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Influence of various levels of milk by-products in weaner diets on growth performance, blood urea nitrogen, diarrhea incidence, and pork quality of weaning to finishing pigs

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Objective: This study was conducted to evaluate various levels of milk by-product in weaning pig diet on growth performance, blood profiles, carcass characteristics and economic performance for weaning to finishing pigs.
Methods: A total of 160 weaning pigs ([Yorkshire×Landrace]×Duroc), average 7.01±1.32 kg body weight (BW), were allotted to four treatments by BW and sex in 10 replications with 4 pigs per pen in a randomized complete block design. Pigs were fed each treatment diet with various levels of milk by-product (Phase 1: 0%, 10%, 20%, and 30%, Phase 2: 0%, 5%, 10%, and 15%, respectively). During weaning period (0 to 5 week), weaning pigs were fed experimental diets and all pigs were fed the same commercial feed during growing-finishing period (6 to 14 week).
Results: In the growth trial, BW, average daily gain (ADG), and average daily feed intake (ADFI) in the nursery period (5 weeks) increased as the milk by-product level in the diet increased (linear, $p<0.05$). Linear increases of pig BW with increasing the milk product levels were observed until late growing period (linear, $p = 0.01$). However, there were no significant differences in BW at the finishing periods, ADG, ADFI, and gain:feed ratio during the entire growing-finishing periods. The blood urea nitrogen concentration had no significant difference among dietary treatments. High inclusion level of milk by-product in weaner diet decreased crude protein (quadratic, $p = 0.05$) and crude ash (Linear, $p = 0.05$) of Longissimus muscle. In addition, cooking loss and water holding capacity increased with increasing milk product levels in the weaner diets (linear, $p<0.01$; $p = 0.05$). High milk by-product treatment had higher feed cost per weight gain compared to non-milk by-products treatment (linear, $p = 0.01$).
Conclusion: Supplementation of 10% to 5% milk by-products in weaning pig diet had results equivalent to the 30% to 15% milk treatment and 0% milk by-product supplementation in the diet had no negative influence on growth performance of finishing pigs.

Keywords: Economic Analysis; Growing-finishing Pig; Growth Performance; Milk By-products; Weaning Pig

INTRODUCTION

Generally, not only corn and soybean meal (SBM) but also lactose and whey powder are also main feed ingredients in weaning pigs diet in Korea. It is well known that lactose and whey powder are used as the main raw materials in weaning pig diets and that supplementation of milk by-products helps maintain an enhanced intestinal environment [1]. Moreover, lactose effects growth and enhances feed intake in weaning pig diets [2-4]. However, according to U.S. Department of Agriculture, international price trends for dairy products are very unstable, and their price is expensive compared to grains. Therefore weaning pig diets which contain high levels of milk by-products are expensive and cause an increase in the cost of pork production. Recent studies indicated that growth performance of weaning pigs was increased by increasing dietary lactose in early weaning period [3-6].

Recently, Jin [7] reported an evaluation of supplementation with barley instead of milk by-products in weaning pig's diet. This demonstrated that barley replacing milk by-product caused low growth performance during the weaning period. However, growth of growing and finishing pigs in the barley treatment caught up with pigs in the milk by-product treatment, resulting in similar days to market weight. For this reason, current study was conducted to understand the effects of various levels of milk by-product in weaning pig diet on growth performance and blood profiles, thereafter growth, carcass characteristics and economics analysis in growing-finishing pigs.

MATERIALS AND METHODS

Experimental design and diet

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Use and Care Committee (SNUIAUCC; SNU-160513-1).

A total of 160 weaning pigs ([Yorkshire×Landrace]×Duroc), 7.01±1.32 kg initial body weight (BW), were used in a 19 week feeding trial. Pigs were allotted to four treatments based on BW and sex in 10 replications with 4 pigs per pen in a randomized complete block design.

Dietary treatments were: i) Non: corn-SBM based diet+milk by-product 0% (Phases 1 and 2: whey powder and lactose 0%), ii) Low: basal diet+milk by-product 10% to 5% (Phase 1: whey powder 4% and lactose 6%, Phase 2: whey powder 2% and lactose 3%), iii) Medium: basal diet+milk by-product 20% to 10% (Phase 1: whey powder 8% and lactose 12%, Phase 2: whey powder 4% and lactose 6%), iv) High: basal diet+milk by-product 30% to 15% (Phase 1: whey powder 12% and lactose 18%, Phase 2: whey powder 6% and lactose 9%). Those experimental diets were fed during the weaning period (0 to 5 week). All nutrients met or exceeded the requirement estimates of NRC [8]. The formula and chemical compositions of weaning pigs' diets are presented in Tables 1 and 2. After weaning period (5 weeks), all pigs were fed a common commercial feed during the entire growing-finishing period (14 weeks). Early-growing diet had metabolizable energy (ME) 3,277 kcal/kg, crude protein (CP) 16.4%, total lysine 0.98%, late-growing diet had ME 3,274 kcal/kg, CP 15.24%, total lysine 0.93%, early-finishing diet had ME 3,279 kcal/kg, CP 14.11%, total lysine 0.86%, late-finishing diet had ME 3,280 kcal/kg, CP 12.53%, total lysine 0.74%. The chemical composition of commercial diets during growing-finishing period are presented in Table 3.

Table 1. Formula and chemical composition of the experimental diets in phase1 (0 to 2 wks)

Item	Treatments[1)]			
	Non	Low	Medium	High
Ingredients (%)				
Corn	38.93	28.79	18.61	8.51
Soybean meal	37.62	38.30	38.98	39.64
Wheat bran	1.76	1.72	1.71	1.68
Whey powder[2)]	0.00	4.00	8.00	12.00
Lactose[3)]	0.00	6.00	12.00	18.00
Fish meal	2.83	2.83	2.83	2.83
Barley	10.13	10.13	10.13	10.13
Palm kernel meal	3.00	3.00	3.00	3.00
Soy-oil	2.76	2.38	2.01	1.61
Monodicalcium phosphate	1.43	1.40	1.37	1.32
Limestone	0.71	0.65	0.59	0.53
L-lysine·HCl	0.16	0.13	0.09	0.06
DL-methionine	0.02	0.02	0.03	0.04
Vit. Mix[4)]	0.10	0.10	0.10	0.10
Min. Mix[5)]	0.10	0.10	0.10	0.10
Salt	0.20	0.20	0.20	0.20
Choline-Cl (50%)	0.10	0.10	0.10	0.10
ZnO[6)]	0.10	0.10	0.10	0.10
β-Mannanase[7)]	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition				
Dry matter[8)] (%)	90.68	90.34	91.55	92.41
Crude protein[8)] (%)	23.90	23.73	23.32	23.49
Crude fat[8)] (%)	3.93	3.55	3.18	2.98
Crude ash[8)] (%)	6.91	7.09	6.89	7.08
Metabolizable energy[9)] (kcal/kg)	3,265.00	3,265.06	3,265.09	3,265.00
Lysine[9)] (%)	1.35	1.35	1.35	1.35
Methionine[9)] (%)	0.35	0.35	0.35	0.35
Ca[9)] (%)	0.80	0.80	0.80	0.80
P[9)] (%)	0.65	0.65	0.65	0.65

1) Non (0/0% milk by-products), Low (10/5% milk by-products), Medium (20/10% milk by-products), High (30/15% milk by-products) in weaner diet.
2) Whey powder, provided from Saputo Inc., Tulare, CA, USA
3) Lactose, provided from Grande cheese company, Fond du Lac, WI, USA
4) Provided the following quantities of vitamins per kilogram of complete diet: Vit A, 16,000 IU; Vit D_3, 3,200 IU; Vit. E, 35 IU; Vit. K_3, 5 mg; rivoflavin, 6 mg; calcium pantothenic acid, 16 mg; niacin, 32 mg; d–biotin, 128 μg; Vit. B_{12}, 20 μg.
5) Provided the following quantities of minerals per kilogram of complete diet: Fe, 281 mg; Cu, 288 mg; Mn, 49 mg; I, 0.3 mg; Se, 0.3 mg.
6) ZnO 800,000 ppm.
7) β-Mannanase 800 IU/g, provided from CTCbio Inc. Seoul, Korea.
8) Analyzed value.
9) Calculated value.

Feeding trial

All pigs were housed in an environmentally controlled building with half-slotted concrete floors and each pen equipped with a feeder and a nipple drinker to provide *ad-libitum* access. The BW and feed intake were recorded at 0, 2, 5, 9, 13, 17, and 19 week to calculate the average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) ratio.

Table 2. Formula and chemical composition of the experimental diets in phase2 (3 to 5 wks)

Item	Treatments[1)]			
	Non	Low	Medium	High
Ingredients (%)				
Corn	45.64	40.46	35.26	30.06
Soybean meal	30.06	30.23	30.41	30.56
Wheat bran	1.98	2.12	2.28	2.48
Whey powder[2)]	0.00	2.00	4.00	6.00
Lactose[3)]	0.00	3.00	6.00	9.00
Fish meal	2.65	2.75	2.85	2.95
Barley	12.00	12.00	12.00	12.00
Palm kernel meal	3.00	3.00	3.00	3.00
Soy-oil	2.16	2.00	1.84	1.68
Monodicalcium phosphate	1.26	1.25	1.23	1.20
Limestone	0.57	0.53	0.49	0.45
L-Lysine·HCl	0.13	0.11	0.09	0.07
DL-methionine	0.00	0.00	0.00	0.00
Vit. Mix[4)]	0.10	0.10	0.10	0.10
Min. Mix[5)]	0.10	0.10	0.10	0.10
Salt	0.20	0.20	0.20	0.20
Choline-Cl (50%)	0.10	0.10	0.10	0.10
ZnO	0.00	0.00	0.00	0.00
β-Mannanase[6)]	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00
Chemical composition				
Dry matter[7)] (%)	88.45	87.40	88.63.	89.01
Crude protein[7)] (%)	20.60	21.02	20.93	20.92
Crude fat[7)] (%)	3.45	3.33	3.12	3.02
Crude ash[7)] (%)	5.18	6.97	5.67	6.33
ME[8)] (kcal/kg)	3,265.00	3,265.08	3,265.07	3,265.02
Lysine[8)] (%)	1.15	1.15	1.15	1.15
Methionine[8)] (%)	0.30	0.30	0.31	0.31
Ca[8)] (%)	0.70	0.70	0.70	0.70
P[8)] (%)	0.60	0.60	0.60	0.60

1) Non (0/0% milk by-products), Low (10/5% milk by-products), Medium (20/10% milk by-products), High (30/15% milk by-products) in weaner diet.
2) Whey powder, provided from Saputo Inc., Tulare, CA, USA
3) Lactose, provided from Grande cheese company, Fond du Lac, WI, USA
4) Provided the following quantities of vitamins per kilogram of complete diet: Vit A, 16,000 IU; Vit D_3, 3,200 IU; Vit. E, 35 IU; Vit. K_3, 5 mg; rivoflavin, 6 mg; calcium pantothenic acid, 16 mg; niacin, 32 mg; d–biotin, 128 μg; Vit. B_{12}, 20 μg.
5) Provided the following quantities of minerals per kilogram of complete diet: Fe, 281 mg; Cu, 288 mg; Mn, 49 mg; I, 0.3 mg; Se, 0.3 mg.
6) β-Mannanase 800 IU/g, provided from CTCbio Inc. Seoul, Korea
7) Analyzed value.
8) Calculated value.

Table 3. Chemical composition of experimental diets in growing-finishing period (6 to 19 wks)

Proximate analysis[1)] (%)	Early growing period (6-9 wk)	Last growing period (10-13 wk)	Early finishing period (14-17 wk)	Last finishing period (18-19 wk)
Dry matter	88.57	88.68	88.44	88.21
Crude protein	16.40	15.24	14.11	12.53
Crude ash	4.45	4.05	3.47	3.01
Crude fat	4.40	3.97	3.71	3.46

1) Analyzed value.

Blood urea nitrogen

Blood samples were collected from anterior vena cava of 6 pigs per treatment for measuring blood urea nitrogen (BUN) after 3 hours of fasting at 0, 2, 5, 9, 13, 17, and 19 weeks. Collected blood samples were centrifuged for 15 min by 1,700 g at 4°C (Eppendorf centrifuge 5810R, Hamburg, Germany). Then, sera samples were aspirated by pipette and stored at –20°C until analysis. The BUN concentration was analyzed using analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co., Basel, Switzerland).

Diarrhea incidence

Incidence of diarrhea was measured every 9:00 am for 35 days post weaning. Data were recorded by each pen and divided into 2 phases to assess the general pattern (Phase 1 and Phase 2). A score of diarrhea incidence from 0 to 4 score (0 = no evidence of watery diarrhea, 1 = 1 pig showed evidence of watery diarrhea, 2 = 2 pigs, 3 = 3 pigs, and 4 = all pigs (n = 4) showed evidence of watery diarrhea in the pen) was determined by counting pigs with evidence of watery diarrhea [9]. After recording data, evidence of watery diarrhea was cleaned away.

Carcass characteristics

Five pigs from each treatment were slaughtered at an average 113 kg for the carcass analysis at the end of experiment. Longissimus muscle (LM) samples were collected from nearby 10th rib on the right side of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time (0 h). Longissimus muscle pH and color were measured at initial, 3, 6, 12, and 24 h. The pH of LM was measured using a pH meter (Φ 500 Series, Bechman Coulter, S. Kraember Blvd Brea, CA, USA) and pork color was measured by Commission Internationale de l'Eclairage (CIE) color L*, a*, and b* value using a CR300 spectrophotometer (Minolta Camera Co., Tokyo, Japan). Proximate analysis of LM samples was conducted by the method of AOAC [10].

Water holding capacity (WHC) of pork was measured by centrifuge method. Longissimus muscles were ground and sampled in filter tube, then heated in water bath at 80°C for 20 min and centrifuged for 10 min at 252 g and 10°C (Eppendorf centrifuge 5810R, Hamburg, Germany). For cooking loss analysis, LM samples were packed in a polyethylene bag and weighted then heated in water bath until core temperature reached 72°C and weighed again. After heated, samples were cored (0.75 cm^3) parallel to muscle fiber and the cores were used to measure the shear force (Warner Bratzler Shear, Chichago, IL, USA). Cooking loss, shear force, and WHC of LM samples were analyzed by National Institute of Animal

Science.

Economic analysis

Economic efficiency was calculated by feed intake, feed cost, and feed efficiency. The total feed cost (won) per weight gain (kg) was calculated using G:F ratio and feed cost. In addition, calculation of estimated feed cost to 110 kg as follows;

$$\text{Estimated feed cost to 110 kg (won)} = \text{Total feed cost (won)} + \frac{\text{Finishing period feed cost (won)}}{\text{Finishing period weight gain (kg)}} \times (110\text{kg} - 19^{th}\text{ week BW})$$

The days to market weight (110 kg) was estimated from 19th week as the end of feeding trial and added the estimated days by ADG of 17 to 19 weeks.

Chemical analysis

Diets were ground by a Cyclotec 1093 Sample Mill (Foss Tecator, Hillerod, Denmark) and then the contents analyzed; dry matter (procedure 967.03; AOAC [10]), crude ash (procedure 923.03; AOAC [10]) and crude fat (procedure 920.39; AOAC [10]). The nitrogen content was analyzed by using the Kjeldahl procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Höganäs, Sweden) and calculating the CP content (Nitrogen×6.25; procedure 981.10; AOAC [10]).

Statistical analysis

Statistical analysis was carried out by general linear model procedure of SAS [11] and orthogonal polynomial contrasts were used to determine linear and quadratic effects by increasing dietary milk by-products levels in weaning pig diet. For data on growth performance, diarrhea incidence, and economic analysis, each pen was considered as experimental unit, while individual pig was used as experimental unit for data on blood profile and carcass characteristics. The differences were declared significant at $p<0.05$ or highly significant at $p<0.01$ and the determination of tendency for all analysis was $0.05<p<0.10$.

RESULTS AND DISCUSSION

Growth performance

The influence of various levels of milk by-products in weaning pig diet on growth performance during weaning to finishing pig period are presented in Table 4 and 5. During weaning period, BW, ADG, and ADFI increased linearly with increasing milk by-product levels in the weaner diets (linear, $p<0.05$). The BW increased linearly at 5 and 13 weeks (linear, $p<0.01$, $p = 0.01$), ADG increased linearly with tendency during 10-13 weeks (linear, $p = 0.09$) but decreased during 14-17 weeks (linear, $p = 0.08$), ADFI increased linearly with tendency during 5-9 weeks (linear, $p = 0.08$) and G:F ratio decreased quadratically during 14-17 weeks (quadratic, $p = 0.03$). The trend of weaning phase was continued until the end of 13 week, thereafter there was no significant difference in growth performance among treatments. However, G:F ratios both in weaning and growing-finishing period were not affected by dietary milk by-products treatment.

In the current study, pigs fed the diets containing high level of milk products had greater BW, ADG, and ADFI during weaning period, because the gastrointestinal tract of the newly weaned pig is easily adapted to a milk based diet as a result of high lactase activity [12,13]. Numerous researches reported that the beneficial effects of high dietary lactose improved growth performance of pigs in early weaning phase [3,5,14-16]. In addition, high dietary lactose improved initial stimulation of appetite and feed intake [4,6]. The growth response in BW to dietary treatment continued until late growing period (13 week). However, differences in growth performance during the weaning period disappeared and significant difference was not observed among treatments at the end of experiment (19 week). Shearer and Dunkin [17] demonstrated that growth of pigs could be improved by high levels of dietary lactose (30% or 45% but subsequent growing-finishing pigs grew slower than those fed low lactose diet (0% or 15%). Tokach et al [18] also reported that different levels of milk by-product (0% or 40%) in weaning pig diets produced significant differences in growth performance only during the weaning period and any significant difference was not observed in growth performance during the growing-finishing. Also, growth retardation due

Table 4. Influence of various milk by-products levels in weaning pig diet on growth performance in weaning pigs[1)]

Criteria	Treatments[2)]				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Body weight (kg)							
Initial	7.006	7.011	7.008	7.013	0.288	-	-
2 wk	11.59	12.36	12.21	12.64	0.502	0.04	0.59
5 wk	21.82	24.09	24.72	25.27	0.919	<0.01	0.15
ADG (g)							
0-2 wk	319	387	372	402	17.0	0.04	0.41
3-5 wk	487	558	596	601	23.1	0.01	0.23
0-5 wk	420	490	506	522	18.6	<0.01	0.12
ADFI (g)							
0-2 wk	436	474	503	507	21.7	0.01	0.40
3-5 wk	801	978	955	1,051	39.8	<0.01	0.22
0-5 wk	655	776	774	834	31.6	<0.01	0.19
Gain:feed ratio							
0-2 wk	0.737	0.773	0.737	0.790	0.0158	0.40	0.81
3-5 wk	0.609	0.533	0.628	0.576	0.0201	0.98	0.75
0-5 wk	0.644	0.640	0.655	0.628	0.0140	0.88	0.60

SEM, standard error of the mean.
1) A total 160 crossbred pigs was fed from average initial body 7.01 ± 1.32 kg and the average final body weight was 23.97 kg.
2) Non (0/0% milk by-products), Low (10/5% milk by-products), Medium (20/10% milk by-products), High (30/15% milk by-products) in weaner diet.

Table 5. Influence of various milk by-products levels in weaning pig diet on growth performance in growing-finishing pigs[1)]

Criteria	Treatments[2)]				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Body weight (kg)							
5 wk	21.82	24.09	24.72	25.27A	0.919	< 0.01	0.15
9 wk	40.87	45.84	44.95	44.62	1.117	0.12	0.35
13 wk	66.03	73.62	73.00a	73.73	1.312	0.01	0.07
17 wk	89.67	95.49	91.88	93.01	1.467	0.59	0.38
19 wk	105.41	112.10	109.87	109.71	1.806	0.47	0.31
ADG (g)							
6-9 wk	681	777	723	691	25.2	0.91	0.17
10-13 wk	867	926	935	970	22.7	0.09	0.76
14-17 wk	877	841	726	742	30.3	0.08	0.68
18-19 wk	926	977	1,058	982	42.3	0.56	0.51
6-13 wk	777	854	836	836	12.7	0.18	0.15
14-19 wk	896	895	837	837	26.8	0.43	0.87
6-19 wk	828	871	843	836	15.4	0.99	0.45
0-19 wk	723	773	756	755	12.9	0.46	0.30
ADFI (g)							
6-9 wk	1,655	2,017	1,853	1,955	62.6	0.08	0.16
10-13 wk	2,614	2,823	2,636	2,880	61.4	0.26	0.88
14-17 wk	2,719	2,976	2,678	2,584	100.3	0.49	0.44
18-19 wk	3,161	3,387	3,240	3,079	104.2	0.71	0.43
6-13 wk	2,151	2,434	2,258	2,433	53.2	0.12	0.56
14-19 wk	2,894	3,139	2,900	2,780	92.1	0.53	0.38
6-19 wk	2,467	2,734	2,532	2,581	57.9	0.79	0.36
0-19 wk	2,001	2,230	2,079	2,131	46.1	0.55	0.32
G:F ratio							
6-9 wk	0.417	0.361	0.391	0.356	0.0130	0.17	0.66
10-13 wk	0.333	0.306	0.355	0.342	0.0096	0.39	0.71
14-17 wk	0.323	0.262	0.271	0.292	0.0086	0.26	0.03
18-19 wk	0.292	0.274	0.331	0.325	0.0040	0.26	0.84
6-13 wk	0.362	0.327	0.369	0.346	0.0077	0.95	0.73
14-19 wk	0.309	0.268	0.298	0.304	0.0090	0.85	0.24
6-19 wk	0.335	0.298	0.334	0.327	0.0078	0.90	0.39
0-19 wk	0.362	0.324	0.365	0.357	0.0082	0.74	0.40

SEM, standard error of the mean; ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed.

1) A total 160 crossbred pigs was fed from average initial body 23.97 kg and the average final body weight was 109.2 kg.

2) Non (0/0% milk by-products), Low (10/5% milk by-products), Medium (20/10% milk by-products), High (30/15% milk by-products) in weaner diet.

to nutrient limitation in weaning pigs induced compensated growth of growing-finishing pigs resulting in similar BW at the end of finishing period [19,20]. Weaning pigs with low growth rate due to limited nutrient intake recovered the normal growth rate compared with other pigs on the same nutritional supply [21]. Ishida et al [20] reported that compensatory growth of pigs induced by lysine sufficiency was partly attributed to greater N retention which increased protein synthesis in skeletal muscle. In this way, pigs fed low milk by-product diet had growth retardation compared with pigs fed high milk by-product diet, however, compensated growth occurred in growing-finishing period. In the present study, BW, ADG, and ADFI decreased in non or low level of milk by-product in the weaning diet, but this trend changed dramatically in the finishing period resulting in no significant difference of BW, ADG, ADFI, and G:F ratio at the end of late finishing period.

Blood urea nitrogen

The concentration of BUN has been used as a good indicator of maximal amino acid utilization [22]. It has been found that BUN is related directly to protein intake and inversely to protein quality [23,24]. In the current study, the concentration of BUN had no significant difference among treatments during whole experimental period except at 19 week where BUN concentrations tended to decrease with increasing milk by-product levels (linear, p = 0.07; Table 6). Dried milk or milk by-products were used as a protein source for young pigs were considered useful feed ingredients due to their nutrient composition, high digestibility, similarity to a sow's milk [12], and high lactase activity in weaning pig [12,13]. However, the current study demonstrated that protein utilization in pigs fed no or low levels of milk by-product did not differ from high milk by-products treatment.

Diarrhea incidence

The influence of various levels of milk by-products in weaning pig diet on diarrhea incidence is shown in Table 7. In weaning period, there was not any significant difference in the diarrhea incidence due to reduction of milk by-products in weaning pig's diet. Zinc oxide at pharmacological concentrations (2,000 to 3,000 mg/kg) has been reported to reduce diarrhea during weaning period [25]. In current study, usage of zinc oxide in phase1 diet was 800 ppm and in phase2 diet was 0 ppm. Also, barley has relatively high fiber source which reduced diarrhea occurrence and is helpful in preventing diarrhea [26]. Also, Jin [7] demonstrated that supplement of barley in weaning pig diet reduced the incidence of diarrhea. Due to the effect

Table 6. Influence of various milk by-products levels in weaning pig diet on blood urea nitrogen in weaning to finishing pigs[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Blood urea nitrogen (mg/dL)							
Initial	14.0	15.2	14.6	15.0	0.46	-	-
2 wk	19.6	19.6	18.7	18.9	0.47	0.53	0.93
5 wk	14.8	14.9	15.3	12.7	0.65	0.36	0.37
9 wk	10.3	10.1	9.4	11.7	0.50	0.38	0.15
13 wk	11.7	11.2	9.8	10.1	0.33	0.11	0.28
17 wk	9.3	8.4	9.5	8.4	0.44	0.69	0.93
19 wk	10.7	10.9	9.2	7.3	0.66	0.07	0.45

SEM, standard error of means.

1) Least squares means of 6 observations per treatment.

Table 7. Influence of various milk by-products levels in weaning pig diet on diarrhea incidence in weaning pigs[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Diarrhea incidence[2)]							
0-2 wk	1.09	1.29	1.68	1.64	0.133	0.28	0.67
3-5 wk	0.57	0.49	0.45	0.66	0.064	0.69	0.32
0-5 wk	0.80	0.85	0.99	1.09	0.080	0.22	0.88

SEM, standard error of means.
1) Least squares means of 10 replications per treatment.
2) Diarrhea incidence: 0 (no occurrence) to 4 (diarrhea on all pigs): Data were measured by average diarrhea incidence during each phases.

of ZnO and barley, weaning pigs fed no or low milk by-product had no significant difference in diarrhea incidence compared with pigs fed high milk by-product content.

Pork quality

The pork quality was measured in order to investigate how the reduction in milk by-product in weaner diets affects the pork quality after slaughter. In the present study, moisture and crude fat of LM had no significant differences among dietary treatments (Table 8). However, crude protein of LM had a quadratic response (quadratic, p = 0.05) and crude ash of LM had a linear response (linear, p 0.05). Frape et al [27] found that early growth rate of weaning pigs was influenced by dietary nutrients but it did not affect the chemical compositions of the carcass in finishing pigs. Although there were no significant differences in moisture and crude fat, high milk by-product treatment had low crude protein and crude ash content in LM. As the dietary milk by-product supplementation increased in weaning period, cooking loss was increased linearly (linear, p<0.01) and WHC was decreased linearly (linear, p = 0.05). Also, shear force of LM tended to increase linearly with dietary milk by-product content increased in weaning pig's diet (linear, p = 0.07). Beilken et al [28] demonstrated that shear force was increased when WHC decreased. Cooking loss is an indirect index of WHC because it decreases when WHC increases [29]. In addition, WHC is an important factor of pork quality [30,31] and high WHC improves pork quality [32,33]. Consequently these results demonstrated that pork quality of finishing pigs was improved when low milk by-products was provided in weaning pigs' diet.

In general, the pH change of pork is a critical factor that determines the quality of pork and it has an effect on freshness, WHC, tenderness, binding ability, meat color and texture [34]. Maganhini et al [35] reported that initial pH was regarded as an indication of PSE (pale, soft and exudative) pork and the final pH was acknowledged as an estimation of DFD (dark, firm and dry). The measured pH (0 hour to 24 hour) was not significantly different among treatments (Table 9) and pH of LM was in the normal range (pH 5.5 to pH 6.0).

The result of pork color (CIE value) of LM is presented in Table 10. There were no significantly difference in a value, L*, a*, and b* value at 0, 3, 6, 12, 24 h after slaughter. In pork color, decreasing in redness and increasing in yellowness had a negative influence on the freshness of pork [36]. However, there were no change in redness or yellowness by milk by-products levels in weaning pig diets. Therefore, these results demonstrated that low levels of milk by-products in weaning pig diet had no negative influence on pH and color of pork after

Table 9. Influence of various milk by-products levels in weaning pig diet on pH of Longissimus muscle after slaughter[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Time after slaughter (h)							
0 h	5.72	5.77	5.75	5.68	0.046	0.71	0.54
3 h	5.49	5.51	5.50	5.50	0.018	0.89	0.37
6 h	5.63	5.62	5.52	5.63	0.028	0.68	0.20
12 h	5.64	5.62	5.53	5.65	0.025	0.56	0.21
24 h	5.69	5.63	5.51	5.63	0.028	0.23	0.06

SEM, standard error of means.
1) Least squares means for five observations per treatment.

Table 8. Influence of various milk by-products levels in weaning pig diet on carcass chracteristics[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Proximate analysis (%)							
Moisture	71.70	70.14	71.35	71.64	0.431	0.82	0.35
Crude protein	21.53	21.62	22.41	20.69	0.236	0.37	0.05
Crude fat	2.27	2.72	3.47	3.21	0.254	0.13	0.48
Crude ash	1.46	1.46	1.19	1.13	0.066	0.05	0.85
Physiochemical property							
Cooking loss (%)	34.10	30.59	35.05	37.08	0.608	< 0.01	< 0.01
Shear force (kg/0.75 cm^3)	6.67	6.49	6.85	7.45	0.167	0.07	0.23
WHC (%)	95.79	96.97	96.46	95.40	0.164	0.05	< 0.01

SEM, standard error of means; WHC, water holding capacity.
1) Least squares means for five observations per treatment.

Table 10. Influence of various milk by-products levels in weaning pig diet on meat color of Longissimus muscle after slaughter[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
CIE value, L[2)]							
0 h	41.49	41.89	43.19	42.33	0.546	0.51	0.61
3 h	41.46	42.46	43.38	42.62	0.670	0.54	0.58
6 h	42.81	44.56	45.45	44.50	0.676	0.41	0.40
12 h	43.84	45.33	46.83	46.00	0.609	0.19	0.38
24 h	45.25	46.61	48.36	46.97	0.516	0.16	0.20
CIE value, a[3)]							
0 h	2.29	3.18	2.32	3.17	0.224	0.41	0.95
3 h	2.39	3.06	3.03	3.28	0.210	0.15	0.61
6 h	3.62	3.71	4.26	3.76	0.237	0.68	0.58
12 h	3.74	3.92	3.82	4.17	0.196	0.54	0.85
24 h	4.31	3.90	4.10	4.83	0.169	0.30	0.14
CIE value, b[4)]							
0 h	4.60	5.12	4.93	5.23	0.187	0.37	0.82
3 h	4.65	5.47	5.59	5.55	0.210	0.14	0.28
6 h	5.86	6.13	6.93	6.36	0.232	0.36	0.44
12 h	6.00	6.35	6.68	6.75	0.197	0.23	0.76
24 h	6.44	6.41	7.10	7.25	0.153	0.20	0.94

SEM, standard error of mean; CIE, Commission Internationale de l'Eclairage.
[1)] Least squares means for five observations per treatment.
[2)] L, luminance or brightness (vary from black to white).
[3)] a, red·green component (+a = red, –a = green).
[4)] b, yellow·blue component (+b = yellow, –b = blue).

slaughter.

Economic analysis

The influence of various level of milk by-product in weaning pig diet on feed cost per weight gain, days to market weight (reached 110 kg BW) and estimated feed cost to 110 kg are presented in Table 11. There were linear increases in feed cost per weight gain during 0 to 2 week, 3 to 5 week, 0 to 5 week, and 0 to 19 week (linear, p<0.01; p<0.01; p<0.01; p<0.01) as the dietary milk by-product supplementation was increased in weaning pigs' diet. Increasing feed cost of high milk by-products treatment was mainly caused by milk by-products supplementation, since high price of milk by-products caused increasing feed cost of weaning pig diet. In addition, there was no significant difference in days to market weight because growth performance of late-finishing period (18 to 19 week) was not affected by dietary treatments. In estimated feed cost to 110 kg, no significant difference was observed. However, estimated feed cost was reduced numerically as supplement of milk by-product in weaning pig diet decreased. Thus pigs fed lower milk by-products supplemented in weaning pig diet had greater economic profits.

IMPLICATIONS

Feeding of milk by-product in weaning pigs' diet increased growth performance during weaning period but its carry-over effect disappeared by the end of late finishing period. Also feeding high levels of milk by-products during the weaning period did not show a positive response in the marketing weight of pigs and no beneficial effects were observed in pork quality. Feed cost during whole experimental period could be reduced by about 11% when weaning pigs were fed no milk by-products treatment diet during weaning period. Consequently, supplementation of 10% to 5% milk by-products in weaning pigs' diet had results equivalent to the high milk treatment. Supplementation with non-milk by-products in the diet had no negative effects on growth performance of finishing

Table 11. Influence of various milk by-products levels in weaning pig diet on economic analysis in weaning to finishing pigs[1)]

Criteria	Treatments				SEM	p-value	
	Non	Low	Medium	High		Lin.	Quad.
Feed cost per weight gain (won/kg)							
0-2 wk	789	915	1,152	1,228	47.3	<0.01	0.62
3-5 wk	905	1,070	1,095	1,682	73.1	<0.01	0.33
6-9 wk	1,095	1,116	1,159	1,339	51.3	0.04	0.32
10-13 wk	1,337	1,449	1,254	1,339	39.4	0.59	0.86
14-17 wk	1,348	1,550	1,615	1,507	38.0	0.11	0.05
18-19 wk	1,471	1,545	1,290	1,302	66.4	0.25	0.83
Weaning period (0-5 wk)	847	992	1,124	1,455	53.5	<0.01	0.02
Growing period (6-13 wk)	1,216	1,283	1,207	1,339	24.7	0.17	0.48
Finishing period (14-19 wk)	1,410	1,548	1,452	1,405	37.0	0.76	0.26
Overall period (0-19 wk)	1,158	1,261	1,274	1,400	26.8	0.01	0.79
Days to market weight from 7.01 kg (reached 110 kg BW)	141.7	137.7	137.4	137.1	2.11	0.46	0.67
Estimated feed cost to 110 kg (won)	123,517	131,349	132,449	137,231	2,534.9	0.11	0.40

SEM, standard error of mean; BW, body weight.
[1)] Least squares means of 10 replications per treatment.

pigs and was the most economically efficient.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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