



Effects of dietary energy and protein levels on reproductive performance in gestating sows and growth of their progeny

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Abstract

This experiment was conducted to evaluate the effect of dietary energy and crude protein (CP) levels on reproductive performance, litter performance, milk quality, and blood profiles in gestating sows. A total of 59 multiparous sows (Yorkshire × Landrace) with similar body weights (BW), backfat thickness (BF), and parity were assigned to one of six treatments with 9 or 10 sows per treatment using a 2 × 3 factorial arrangement and completely randomized design. The first factor was two levels of dietary metabolizable energy (ME) density (13.40 or 13.82 MJ/kg) and the second factor was three dietary protein levels based from 35 day in gestating phases (10.5%, 12%, and 13.5%). Backfat thickness change in lactating sows decreased linearly as CP level increased ($p = 0.03$). Increased energy level in the gestating sow diet tended to increase the total number of piglets born ($p = 0.07$), but piglet weight decreased ($p = 0.02$). Dietary CP level had a negative effect on colostrum quality. Casein, protein, total solid, and solids-not-fat concentrations decreased linearly and lactose level increased linearly as CP level in the gestating sow diet increased (casein%: $p = 0.03$; protein%: $p = 0.04$; lactose%: $p = 0.06$; total solids: $p = 0.03$; solid-not-fat: $p = 0.03$, respectively). However, improving ME by 0.42 MJ/kg had no significant effect on the chemical composition of sow colostrum. There were no significant differences in blood glucose concentration in gestating sows when sows were fed different levels of energy during gestation, but blood glucose increased at 21 day of lactation when energy increased by 0.42 MJ/kg ($p = 0.04$). Blood urea nitrogen concentration increased linearly when dietary CP levels increased at 110 day in gestation, 24-hours postpartum, and 21 days of lactation (linear, $p < 0.05$, $p < 0.05$, and $p < 0.05$, respectively), and it also increased when dietary energy increased at 110 days of gestation and 24-hours postpartum ($p < 0.01$, and $p < 0.01$, respectively). A gestating sow diet containing 13.82 MJ/kg ME and 10.5% CP can improve reproductive performance, litter performance, and colostrum quality.

Keywords: Energy, Crude protein, Reproductive performance, Litter performance, Blood profiles, Gestating sows

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Background

Various management practices coupled with research on physiology, nutrition, genetics, animal behavior, and the environment and housing have improved reproductive efficiency in sows over the past 40 years [1]. In the swine industry, an accepted measure of reproductive performance is piglets per sow per year (PSY). Total piglets born and PSY have increased every year for more than 6 years in Europe [2]. In Korea, PSY increased by 1.5 piglets from 2011 to 2013 respectively [3], but still trails behind Europe [2]. Boyd et al. [4] reported that the increase in number of litters and milk production in recent years was due to provision of more nutrients during the normal reproductive cycle. In addition, gestating sows should be fed a diet that ensures sufficient maternal protein and fat deposition to optimize fetal growth [5]. Therefore, the nutritional requirements of gestating sows should be met to satisfy both body maintenance and fetal growth [6].

Many studies had shown that adequate energy intake during the gestation period has favorable effects on fetal growth and mammary development [7,8]. However, excessive energy intake in gestation can reduce feed intake during lactation [9] and have a negative effect on milk production [10].

Protein deposition affects the reproductive performance of sows [11]. Pettigrew and Yang [12] reported that high protein storage in sows influenced milk production and reproductive performance. High dietary protein intake in gestating sows was shown to improve litter weight and piglet weight [13], but had no detectable effect on mammary gland development [14]. Low-protein intake had a negative effect on lactation performance [15] and performance at next parity [16]. Other studies showed that low dietary protein intake during gestation did not affect litter size or litter birth weight, but had a detrimental influence on litter weight gain even though lactating sows were fed an adequate amount of protein [17,18].

Some studies have been conducted on the energy and crude protein (CP) requirements for gestating gilts, but few studies have focused on multiparous sows. Consequently, this experiment was conducted to evaluate the effects of dietary energy and CP levels on reproductive performance, litter performance, milk quality, and blood profiles in multiparous gestating sows.

Materials and Methods

Experimental animals and housing environment

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee (SNUACUC; SNU-160819-9). A total of 59

multiparous sows (Yorkshire × Landrace) with body weights (BW) around 241.67 ± 8.86 kg were used in this study. Each sow was kept in an individual gestation stall (2.4×0.64 m) with a feeder and a nipple drinker. Sows (parity: 3–6) were fed 2.4 kg/day. On day 110 of gestation, sows were transferred into environmentally controlled farrowing rooms and placed in individual farrowing crates (2.5×1.8 m). Each farrowing crate was equipped with a feeder and a nipple waterer.

Experimental diet, treatment, and animal management

Experimental sows (Yorkshire × Landrace) with similar BW, backfat thickness (BF), and parity were assigned to one of six treatments with 9 or 10 sows per treatment using a 2×3 factorial arrangement and completely randomized design. The first factor was two levels of dietary metabolizable energy (ME) density (13.40 MJ/kg or 13.82 MJ/kg), and the second factor was three dietary CP levels based on subdivision of gestating phases (10.5 %, 12 %, and 13.5%). All nutrients in the experimental diets met or exceeded the nutrient requirements of the NRC except ME and CP [6]. Sows in the lactating period were fed the same lactation diet. Formulae and chemical compositions of the experimental gestation and lactation diets are presented in Tables 1 and 2.

After farrowing, sow lactation diet was restricted to 1 kg on the first day and gradually increased by 1 kg per day for the first 5 days, with no limitation for the remaining lactation period. Within 24 hours after farrowing, each sow lactated 11 or 12 healthy piglets. When an experiment sow had less than 11 piglets, cross-fostering piglets were obtained from extra sows. All piglets were processed as follows: Fe-dextran (150 ppm) injection, ears notching, and tail docking. Piglets were weaned at approximately 24 ± 2 days, and then sows were transferred to a gestating crate.

Measurements and analysis

Gestation and lactation period, BW (BI-2RB., BI series., CAS Co., Ltd., SEL, Korea) and BF (P_2 position, Renco Crop., Minneapolis, MN, USA) of sows were measured at day 35 and 110 of gestation, at 24 hours post-farrowing, and at day 21 of lactation. The number of piglets born alive, still born, mummified fetuses, total born, and BW were measured at 24 hours post-farrowing and at day 21 of lactation. Individual piglet weight and litter size of lactating sows were recorded postpartum and at day 21 of lactation. Weaning to estrus interval (WEI) of weaned sows was recorded after weaning, as this is an important marker of reproductive performance. Voluntary feed intake of sows was also measured during lactation.

Gestating and lactating sows were bled via the anterior vena cava. Samples were collected on days 35 and 110 of gestation, and 24 hours post-farrowing. Blood samples were collected in dispos-

Table 1. Formulae and chemical compositions of diets in the gestation phase

Energy CP (%)	ME 13.40 MJ/kg (%)			ME 13.82 MJ/kg (%)		
	10.5	12	13.5	10.5	12	13.5
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (%)						
Corn	78.81	74.79	70.72	76.12	72.20	68.13
Soybean meal	7.02	11.59	16.14	7.43	11.99	16.54
Wheat bran	8.02	8.01	8.04	8.08	7.99	8.02
Soy-oil	1.62	1.66	1.71	3.83	3.85	3.90
Mono-dicalcium phosphate	1.38	1.31	1.24	1.40	1.33	1.26
Limestone	1.55	1.55	1.55	1.54	1.54	1.54
L-lysine, 78%	0.31	0.15	0.00	0.30	0.15	0.00
DL-methionine, 99%	0.04	0.02	0.00	0.05	0.03	0.01
L-threonine, 99%	0.15	0.08	0.00	0.15	0.08	0.00
Tryptophan, 10%	0.50	0.24	0.00	0.50	0.24	0.00
Vit. Mix ¹⁾	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix ²⁾	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Choline-Cl	0.10	0.10	0.10	0.10	0.10	0.10
Chemical composition ³⁾						
Metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.82	13.82	13.82
Crude protein (%)	10.50	12.00	13.50	10.50	12.00	13.50
Total lysine (%)	0.67	0.67	0.67	0.67	0.67	0.67
Total methionine (%)	0.24	0.24	0.24	0.24	0.24	0.24
Total threonine (%)	0.54	0.54	0.54	0.54	0.54	0.54
Total tryptophan (%)	0.14	0.14	0.14	0.14	0.14	0.14
Calcium (%)	0.88	0.88	0.88	0.88	0.88	0.88
Total phosphorus (%)	0.60	0.60	0.60	0.60	0.60	0.60

¹⁾Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 12,000 IU; vitamin D₃, 2,000 IU; vitamin E, 100 IU; vitamin K₃, 4.5 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 30 mg; niacin, 45 mg; pyridoxine, 4.50 mg; d-biotin, 0.5 mg; folic acid, 3.5 mg; vitamin B₁₂, 0.03 mg.

²⁾Provided per kg of diet. Minerals per kg of complete diet: Se, 0.15 mg; I, 0.3 mg; Mn, 37 mg; Cu, 11 mg; Fe, 150 mg; Zn, 85 mg; Co, 2 mg.

³⁾Calculated value.

CP, crude protein; ME, metabolizable energy.

able culture tubes, and centrifuged at 1,957 × g for 15 min; the serum was harvested from all blood samples and stored at -20 °C until analysis. After injection of 0.3 mL of oxytocin (Komi oxytocin inj. Komipharm International Co., Ltd., Siheung-Si, Gyeonggi-Do, Korea), colostrum and milk samples were collected in falcon tubes (Milkoscan FT 120., FOSS, Hillerod, Demark) and stored at -20 °C until analysis. Concentrations of glucose and blood urea nitrogen (BUN) were analyzed at a later stage. BUN (kinetic UV assay, Roche, Germany) and glucose (enzymatic kinetic assay, Roche, Germany) concentrations were analyzed using a blood analyzer.

Colostrum and milk samples were taken from functional mammary glands of each sow at 24 hours post-farrowing and at day 21 of lactation, respectively. After collection, samples were stored in a freezer (-20 °C) until further analysis. Proximate analysis of colostrum and milk was conducted using the Milkoscan FT120 system

(FOSS, Hillerod, Denmark).

Statistical analyses

All collected data were analyzed using least squares mean comparisons and evaluated using general linear models (GLMs) in the statistical software package SAS (SAS Institute Inc., Cary, NC, USA). Individual sow was considered the experimental units when comparing reproductive performance, blood profiles, and milk composition among groups. Litters were used as the experimental units when assessing piglet growth. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to CP levels when a significant CP effect was detected. Differences were considered significant at *p* < 0.05 or highly significant at *p* < 0.01, while *p* ≥ 0.05 and *p* < 0.10 was considered to indicate a tendency in the data.

Table 2. Formulae and chemical compositions of diets in the lactation phase

Item	%
Ingredient (%)	100.00
Corn	65.35
Soybean meal	27.23
Wheat bran	2.01
Soy-oil	2.42
Mono-dicalcium phosphate	1.26
Limestone	1.13
Vit. Mix ¹⁾	0.10
Min. Mix ²⁾	0.10
Salt	0.30
Choline-Cl	0.10
Chemical composition ³⁾	
Metabolizable energy (MJ/kg)	13.82
Crude protein (%)	17.20
Total lysine (%)	0.94
Total methionine (%)	0.28
Total threonine (%)	0.70
Total tryptophan (%)	0.19
Calcium (%)	0.75
Total phosphorus (%)	0.60

¹⁾Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 10,000 IU; vitamin D₃, 1,900 IU; vitamin E, 80 IU; vitamin K₃, 3.25 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 27.5 mg; niacin, 36 mg; pyridoxine, 3.75 mg; d-biotin, 0.35 mg; folic acid, 2.25 mg; vitamin B₁₂, 0.03 mg.

²⁾Provided per kg of diet. Minerals per kg of complete diet: Se, 0.15 mg; I, 0.3 mg; Mn, 37 mg; Cu, 11 mg; Fe, 150 mg; Zn, 85 mg; Co, 2 mg.

³⁾Calculated value.

Results and Discussion

Sow performance

Effects of dietary energy and CP levels on performance of gestating-lactating sows are shown in Table 3. There were no significant differences in BW, BW change, BF, average daily feed intake (ADFI), or WEI of sows among groups. However, BF change in the lactating period decreased linearly as dietary CP level increased ($p = 0.03$).

Long et al. [19] reported that BW gain and BW change increased when gestating gilts was fed diets with increased dietary ME (ME: 26.50–29.01 MJ/day). Numerous studies have reported similar results [18,20–21]. In this study, there were no significant differences in BW and BW loss when dietary ME was increased by 0.42 MJ/kg. This discrepancy with previous studies may be due to the small difference between the two energy levels or because we used multiparous sows compared with previous studies that used first parity sows. The growth of sows during their third parity has

been shown to be slower than that of first and second parity sows [22]. The current study showed that dietary CP levels ranging from 10.5% to 13.5% had no effect on the BW of sows, consistent with previous studies. Jang et al. [13] reported that there was no significant difference in BW when sows were fed diets with different CP levels (11.4%–17.1%). Mahan [22] also reported no differences in BW or BW change when CP levels were varied from 13% to 16% in the first to fifth parities.

Backfat thickness and BF change did not change when the ME in the diet of gestating sows was increased from 13.40 to 13.82 MJ/kg. Another study showed that BF changed from 17 mm to 21 mm as dietary ME was increased from 26.50 to 29.01 MJ per day in gestating gilts [19]. Backfat thickness changes in lactating sows decreased as dietary CP level increased ($p = 0.03$). Mahan [22] and Jang et al. [13] reported a similar result; BF change in lactation decreased numerically when dietary CP level in gestating sows was increased.

Average daily feed intake in lactating sows and WEI were not significantly affected by dietary energy and CP levels. In general, low feed intake has a negative effect on body condition and WEI [23,24] and can decrease ovulation in the next parity [25]. Long et al. [19] reported that increasing ME by 2.51 MJ/day during gestation could reduce ADFI in lactation. A similar result was reported by Revell and colleagues [9]. Previous studies have reported that dietary CP levels during gestation have no effects on ADFI and WEI [13,22].

Reproductive performance and litter performance

The effects of dietary energy and CP levels on total piglets born per litter, litter weight, litter weight gain, average BW of piglets, and average BW gain of piglets are shown in Table 4. The total number of piglets born tended to increase ($p = 0.07$) and piglet weight decreased ($p = 0.02$) when dietary energy level in the gestating sow diet was increased. A study performed more than 40 years ago demonstrated that litter size was maximized when daily ME intake was 25.12 MJ per day [26]. However, Long et al. [19] showed that sows that received 28.18 MJ (ME) per day give birth to more piglets that were born alive. In addition, multiparous sows require more energy than first parity sows [27]. The NRC increased the recommended dietary energy requirements for gestating sows from 1998 to 2012 [6,27]. In our study, gestating sows (parity: 3–6) with a daily intake of 33.16 MJ of ME (13.82 MJ/kg) tended to have more total born piglets than those with a daily intake of 32.15 MJ of ME (13.40 MJ/kg).

Litter weight gain was not affected by dietary energy or CP level. However, a diet containing 12% dietary CP during gestation was associated with greater piglet weight at 21 days ($p = 0.06$) as well as piglet weight gain ($p = 0.04$) because the number of wean-

Table 3. Effects of dietary energy and crude protein levels on body weight, backfat thickness, weaning to estrus interval, and daily feed intake of gestating-lactating sows

Energy CP (%)	ME 13.40 MJ /kg (%)			ME 13.82 MJ/kg (%)			SEM	p-value		
	10.5	12	13.5	10.5	12	13.5		ME	CP	M × C
No. of sows	10	10	10	10	9	10				
Body weight (kg)										
Day 35	244.0	239.1	239.7	239.9	239.3	243.0	2.56	0.98	0.91	0.85
Day 110	259.0	254.0	252.3	252.7	254.0	259.2	2.40	0.96	0.93	0.56
Change (d 35–110)	15.0	14.9	12.6	12.9	14.7	16.2	1.67	0.97	0.91	0.99
24 hours. postpartum	239.6	233.4	226.2	230.3	234.4	243.1	2.57	0.57	0.97	0.12
Day 21 of lactation	238.7	241.2	231.8	230.7	235.0	243.8	2.89	0.93	0.88	0.32
Changes (d 0–21)	0.9	7.8	5.6	0.4	0.6	0.7	1.36	0.21	0.35	0.42
Backfat thickness (mm)										
Day 35	20.2	20.2	20.2	21.6	21.8	20.2	0.76	0.51	0.90	0.90
Day 110	20.7	21.4	21.3	23.8	22.8	22.3	0.83	0.30	0.98	0.85
Gain (d 35–110)	0.5	1.2	1.1	2.2	1.0	2.1	0.71	0.41	0.95	0.75
24 hours. Postpartum	20.2	18.9	18.7	23.9	22.2	20.4	0.84	0.10	0.47	0.87
Day 21 of lactation	16.7	18.6	19.6	21.6	21.9	19.1	0.81	0.13	0.84	0.39
Changes (d 0–21) ¹⁾	–3.4	–0.3	0.9	–2.3	–0.3	–1.3	0.46	0.73	0.03	0.31
Lactation ADFI (kg/d)	6.58	7.20	6.93	6.49	6.40	6.93	0.139	0.37	0.48	0.48
WEI (d)	4.61	4.61	4.94	4.72	4.93	5.00	0.087	0.37	0.35	0.82

¹⁾Linear response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected.

CP, crude protein; ME, metabolizable energy; SEM, Standard error of means; ADFI, average daily feed intake; WEI, weaning to estrus interval.

Table 4. Effects of dietary energy and crude protein levels in the diets of gestating sows on reproductive performance and litter performance

Energy CP (%)	ME 13.40 MJ /kg (%)			ME 13.82 MJ/kg (%)			SEM	p-value		
	10.5	12	13.5	10.5	12	13.5		ME	CP	M × C
No. of sows	10	10	10	10	9	10				
Litter size, no. of piglets										
Total born	12.90	10.40	12.90	13.80	13.44	13.50	0.426	0.07	0.30	0.44
Born alive	12.90	10.40	12.30	13.30	13.22	12.40	0.395	0.17	0.39	0.31
After cross-fostering	11.40	11.80	11.80	11.50	11.56	11.88	0.093	0.81	0.31	0.75
No. of deaths upon weaning	0.20 ^c	0.60 ^b	0.50 ^b	0 ^d	1.00 ^a	0.88 ^a	0.508	0.48	0.03	0.48
Weaning pigs (d 21)	11.20 ^b	11.20 ^b	11.30 ^{ab}	11.50 ^a	10.56 ^c	11.00 ^{bc}	0.127	0.43	0.34	0.31
Litter weight (kg)										
At birth	18.58	16.44	19.55	19.34	18.64	18.31	0.477	0.55	0.35	0.35
After cross-fostering	17.41	19.06	18.96	17.18	16.66	17.96	0.289	0.04	0.23	0.28
Day 21 of lactation	66.38	72.95	69.55	69.32	66.96	64.89	1.286	0.33	0.65	0.32
Weight gain (d 0–21, kg)	48.97	53.89	50.59	52.14	50.30	46.94	1.200	0.58	0.53	0.43
Piglet weight (kg)										
At birth	1.47	1.62	1.54	1.41	1.39	1.41	0.028	0.02	0.75	0.31
After cross-fostering	1.53	1.61	1.61	1.50	1.44	1.52	0.022	0.03	0.63	0.43
Day 21 of lactation	5.94	6.51	6.14	6.02	6.33	5.86	0.084	0.41	0.06	0.63
Weight gain (d 0–21, kg) ¹⁾	4.41	4.90	4.53	4.53	4.89	4.34	0.080	0.81	0.04	0.71

¹⁾Quadratic response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected.

^{a-c}Means with different superscripts in the same row differ significantly ($p < 0.05$).

CP, crude protein; ME, metabolizable energy; SEM, Standard error of means.

ing pigs was lower than in other treatments. Although there was no significant difference in milk quality, a 10.5% CP diet resulted in the best colostrum quality. The number of piglet deaths upon weaning was lower in sows that received a diet with 10.5% CP. This is consistent with the results of Mahan [22] who reported that the number of piglet deaths increased as dietary CP level was increased by 3% in gestating sows. Previous studies have reported that low dietary protein intake in gestating sows did not affect litter size or litter birth weight, but had a detrimental influence on litter weight gain even though lactating sows were fed an adequate protein level [17,18]. Results in this study are not consistent with those of previous studies; this may be because a CP level of 10.5% is sufficient for gestating sows.

Milk composition

The effects of dietary energy and CP levels on the chemical composition of colostrum and milk in sows are shown in Table 5. There were no significant differences in milk quality on day 21 of lactation according to dietary gestation energy level (ME: 13.40–13.82 MJ/kg) or CP level (10.5%–13.5%), but casein ($p = 0.03$), protein ($p = 0.04$), total solids ($p = 0.03$) and solids-not-fat ($p = 0.03$) concentration increased linearly and lactose ($p = 0.06$) level tended to decrease linearly in colostrum when decreasing CP level in gestating sow diets. The high protein content in colostrum is due to presence of immunoglobulins [28]. Immunoglobulins content was increased when protein content increased in colostrum [29]. The sow prioritizes protein content in colostrum and milk if the protein content

in the feed is scarce, by metabolizing body reserves, which indicates that protein is extremely important to the piglets. The newborn piglet depends on colostrum to ingest immunoglobulins because of the structure of the pig placenta does not allow immunoglobulins to pass over from the sow to the fetus [30]. The ingestion is needed in order to be able to obtain passive immunity. A piglet that does not ingest colostrum will consequently not only be more sensitive to infections, but also to starvation and hypothermia.

The findings of this study demonstrate that decreasing CP level in gestating sow diet increased casein, protein, total solids and solids-not-fat linearly of colostrum. Therefore, low CP level in gestating sow diet found better colostrum quality. However, other researchers did not find any effect on colostrum composition when gilts were fed different levels of CP in gestation diets [13,22,31]. The sows reduced feed intake at the first day postpartum. It means that nutrients accumulated in the sow body are used to produce colostrum. So, the ability for catabolism of the nutrients in the body is important in farrowing sows. In this study, BF change in lactating sows decreased as gestation dietary CP level increased ($p = 0.03$), and ADFI of lactating sows was not significant ($p = 0.48$). It may agree that low CP intake (10.5%) in gestating sows was found higher catabolism of the body reserves to make higher quality of colostrum than high CP intake (13.5%). However, further study is needed to clearly demonstrate a possible correlation among protein level in gestating sows diet, catabolism of the body reserves and colostrum composition.

Table 5. Effects of dietary energy and crude protein levels in the diets of gestating sows on chemical compositions of the colostrum and milk of sows

Energy CP (%)	ME 13.40 MJ/kg (%)			ME 13.82 MJ/kg (%)			SEM	p-value		
	10.5	12	13.5	10.5	12	13.5		ME	CP	M × C
24 hours postpartum (%)										
Casein ¹⁾	9.83	7.37	5.46	8.35	8.06	5.67	0.550	0.85	0.03	0.66
Fat	6.63	6.71	5.38	6.73	3.45	4.99	0.497	0.24	0.34	0.33
Protein ¹⁾	13.31	9.83	7.30	11.28	10.85	7.47	0.767	0.85	0.04	0.67
Lactose ¹⁾	3.42	4.08	4.28	3.65	3.95	4.54	0.146	0.68	0.06	0.82
Total solids ¹⁾	27.16	23.36	19.14	24.77	21.10	18.98	1.042	0.41	0.03	0.87
Solids-not-fat ¹⁾	16.94	13.91	11.75	14.98	14.96	12.05	0.641	0.86	0.03	0.56
Day 21 of lactation (%)										
Casein	4.29	4.68	4.58	4.10	4.62	4.54	0.086	0.58	0.11	0.93
Fat	5.95	7.08	6.79	5.67	6.51	6.66	0.245	0.53	0.23	0.93
Protein	4.86	5.19	5.21	4.54	5.24	5.00	0.122	0.53	0.24	0.83
Lactose	6.04	6.37	6.11	6.50	6.12	6.38	0.067	0.22	0.98	0.10
Total solids	18.61	20.19	19.76	18.34	19.42	19.46	0.321	0.50	0.24	0.94
Solids-not-fat	11.02	11.44	11.37	10.87	11.42	11.34	0.085	0.69	0.11	0.94

¹⁾Linear response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected. ME, metabolizable energy; CP, crude protein; SEM, Standard error of means.

Blood profiles of sows

The effects of dietary energy and CP levels on blood glucose and BUN concentration during the gestation-lactation period are shown in Table 6. There was no significant difference in blood glucose concentration in gestating when sows were fed different levels of ME during gestation, but blood glucose concentration increased at 21 day of lactation when ME levels increased by 0.42 MJ/kg ($p = 0.04$). In this study, the treatment with 13.82 MJ/kg of dietary ME showed lower ADFI than 13.40 MJ/kg of ME, and it had an agreement with Cozler et al. [32] who reported blood glucose concentration had a negative effect on ADFI.

Blood urea nitrogen is one of the indicator of protein utilization. A low BUN level is associated with improved protein synthesis and reduced amino acid oxidation, which can lead to reduced availability of ammonia [33]. Fuller et al. [34] reported that CP synthesis was improved by carbohydrate intake. In addition, increasing total N intake could increase BUN concentration [35]. In this study, BUN concentration increased linearly with dietary CP level at 110 day of gestation, 24 hours postpartum and 21 day of lactation ($p < 0.05$, $p < 0.05$, and $p < 0.05$, respectively), and also increased with an increase in dietary energy at day 110 of gestation and 24 hours postpartum ($p < 0.01$, and $p < 0.01$, respectively). Results of the study by Jang et al. [13] are consistent with the current results, they reported that plasma urea nitrogen concentration increased when dietary CP level in gestating sows was increased.

Conclusion

Total number of piglets born increased with an increase in daily dietary ME of 0.42 MJ/kg (13.40 MJ/kg to 13.42 MJ/kg) in gestating sows. Backfat thickness changes and colostrum quality decreased and piglet death during lactation and BUN level increased

as dietary CP level increased (10.5%–13.5%). A gestating sow diet containing 13.82 MJ/kg ME and 10.5% CP can improve reproductive performance, litter performance, and colostrum quality.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions

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Table 6. Effects of dietary energy and crude protein levels on blood profiles of sows

Energy CP (%)	ME 13.40 MJ /kg (%)			ME 13.82 MJ/kg (%)			SEM	p-value		
	10.5	12	13.5	10.5	12	13.5		ME	CP	M × C
Glucose (mmol/L)										
Day 35	4.03						-	-	-	-
Day 110	4.39	4.49	4.39	4.13	4.43	4.59	0.055	0.82	0.28	0.25
24 hours postpartum	5.60	5.59	5.92	5.19	5.97	5.65	0.128	0.33	0.95	0.13
Day 21 of lactation	4.54	4.05	4.31	4.55	4.58	4.52	0.064	0.04	0.27	0.22
BUN (mmol/L)										
Day 35	3.68						-	-	-	-
Day 110 ¹⁾	2.46	2.70	3.50	3.25	3.29	3.33	0.109	< .01	0.01	0.05
24 hours postpartum [†]	2.30	2.26	4.00	2.90	3.61	3.68	0.176	< .01	< .01	< .01
Day 21 of lactation [†]	5.93	7.46	7.61	7.38	7.06	6.94	0.159	0.24	0.02	< .01

¹⁾Linear response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected.
 CP, crude protein; ME, metabolizable energy; SEM, Standard error of means; BUN, blood urea nitrogen.

Ethics approval and consent to participate

This article does not require IRB/IACUC approval because there are no human and animal participants.

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