the same time daily for at least 18 days. Afterward, all sows were stopped from receiving Regumate® for 5 days, and sows began estrus at the same time and were ready to mate. Mating was conducted in the early morning and evening for 3 days. In total, the sows were mated 6 times using artificial insemination. Sows were checked for pregnancy by an ultrasound machine (POC Medical Inc., Changhua, Taiwan) on days 18, 25, and 32 of gestation. In the late gestation stage (80 days of gestation), sows were moved to a farrowing pen in a climate chamber.

Animal treatment: This experiment emphasizes feeding management in the early gestation stage of first parity sows, especially the levels of feed intake, vitamins, and minerals, as well as the period to increase vitamins and minerals.

Sows were randomized into four treatment groups based on the initial body weight. Sows received treatment only in the early gestation stage: Treatment 1: sow received control feed 1.5 kg/day from days 1-30 of gestation; Treatment 2: sow received feed 1.5 kg/day containing 1.7 times the vitamins and minerals (containing total vitamin E 150 IU/kg) from days 1-15 of gestation and received control feed 1.5 kg/day from days 16-30 of gestation; Treatment 3: sow received feed 1.5 kg/day containing 1.7 times the vitamins and minerals (containing total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: sow received feed 2.5 kg/day from days 1-30 of gestation. Each treatment had nine replications. The diet composition is shown in Table 1, and the comparison of feed intake and vitamins and minerals levels in each treatment group

is shown in Table 2. Feed intake was measured by weighing 0.75 or 1.25 kg of feed per meal and providing it in an individual feeder (twice a day).

Animal care: Before mating until 80 days of gestation, sows were located in the dry sow house of National Pingtung University of Science and Technology's animal farm. The pen featured a partially slotted solid concrete floor, an individual feeder, and a nipple drinker. Sows had access to water ad libitum at all stages. Feed was provided a complete diet in mash form, with the amount following the treatment group in the early stage (days 1-30 of gestation). After 30 days of gestation, all sows were switched to control feed (diet A: the details shown in Table 1). The middle stage (days 31-79 of gestation) provided 2.2-2.6 kilograms/sow/day, restricted according to body weight size. The late stage (day 80 of gestation to the weaning day) provided 4.8 kilograms/sow/day. The lactation period lasted 35 days. After weaning, all sows were observed and inspected for estrus behavior.

Data and sample collection: Data for all 36 sows were recorded as follows: physical parameters, including body weight, backfat thickness (P2), and body condition score one day before mating, gestation stage on days 30, 80, and 100, and lactation stage on days 1 and 35 (weaning day). Backfat thickness was measured at the P2 position on the right side of the sow's body using an A-mode ultrasonography (Renco Lean Meter®, Minneapolis, Minnesota, USA). P2 is the last rib of the sow, 6 cm from the dorsal midline (Roongsitthichai and Olanratmanee, 2021). The body condition score (BCS) in this experiment ranged from 1 (emaciated) to

5 (obese), according to the standard described by Li *et al.* (2018). The optimum body condition score during days 31-79 of gestation was controlled at 3.

The reproductive performance parameters were recorded as the number of litter size, stillborn, farrowing time, farrowing length, farrowing day, and weaning-to-estrus interval. Data for a total of 262 piglets were recorded as follows: the number of weaned piglets, litter birth weight, piglet birth weight, and piglet weight on days 18 and 35 (weaned weight).

Blood samples were collected at 5 a.m. on days 10, 20, and 30 of gestation. Twenty-four sows (six sows in each treatment) had 5 mL of their blood sampled from the jugular vein, and blood samples were collected in an EDTA tube, with the details labeled. The samples were centrifuged at 3000 rpm for 15 minutes to collect at least 1 mL of blood plasma, which was stored frozen at -20°C until analysis of the plasma progesterone concentrations were analyzed.

Statistical analyses: Statistical analyses were conducted using the Statistical Analysis System (SAS Inst., Inc., Cary, North Carolina, USA, 2021). Descriptive statistics, including the number of observations, mean, standard deviation, and range, were calculated for continuous variables such as sow physical parameters, reproductive performance, piglet data, and progesterone concentration. All completed data for sow physical parameters, reproductive performance, and piglet data were determined using Duncan's new multiple range test. The significance of differences was determined at $P \leq 0.05$ was considered significant, and at $P \leq 0.10$ was considered a trend.

Table 1 Composition and calculated nutrient content of the diet (% as fed basis).

Ingredients (%)	Gestation diet		Lactation diet ³
	A ¹	B ²	
Corn	68.90	68.90	63.60
Soybean meal	17.10	17.10	22.10
Wheat bran	8.00	8.00	8.00
Oil	3.00	3.00	3.00
Monocalcium Phosphorus	1.40	1.40	1.70
Calcium	1.10	1.10	0.90
Salt	0.30	0.30	0.50
Minerals ⁴	0.10	0.17	0.10
Vitamins ⁵	0.10	0.17	0.10
Energy digestibility (kcal)	3486.00	3486.00	3484.00
Crude Protein, (%)	14.40	14.40	16.40
Calcium, (%)	0.80	0.80	0.86
Phosphorus, (%)	0.38	0.38	0.46
Lysine, (%)	0.74	0.74	0.88
Methionine + Cysteine, (%)	0.38	0.38	0.44

¹The diet provided for sows in Treatment 1, Treatment 2 (since day 16 of gestation), and Treatment 4 at the early gestation stage, and from day 31 to farrowing for all treatment groups.

²The diet contained 1.7 times the vitamins and minerals (total vitamin E 150 IU) provided for sows in Treatment 2 (Day 1-15 of gestation) and Treatment 3.

³The diet provided to all sows from day 1 after farrowing until weaning day.

⁴Minerals contained: Fe at least 150,000 mg; Zn 90,000-100,000 mg; Mn at least 60,000 mg; Cu 20,000-25,000 mg; I at least 600 mg; Se at least 300 mg; and Co at least 300 mg.

⁵Vitamins contained: vitamin A 12,000,000 IU; D3 1,500,000 IU; E 60,000 mg; K3 2,000 mg; B1 2,000 mg; B2 10,000 mg; B6 5,000 mg; B12 60 mg; pantothenic acid 30,000 mg; niacin 35,000 mg; folic acid 3,000 mg; and biotin 300 mg.

Table 2 The comparison of feed intake, vitamins, and minerals levels in each treatment.

Nutritional	Treatment ¹				
	1	2	3	4	
Feed intake (kg)	1.5	1.5	1.5	1.5	2.5
Vitamins and Minerals levels (times)	1X	1.7X + vitamin E 150IU/kg	1X	1.7X + vitamin E 150IU/kg	1.7X
(FI) (VM) ²	(L)(L)	(L)(H)	(L)(L)	(L)(H)	(H)(H)
Duration	Day 1-30	Day 1-15	Day 16-30	Day1-30	Day 1-30

¹Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

²FI means feed intake levels, VM means vitamins and minerals, L is low, and H is high.

Results

Sow body weight, backfat thickness, and body condition score: Body weights are shown in Table 3. All treatments showed no significant difference in initial body weight (measured 1 day before mating). On day 30 of gestation, sows in treatment 4 had the highest average body weight of all groups ($P < 0.01$) due to treatment 4 receiving high feed intake. Therefore, high feed intake resulted in higher body weight on day 80 of gestation ($P = 0.05$). Afterwards, the body weight on day 100 of gestation and during the lactation stage showed no significant difference ($P > 0.05$).

The backfat thickness of sows is shown in Table 4. Initial backfat thickness showed no significant difference. On day 30 of gestation, sows in treatment 4 had the highest backfat thickness ($P < 0.01$), but treatments 1, 2, and 3 showed no significant difference. On days 80 and 100 of gestation, and days 1 and 35 of lactation, all sows exhibited no significant difference in backfat thickness ($P > 0.05$).

The body condition score of sows is shown in Table 5. On day 30 of gestation, sows in treatment 4 had the highest body condition score ($P < 0.01$). On days 80 and 100 of gestation, sows in treatment 4 had the highest body condition score ($P = 0.05$), but in the lactation stage, they showed no significant difference ($P > 0.05$).

Sow reproductive performance: The reproductive performance of the sows is shown in Table 6. Litter size was affected by treatment ($P = 0.05$): sows receiving feed 1.5 kg/day without added vitamins and minerals had a lower litter size than sows receiving feed 2.5 kg/day and sows receiving feed 1.5 kg/day with 1.7 times the vitamins and minerals (total 150 IU of vitamin E) in both supplements from days 1-15 and days 1-30 of gestation. Litter size in this experiment was effective in determining the number of weaned piglets ($P = 0.05$). The stillborn piglets and the number of piglets born alive showed no significant difference ($P > 0.05$). Treatment 3 had a trend to increase litter birth weight because it had a high litter size, but showed no significant difference from the other groups ($P > 0.05$). However, the average piglet birth weight in treatment 1 was higher than in the other groups because it had a small litter size, but did not differ from treatments 3 and 4 ($P > 0.05$). The wean-to-estrus interval in treatment 3 was higher than in other groups, but did not exceed 7 days. The piglet weaning weight, farrowing time, and farrowing day in all treatment groups showed no significant difference ($P > 0.05$). However, treatment 4 had the longest farrowing duration.

Table 3 The effect of different feed intake and micronutrient levels on the sow body weight (kg).

Stage	Treatment				SEM	P-value
	1	2	3	4		
Before mating	160.9	161.8	160.9	160.0	2.61	0.098
Gestation						
Day 30	166.6 ^a	168.4 ^a	169.2 ^a	183.0 ^b	2.30	0.002
Day 80	198.1 ^a	201.1 ^a	202.0 ^a	209.2 ^b	3.25	0.050
Day 100	227.8	236.3	241.4	230.9	4.28	0.595
Lactation						
Day 1	218.1	225.9	223.4	215.9	7.03	0.491
Day 35	216.5	202.6	204.4	199.0	7.72	0.135

Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

*: significantly different ($P \leq 0.05$); non-sig: not significantly different ($P > 0.05$).

Table 4 The effect of different feed intake and micronutrient levels on the sow backfat thickness at P2 (mm).

Stage	Treatment				SEM	P-value
	1	2	3	4		
Before mating	18.17	19.44	20.08	20.17	0.56	0.126
Gestation						
Day 30	18.42 ^a	20.00 ^a	19.92 ^a	22.67 ^b	0.70	0.009
Day 80	20.50	21.33	22.57	22.44	0.71	0.108
Day 100	22.75	24.00	24.50	23.44	0.62	0.534
Lactation						
Day 1	24.33	24.75	26.20	24.43	1.01	0.842
Day 35	20.33	18.00	21.50	20.43	1.47	0.677

Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

*: significantly different ($P \leq 0.05$); non-sig: not significantly different ($P > 0.05$).

Table 5 The effect of different feed intake and micronutrient levels on the sow body condition score¹.

Stage	Treatment				SEM	P-value
	1	2	3	4		
Before mating	3.13	3.11	3.17	3.33	0.06	0.111
Gestation						
Day 30	3.25 ^a	3.39 ^a	3.38 ^a	3.79 ^b	0.08	0.004
Day 80	3.50 ^a	3.58 ^a	3.50 ^a	3.80 ^b	0.06	0.050
Day 100	3.64 ^a	3.67 ^a	3.58 ^a	3.94 ^b	0.13	0.050
Lactation						
Day 1	3.25	3.13	3.13	3.29	0.12	0.781
Day 35	3.25	3.17	3.00	2.86	0.21	0.154

¹score: 1 = very thin, 2 = thin, 3 = good, 4 = fat, and 5 = obese

Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

*: significantly different ($P \leq 0.05$); non-sig: not significantly different ($P > 0.05$).

Table 6 The effect of different feed intake and micronutrient levels on the sow reproductive performance.

Item	Treatment				SEM	P-value
	1	2	3	4		
Litter size (piglets/litter)	10.71 ^a	12.00 ^{ab}	12.50 ^{ab}	13.33 ^b	0.92	0.050
Still born (piglets/litter)	4.57	4.20	4.17	6.00	2.15	0.996
Weaned number (piglets/litter)	6.33 ^a	10.67 ^b	9.50 ^b	8.71 ^{ab}	1.25	0.050
Litter birth weight (kg/litter)	12.03	13.92	15.56	14.42	2.69	0.945
Birth weight (kg/piglet)	1.68 ^b	1.43 ^a	1.56 ^b	1.53 ^b	0.05	0.050
Weaned weight (kg/piglet)	10.32	8.55	9.68	8.64	1.14	0.616
Farrowing time ¹	2.43	2.20	2.67	3.00	0.48	0.655
Farrowing duration (mins)	83.71	86.80	92.71	114.67	16.29	0.624
Farrowing day (days)	120.00	120.00	119.86	120.78	1.08	0.912
Wean-to-estrus interval (days)	3.57 ^a	4.67 ^{ab}	5.50 ^b	4.57 ^{ab}	0.36	0.050

¹Farrowing time; 1= 00.00-5.59 am, 2= 6.00-11.59 am, 3= 12.00-05.59 pm, 4= 06.00-11.59 pm.

Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

*: significantly different ($P \leq 0.05$); non-sig: not significantly different ($P > 0.05$).

Plasma progesterone concentration: The levels of plasma progesterone concentration are shown in Figure 1. During early gestation, all groups showed no differences in plasma progesterone concentration ($P > 0.05$). However, on day 10 of gestation, sows receiving low feed intake with high vitamins and minerals

(treatment 3) showed the highest plasma progesterone concentration. The concentrations were 25.70, 28.93, 34.32, and 27.25 ng/mL (treatments 1, 2, 3, and 4, respectively).

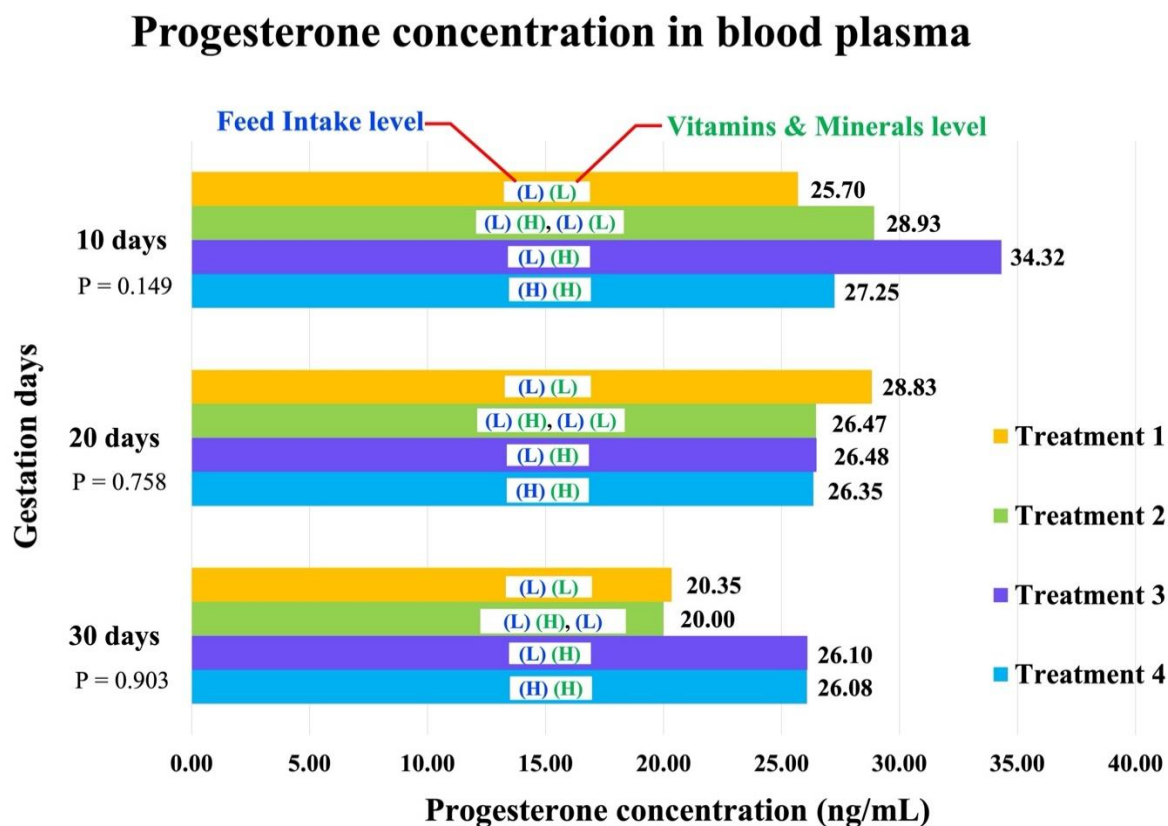


Figure 1 The effect of feeding levels with high micronutrients on the sow progesterone concentration. In the bar, feed intake levels are navy blue, and vitamins & minerals intake is green.

Treatment 1: Sows received 1.5 kg/day of feed from days 1-30 of gestation; Treatment 2: Sows received 1.5 kg/day of feed containing 1.7 times the vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-15 of gestation; Treatment 3: Sows received 1.5 kg/day of feed containing 1.7 times of vitamins and minerals (contained total vitamin E 150 IU/kg) from days 1-30 of gestation; Treatment 4: Sows received 2.5 kg/day of feed from days 1-30 of gestation.

*: significantly different ($P \leq 0.05$); non-sig: not significantly different ($P > 0.05$).

Discussion

Sow body weight, backfat thickness, and body condition score: All sows had an initial body weight above 160 kg at first service. Sows in treatment 4 had the highest body weight during 30 days in the early gestation stage due to receiving the highest feed intake (2.5 kg/day), effectively gaining more weight until day 80 of gestation; however, not by day 100 of gestation, since during days 31-79 of gestation, the feed provided was 2.2-2.6 kg/day following the BCS to maintain the BCS at score 3. Hoving *et al.* (2011) reported that a 30% increase in feed intake in primiparous sows increased body weight gain during early pregnancy; however, the increased feeding levels during early gestation also resulted in a numerically reduced farrowing rate. In the lactation phase, all sows received feed 4.8 kg/day. Treatment 4 tended to have the lowest body weight during the lactation stage, but showed no significant difference, even though this group had a higher body weight during the gestation stage. In this experiment, Treatment 4 experienced the greatest body weight loss, which may not have been due to litter size. Even though this experimental group had the largest litter

size, it had relatively fewer weaned numbers because it had more stillborn and mummified piglets. Furthermore, the greater the feed intake and weight gain in gestation, the greater the potential weight loss in lactation. Body weight loss exceeding 10-12% decreases reproductive performance in the subsequent productive cycle (Carrión-López *et al.*, 2022). Gestation body weight gain was negatively correlated with lactation body weight changes. Every extra kilogram of BW gained in gestation resulted in a loss of 0.3 kg in lactation (Cooper *et al.*, 2001).

Based on day 30 of gestation, sows in treatment 4 had the highest backfat thickness because they received high feed intake, a result similar to Su *et al.* (2025). Ren *et al.* (2018) showed that BF changes during gestation for sows on 1.5 M and 2.0 M levels of feed intake were greater than sows on 0.5 M and 1.0 M levels of feed intake. From day 80 of gestation until weaning day, sows in all groups had no significant differences because during days 31-79 of gestation, all sows received feed intake at the same levels of 2.2-2.6 kg/day, following the BCS, to ensure all sows had the same body size. Maintaining optimal backfat thickness and body condition during the last third of gestation is

crucial for subsequent reproductive performance (Kim *et al.*, 2015).

Throughout the whole gestation stage, sows in the high feed intake with high vitamins and minerals intake group (treatment 4) had the highest body condition score. This was because during the early gestation stage, sows in this group received higher feed intake (2.5 kg/day) than the other groups (1.5 kg/day). The highest body condition score at the early gestation stage resulted in the highest body condition score on days 80 and 100 of gestation in Treatment 4. Increasing feed allowances to meet 100 to 175% of the National Research Council (NRC, 2012) maintenance metabolizable energy requirement during early gestation in maternal line sows resulted in increased weight and body condition score (measured BCS by caliper method) without impacting performance (Ribas *et al.*, 2022).

Sow reproductive performance: The early gestation stage is crucial for litter size. High progesterone concentrations can maintain a high embryo survival rate, but in terms of embryo survival rate, further research is needed with the treatment in this experiment, due to the limited number of experimental animals and budget constraints. This study showed that low feed intake and low vitamins and minerals (treatment 1) had the lowest progesterone concentration levels, as well as the lowest litter size (10.71 piglets/litter). Sows in treatments 2, 3, and 4 are classified into high vitamins and minerals groups; they showed a higher litter size (12, 12.5, and 13.3 piglets/litter, respectively). This result can be interpreted as high levels of vitamins and minerals having a positive effect on large litter sizes.

Vitamins such as vitamin E and the vitamin B group are known to protect cell membranes by neutralizing reactive oxygen species (ROS) (Ajayi *et al.*, 2019), which can cause lipid peroxidation and damage cellular structures. Particularly, vitamin E and selenium (Xiao *et al.*, 2021), with antioxidant properties, play a crucial role in protecting cell membranes and embryos from oxidative stress. This protection is vital for maintaining cell integrity and promoting healthy development (Swelum *et al.*, 2021). Antioxidants may be molecules that can neutralize free radicals by accepting or donating electrons to eliminate the unpaired electrons of free radicals (Lü *et al.*, 2010). The antioxidant molecules may directly react with the reactive radicals, destroy them, and become new free radicals that are less active, longer-lived, and less dangerous (Aziz *et al.*, 2019). Even high feed intake with a high vitamins and minerals group resulted in a large litter size. However, this group showed the highest stillborn numbers, but with no significant difference.

Su *et al.* (2025) reported that the high feed intake group, provided 2.5 kg/day during the early gestation stage, showed higher stillborn piglets than the low feed intake group (1.5 kg/day). Sows categorized in the <244 kg body weight group for 113 days of gestation had a reduced stillborn rate compared to sows in the weighing between 244 and 261 kg and >262 kg body weight groups (Gourley *et al.*, 2020). High backfat thickness (22–26 mm) on mating day was associated with low concentrations of DNA and RNA in the

parenchymal tissue of the mammary gland. Moreover, a high concentration of fat but a low concentration of protein in parenchymal tissue was noted (Farmer *et al.*, 2016).

Plasma progesterone concentration: Treatments 2 and 3 received low feed intake with high levels of vitamins and minerals. At this point, vitamins and minerals may be more important and enhance the progesterone concentration level more than the feed intake factor. Although the plasma progesterone concentration results showed no significant difference. However, on day 30 of gestation, treatments 3 and 4 seemed to have numerically increased plasma progesterone concentrations compared to treatments 1 and 2. This was due to treatments 3 and 4, which benefit from high levels of vitamins and minerals. By the way, this point needs further research to confirm the result, as this experiment had limited the sample size. Furthermore, treatments 3 and 4 had different feed intakes; perhaps the feed intake is not the main factor influencing progesterone concentration. High concentrations of progesterone hormone are beneficial to the embryo survival rates and litter sizes. Regarding embryo survival, nutritional effects are thought to be mediated via the concentration of progesterone in peripheral plasma (Virolainen *et al.*, 2004). This study showed a high trend in progesterone levels across the two factors, but the results are still unclear and may need further research.

Firstly, concerning feed intake levels, on day 10 of gestation in this experiment, it showed that at the same level of vitamins and minerals intake, low feed intake groups (treatments 2 and 3) had higher progesterone levels than the high feed intake group (treatment 4). Low-level feeding immediately after insemination is associated with higher progesterone concentrations. The detrimental effects of high-level feeding are thought to be mediated via increased progesterone clearance rates, which in turn result in lower circulating progesterone concentrations (Leal *et al.*, 2019). The negative effects of high feeding levels are also mentioned by Jindal *et al.* (1997) stating that providing high feed intake caused plasma progesterone rise to be delayed after ovulation, which may result in increased embryonic losses. High feed consumption can acutely decrease circulating progesterone concentrations due to increased progesterone metabolism (Vasconcelos *et al.*, 2003). High feed intake elevated high insulin levels, while progesterone remained at a low concentration (De *et al.*, 2009).

Secondly, regarding vitamin and mineral levels, on day 10 of gestation in this experiment, it showed that at the same level of feed intake, sows that received a single dose of vitamins and minerals (treatment 1) had lower progesterone concentrations than sows that received 1.7 times the vitamins and minerals intake (treatments 2 and 3). Moreover, on day 30 of gestation, sows in treatment 2 changed to receive the same feed as sows in treatment 1. Sows receiving one time of vitamins and minerals intake (treatments 1 and 2) had lower progesterone concentrations than those receiving 1.7 times of vitamins and minerals intake (treatment 3). Vitamin E is not a hormone, but it acts

like a hormone. It works by impersonating the effects of progesterone on the body (Siddiqui *et al.*, 2021). Anoh (2018) reported that vitamin C is stimulatory to progesterone secretion, and deficiency of vitamin D alters placental development and embryo implantation (Hollis and Wagner, 2017). Progesterone concentration peaks on days 12-14 of gestation and linearly decreases afterward (Tillson and Erb, 1967). Treatment 1 had the lowest progesterone concentration on day 10 of gestation, but had the highest concentration among the other groups on day 20 of gestation. On day 30 of gestation, progesterone in this group had the lowest levels again.

This may indicate that low feed intake with low vitamins and minerals levels slowly increases the progesterone concentration in the initial stage of gestation, but rapidly decreases after 20 days of gestation. At this point need further research is needed to prove this, and future studies will aim to identify the supplementation of specific vitamins, such as vitamin E, to clarify whether single vitamin supplementation has a strong effect on sow reproductive performance and plasma progesterone concentration during early gestation.

In conclusion, sows fed high feed intake in early gestation had the highest sow physical performance, but tended to have lower sow physical performance during the lactation stage. Sows fed 1.7 times vitamins and minerals with low feed intake (1.5 kg/day) during the early gestation can improve litter size, similar to sows fed high feed intake (2.5 kg/day). Sows fed with high vitamins and minerals with low feed intake seem to have numerically increased plasma progesterone concentration on day 10 of gestation and slowly decrease progesterone concentrations from days 10 to 30 in early gestation. Furthermore, increased levels of vitamins and minerals in the diet can enhance litter size and potentially support progesterone levels in sows without increasing feed intake during early gestation.

Statement of Author Contributions

Kewalin Kongngern: Investigation, Methodology, Writing - original draft. **Liang-Chou Hsia:** Conceptualization, Formal analysis, Investigation, Methodology, Writing - review & editing. **Shu-Ping Su:** Investigation, Methodology, Writing - review & editing. **Wantamas Jantasini:** Investigation, Writing - review & editing. **Jai-Wei Lee:** Investigation, Writing - review & editing.

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