RESEARCH

Journal of Animal Science and Technology 2019;61(2):77-86
https://doi.org/10.5187/jast.2019.61.2.77

Journal of Animal Science and Technology
JAST
pISSN 1598-9429 eISSN 2055-0391

Evaluation of barley to replace milk by-product in weaning pig's diet

Kyung Young Jin, Jin Su Hong, Dong Wook Sin, Hyo Kon Kang, Yun Young Jo, Geon Il Lee, Xing Hao Jin, Jae Cheol Jang, Jae Hark Jeong and Yoo Yong Kim*

Department of Agricultural Biotechnology, College of Animal Life Sciences, Seoul National University, Seoul 08826, Korea

Abstract

The supplementation level of barley was limited because of high contents of fiber in monogastric animals. Barley contained high soluble fiber, thus it could prevent to diarrhea of weaning pigs. Moreover, as the barley break down by enzymes, free sugars come out from the barley, which could be used as an energy source in weaning pigs and replace milk by-products in weaning pig's diet. Therefore, present study was conducted to investigate the influence of barley to replace milk by-product in weaning pig's diet on growth performance, blood profile, nutrient digestibility, diarrhea incidence, and economic analysis in weaning pigs. A total of 112 crossbred ([Yorkshire × Landrace] × Duroc, weaned at 28 days of age) piglets were allotted to 4 treatments in a randomized complete block (RCB) design. Each treatment has 7 replications with 4 pigs per pen. Pigs were fed each treatment diet which containing different levels of barley (0%, 10%, 20%, and 30%) at the expense of whey powder and lactose. Three phase feeding programs were used for 6 weeks of growth trial (phase 1: 0–2 weeks; phase 2: 3–4 weeks; phase 3: 5–6 weeks). During 0–2 week, body weight (BW), average daily gain (ADG) and G:F ratio were decreased as barley level increased in the diet (linear response, $p < 0.01$). In blood profile, blood urea nitrogen was decreased as the barley level increased in the diet (linear, $p < 0.01$). However, no significant differences were observed in blood glucose level. In nutrient digestibility, crude fat digestibility was linearly increased as barley increased (linear, $p < 0.01$). The incidence of diarrhea was improved as increasing barley contents in all phases (linear, $p < 0.01$). These results demonstrated that supplementation of barley to replace milk by-product influenced negatively on growth performance during 0–2 week. However, the incidence of diarrhea and later growth performance from 3 week postweaning were improved as dietary barley level increased.

Keywords: Barely, Diarrhea incidence, Growth performance, Milk by-product, Weaning pig

Background

In Korea, lactose and whey powder were primary feed ingredients for weaning pigs for enhancing starter pig performance [1]. However, the international price of major feed ingredients has increased since 2007 because of increasing demand for animal feed in developing countries. Many swine producers and nutritionists have sought ways to reduce the feed cost with minimally sacrificing animal's productivity because of increased cost of raw materials. An alternative to feed ingredients such as high fiber grains and by-products were focused on amount of production, steady supply, and cheap price to improve feed cost and productivity [2]. The use of alternative ingredients, such as broken rice, palm kernel meal, and copra meal, has been limited because of poor nutrient digest-

Received: Jan 20, 2019 Revised: Feb 9, 2019 Accepted: Mar 8, 2019
*Corresponding author: Yoo Yong Kim, Department of Agricultural Biotechnology, College of Animal Life Sciences, Seoul National University, Seoul 08826, Korea.
Tel: +82-2-880-4801, E-mail: yooykim@snu.ac.kr

ibility and the presence of potential anti-nutritional factors in monogastric animals [3–5]. Among the alternative feed ingredients, the high attention was focused on barley because of its comparable nutritional values and low price compared with corn and milk products. It has been reported that barley usually contains high levels of β-glucans [6]. The β-glucans, which were present in the endosperm and cell walls of barley, may interfere with digestion and absorption [7]. The soluble β-glucan fraction is thought to raise digesta viscosity, therefore making it difficult for endogenous enzymes to breakdown substrate for nutrient release [8]. However, β-glucans supplementation resulted in fewer pathogens isolated from liver, indicating that β-glucan reduced the intestinal translocation of bacteria [9] and improved intestinal health of pigs [10]. In addition, the barley had a higher sugar content than other cereal grains [11] and it could be used as an energy source instead of milk by-products in weaning pigs. Therefore, the present study was conducted to investigate the effects of barley supplementation levels replace with milk by-products on the growth performance, blood profiles, nutrient digestibility, and diarrhea incidence in weaning pigs.

Materials and Methods

Animal and dietary treatment

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 (SNU-IACUC; SNU-160513-2).

A total of 112 crossbred ([Yorkshire × Landrace] × Duroc) piglets were allotted to 4 treatments in a randomized complete block (RCB) design. Each treatment had 7 replications with 4 pigs per pen and four diets containing 0% (B0), 10% (B10), 20% (B20), or 30% (B30) barley were fed to weaning pigs. The diets were formulated to contain 3,350, 3,307, 3,277 kcal of ME/kg for phase I, II and III, respectively. For phase I and phase II, milk products were decreased by 39%–26%–13%–0% and 15%–10%–5%–0%, respectively, as the barley level increase from 0% to 30%. All other nutrients were met or exceeded the nutrient requirements of NRC [12]. The experimental diets and chemical composition were presented in Table 1, 2, and 3.

Growth trial

Animals were housed in a 1.2 × 3.6 m^2 plastic floor, equipped with a feeder and a nipple drinker to allow freely access to feed and water during the experimental period. The ambient temperature in the weaning house was maintained at 31℃, and then gradually fallen to 26℃ at the end of the experiment. Individual body weight (BW) and feed intake were recorded at 0, 2, 4, and 6 weeks to calculate the average daily gain (ADG), average daily feed intake (ADFI) and gain-to-feed ratio (G:F ratio).

Table 1. Formula and chemical compositions of the experimental diets in phase I (0 to 2 weeks)

Ingredients (%)	B0[1)]	B10	B20	B30
EP corn	12.83	16.64	20.56	24.46
Dehulled-SBM (48%)	39.70	37.36	34.88	32.40
Fish meal	1.70	1.70	1.70	1.70
HP300[2)]	1.00	1.00	1.00	1.00
SBP	3.00	3.00	3.00	3.00
Whey powder	9.00	6.00	3.00	0.00
Lactose	30.00	20.00	10.00	0.00
Barley	0.00	10.00	20.00	30.00
Soy-oil	0.01	1.65	3.26	4.88
MCP	1.10	1.05	1.00	0.95
Limestone	0.91	0.86	0.81	0.76
L-Lysine·HCl	0.00	0.00	0.06	0.12
DL-Methionine	0.11	0.10	0.09	0.09
Vit. mix[3)]	0.12	0.12	0.12	0.12
Min. mix[4)]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
ZnO	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[5)]				
ME (kcal/kg)	3,350.23	3,350.30	3,350.25	3,350.28
CP (%)	23.00	23.00	23.00	23.00
Lysine (%)	1.35	1.35	1.35	1.35
Methionine (%)	0.44	0.44	0.44	0.44
Ca (%)	0.80	0.80	0.80	0.80
Total P (%)	0.65	0.65	0.65	0.65

1) Abbreviated B0, 0% barley was supplemented; B10, barley 10%; B20, barley 20%; B30, barley 30%.

2) HP300 (Hamlet protein, Horsens, Denmark).

3) Provided the following per kilogram of diet: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 g; vitamin K, 2.4 mg.

4) Provided the following per kilogram of diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; $CuSO_4$, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

5) Calculated values.

SBP, sugar beet pulp; MCP, mono calcium phosphate; ZnO, zinc oxide; ME, metabolizable energy; CP, crude protein.

Blood profiles

Blood samples were taken from the jugular vein of each pig for measuring blood urea nitrogen (BUN) concentration and blood glucose level (BGL) at 0, 2, 4, and 6 weeks. Collected blood samples were centrifuged for 15 min at 700 × g on 4℃ (Eppendorf centrifuge 5810R, Germany). The serum was carefully transferred

https://doi.org/10.5187/jast.2019.61.2.77

Table 2. Formula and chemical compositions of the experimental diets in phase II (2 to 4 weeks)

Ingredients (%)	B0[1)]	B10[1)]	B20[1)]	B30[1)]
EP corn	45.97	41.41	36.89	32.34
SBM (44%)	18.09	17.35	16.66	15.95
Dehulled-SBM (48%)	18.09	17.41	16.68	15.98
Whey powder	6.00	4.00	2.00	0.00
Lactose	9.00	6.00	3.00	0.00
Barley	0.00	10.00	20.00	30.00
Soy-oil	0.31	1.30	2.27	3.25
MCP	1.04	1.03	1.01	1.00
Limestone	0.88	0.85	0.81	0.77
L-Lysine·HCl	0.02	0.05	0.08	0.11
DL-Methionine	0.06	0.06	0.06	0.06
Vit. mix[2)]	0.12	0.12	0.12	0.12
Min. mix[3)]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME (kcal/kg)	3,307.23	3,307.25	3,307.21	3,307.17
CP (%)	21.00	21.00	21.00	21.00
Lysine (%)	1.15	1.15	1.15	1.15
Methionine (%)	0.37	0.37	0.37	0.37
Ca (%)	0.75	0.75	0.75	0.75
Total P (%)	0.63	0.63	0.63	0.63

[1)]Abbreviated B0, 0% barley was supplemented; B10, barley 10%; B20, barley 20%; B30, barley 30%.

[2)]Provided the following per kilogram of diet: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 g; vitamin K, 2.4 mg.

[3)]Provided the following per kilogram of diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; $CuSO_4$, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)]Calculated values.

MCP, mono calcium phosphate; ME, metabolizable energy; CP, crude protein.

Table 3. Formula and chemical compositions of the experimental diets in phase III (4 to 6 weeks)

Ingredients (%)	B0[1)]	B10[1)]	B20[1)]	B30[1)]
EP corn	66.92	57.48	48.02	38.56
SBM (44%)	30.52	29.38	28.24	27.11
Barley	0.00	10.00	20.00	30.00
Soy-oil	0.00	0.63	1.28	1.93
MCP	1.04	1.01	0.98	0.95
Limestone	0.75	0.72	0.69	0.66
L-Lysine·HCl	0.17	0.18	0.19	0.19
DL-Methionine	0.06	0.06	0.06	0.06
Vit. mix[2)]	0.12	0.12	0.12	0.12
Min. mix[3)]	0.12	0.12	0.12	0.12
Salt	0.20	0.20	0.20	0.20
Choline-Cl (25%)	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME (kcal/kg)	3,277.20	3,277.18	3,277.23	3,277.22
CP (%)	19.00	19.00	19.00	19.00
Lysine (%)	1.05	1.05	1.05	1.05
Methionine (%)	0.34	0.34	0.34	0.34
Ca (%)	0.70	0.70	0.70	0.70
Total P (%)	0.60	0.60	0.60	0.60

[1)]Abbreviated B0, 0% barley was supplemented; B10, barley 10%; B20, barley 20%; B30, barley 30%.

[2)]Provided the following per kilogram of diet: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 g; vitamin K, 2.4 mg.

[3)]Provided the following per kilogram of diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; $CuSO_4$, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)]Calculated values.

MCP, mono calcium phosphate; ME, metabolizable energy; CP, crude protein.

to 1.5 mL plastic tubes and stored at –20℃ until further analysis. The BUN concentration was analyzed by kinetic UV assay (Modular analytics, Hitachi, Japan) and the BGL was analyzed by enzymatic kinetic assay with hexokinase (Modular analytics, Hitachi, Japan).

Nutrient digestibility

Digestibility trial was conducted in completely randomized design (CRD) with 6 replicates to evaluate the nutrient digestibility and nitrogen relation. Experimental diets for phase II were provided to each treatment animals. A total of 24 crossbred (YLD) barrows, averaging 11.74 ± 0.72 kg BW, were individually allotted to each treatment and housed in a metabolic crate. Total collection method was utilized for the apparent total tract digestibility. During the digestibility trial, water was provided *ad libitum* and experimental diet was provided twice a day at 0700 and 1900 by three times of the maintenance energy requirement (106 kcal of ME/kg of $BW^{0.75}$, [13]). After 5 days of adaptation period, then 5 days of collection period was followed. To determine the first and last day of collections, 0.1% of ferric oxide and chromium oxide were added in experimental diets as a selection marker. Feces and urine were collected daily and stored –20℃ until analysis. Collected fecal samples were pooled and dried in an air-forced drying oven at 60℃ for 72 h, and ground into 1 mm particles in a Wiley mill for chemical analyses include moisture, crude protein (CP), crude fat, and crude ash contents. Total urine was collected daily in a plastic container containing 50 mL of 4N H_2SO_4 and frozen during the 5 day collection period for nitrogen retention analysis.

Diarrhea incidence

Observation of diarrhea incidence was conducted at 0800 during the whole period of feeding trial. Data was recorded by each pen and divided into 3 phases to assess the general pattern (Phase I: 0–2 week, Phase II: 3–4 week, Phase III: 5–6 week). The score of diarrhea incidence was given into 5 numbers (0 = No evidence of watery diarrhea, 1 = 1 pig shows evidence of watery diarrhea, 2 = 2 pigs, 3 = 3 pigs, and 4 = All pigs show evidence watery diarrhea in the pen) by counting pigs with evidence of watery diarrhea [14]. After recording data, evidence of watery diarrhea was cleaned away every time to separate from the next day.

Economic analysis

Economic analysis was conducted to compare the feed cost per 1 kg weight gain of pigs fed the diets containing different milk products and barley levels. Calculation of feed cost per 1 kg weight gain as follows.

$$Feed\ cost\ per1\ kg\ weight\ gain = \frac{Cost\ of\ feed\,(\$) \times Feed\ intake\ per\ head\ (kg)}{Weight\ gain\ per\ head\ (kg)}$$

Chemical and statistical analyses

Experimental diet and excreta were analyzed for contents of dry matter (DM, procedure 967.03; [15]), crude ash (procedure 923.03; [15]), nitrogen (N) by using the Kjeldahl procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden) and CP content (N × 6.25; procedure 981.10; [15]). Nitrogen of urine was determined by the Kjeldahl procedure.

Statistical analysis was carried out by least squares mean comparisons using PDIFF option of General Linear Model (GLM) procedure of SAS (SAS Institute Inc., Cary, NC, USA). For data on growth performance, a pen was considered the experimental unit, while individual pig was used as the experimental unit for data on blood profiles, nutrient digestibility, diarrhea incidence, and economic analysis. The effects of increasing levels of barley were analyzed as linear and quadratic responses by orthogonal polynomial contrasts. Differences were declared significant at $p < 0.05$ and highly significant at $p < 0.01$.

Results and Discussion

Growth performance

Table 4 showed the influence of barley supplementation on growth performance in weaning pigs. During the phase I, BW, ADG, and G:F ratio was declined as the supplementation level of barley increased, resulting in linear response (linear, $p < 0.01$). However, there was no significant difference in the parameters of growth performance in phase II and III.

Numerous swine researchers and nutritionists have been demonstrated the positive effects of milk products in young pig. Most of studies [16–19] showed the using milk products in combination with cereal grains and soybean meal has resulted in superior postweaning weight gains compared with simple grain and soybean meal mixture diet. Mahan [20] reported increased growth performance of weaning pigs fed diets containing dried whey from 0% to 35% in the early postweaning period and the results of the current study were agreed with those suggested, resulting in increased growth performance in phase I. Although little information about the effects of barley inclusion levels in weaning pig's diet is available, supplementation of barley, which contained high NSP and β-glucan, reduced ADG during 0–10 days in weaned pigs [11]. In addition, there were some findings which suggested added fiber may reduce the effect of lactose supplementation on weaning pigs [21–23]. Touchette et al. [24] also reported that lactase activity is higher than amylase activity at three weeks of age and this trend was maintained from day 0 to 14 postweaning, but the response was inconsistent in late phase because lactase activity was decreased relative to amylase activity [25]. In the current study, ADG and G:F ratio was affected by the supplementation level of barley and milk by-product in phase I, but this trend was changed in late phase in agreement with that of Stephas et al. [25], resulting in no significant difference of ADG, ADFI, and G:F ration during the whole experimental period. Some studies reported that β-glucan within barley was degraded in the small intestine of pigs due to hydrolysis by endogenous β-glucanase and the microflora colonizing the small intestine of pigs [26–28]. It should be noted that the activity of enzymes can change depending on the pig age and diet composition. Thus, no difference in growth performance of weaning pigs during phase II and III among treatments could have been due to barley and milk by-product availability depending on enzyme activities.

Nutrient digestibility

The response of barley supplementation on nutrient digestibility was shown in Table 5. Barley supplementation up to 30% did not affect nutrient digestibility of DM, CP, and crude fat. However, a linear increase of crude fat digestibility was observed as addition level of barley increased, resulting in linear response (linear, $p < 0.01$). In the result of nitrogen retention, there was no significant difference among all parameters supporting this observation of CP digestibility.

The negative effects of fiber diets on energy and nutrient utilization of pigs were reported many times [22,23,29]. In barley, barley β-glucans have been shown to be 70% soluble and 30% insoluble fiber [30]. For the high soluble fiber composition, it can

https://doi.org/10.5187/jast.2019.61.2.77

Table 4. Effect of varying levels of barley supplementation on growth performance in weaning pigs[1)]

	Treatment[2)]				SEM[3)]	*p*-value	
	B0	B10	B20	B30		Lin.[4)]	Quad.
Body weight[5)] (kg)							
Initial	7.04	7.05	7.04	7.07	-	-	-
2 wk	10.46	10.02	9.49	9.58	0.320	0.01	0.22
4 wk	15.84	14.88	14.73	15.20	0.457	0.38	0.18
6 wk	23.96	23.08	22.91	24.18	0.064	0.87	0.13
Average daily gain (g)							
0–2 wk	244	212	176	176	8.9	0.01	0.30
2–4 wk	384	348	374	402	14.3	0.54	0.27
4–6 wk	580	586	584	642	20.4	0.25	0.46
0–6 wk	403	382	378	407	10.4	0.92	0.15
Average daily feed intake (g)							
0–2 wk	308	299	259	284	8.2	0.11	0.26
2–4 wk	728	688	704	682	16.1	0.35	0.76
4–6 wk	1,186	1,108	1,101	1,185	36.2	0.96	0.06
0–6 wk	741	699	688	717	17.9	0.41	0.12
Gain:feed ratio							
0–2 wk	0.794	0.710	0.682	0.622	0.0171	0.01	0.72
2–4 wk	0.527	0.505	0.531	0.589	0.0145	0.10	0.24
4–6 wk	0.490	0.528	0.531	0.542	0.0011	0.17	0.63
0–6 wk	0.544	0.546	0.550	0.567	0.0061	0.31	0.49

[1)]A total of 112 crossbred pigs were fed from average initial body weight 7.04 ± 1.39 kg.

[2)]B0, 0% barley was supplemented in each phase; B10, barley 10%; B20, barley 20%; B30, barley 30%.

[3)]Standard error of means.

[4)]Lin. (linear), Quad. (quadratic).

[5)]Values are means for four pens of four pigs per pen.

cause an increase in digesta viscosity, preventing interaction between nutrients and digestive enzymes [31] and reducing nutrient digestibility in pigs [32]. The digestible energy and CP contents of barley decrease as the percentage of hulls in the barley increases, as a result of the high fiber content [33,34]. Moreover, apparent total tract digestibility of nutrients such as DM, CP, crude fat, crude fiber, NDF, ADF, and energy was decreased by high fiber or β-glucan contents of barley-based diet [35,36]. Although barley contained higher dietary fiber relative to other carbohydrate sources, it also contained a high level of free sugar and there was a study suggesting no detectable difference on DM, organic matter, nitrogen, NDF, and gross energy digestibility between barley and other carbohydrate diets [36]. Also, supplementation of two different barley-based diets with different NSP and β-glucan contents had no difference in apparent digestibility of NSP and amino acids [11], and nitrogen [28]. In the present study, the piglets fed high barley diets showed similar digestibility with those fed barley 0% diet and these might be explained by the high sugar content and the supplementation level.

Increased feed efficiency and fat digestibility by the addition of fat sources have been reported many times in weaned pigs [37–40]. The ability of weaned pigs to digest fat was associated with fat sources and improves as age increased [41]. In the present study, the digestibility trial was conducted in early phase and increased fat digestibility by fat inclusion level was detected with an agreement of the results in growth performance.

Blood analysis

Table 6 showed the effects of barley supplementation on blood profiles in weaning pigs. The significant differences by the addition of barley on BUN and BGL were not observed during the whole experimental period except BUN concentration in phase III. The pigs fed diets containing a high level of barley showed lower BUN concentration relative to those fed diets containing a low level of barley in phase III, resulting in linear response (linear, $p < 0.01$). Although little information is available about the effects of barley supplementation on BGL, the high BGL in pigs fed barley diet was expected because of the high sugar content of barley. However, there was no response of barley supplementation with an agreement of Qureshi [42] who found that BGL was not changed by

Table 5. Effect of varying levels of barley supplementation on nutrient digestibility in weaning pigs[1)]

	Treatment[2)]				SEM[3)]	*p*-value[4)]	
	B0	B10	B20	B30		Lin.	Quad.
Nutrient digestibility (%)							
Dry matter	94.02	93.77	93.92	93.87	0.409	0.88	0.84
Crude protein	92.61	92.10	92.33	92.28	0.561	0.80	0.73
Crude ash	74.98	74.22	75.35	76.30	1.898	0.61	0.70
Crude fat	76.66	84.22	87.77	88.96	2.949	0.01	0.11
N-Retention (g/day)							
N-Intake	15.31	14.72	14.16	13.91	-	-	-
N-Feces	1.13	1.16	1.09	1.07	0.042	0.59	0.83
N-Urine	5.01	5.38	5.12	4.88	0.103	0.46	0.13
N-Retention	9.17	8.18	7.95	7.95	0.124	0.17	0.10
N-Digestibility (%)	59.90	55.56	56.16	57.19	1.637	0.30	0.11

1)A total of 24 crossbred pigs were fed from average initial body weight 11.74 ± 0.72 kg / 42 ± 5 days of age.
2)B0, 0% barley was supplemented in each phase; B10, barley 10%; B20, barley 20%; B30, barley 30%.
3)Standard error of means.
4)Lin. (linear), Quad. (quadratic).

Table 6. Effect of varying levels of barley supplementation on BUN and BGL in weaning pigs[1)]

	Treatment[2)]				SEM[3)]	*p*-value[4)]	
	B0	B10	B20	B30		Lin.	Quad.
BUN[5)] (mg/dL)							
Initial	9.20	9.20	9.20	9.20	-	-	-
2 week	12.45	14.70	14.18	14.15	0.458	0.32	0.27
4 week	14.58	14.82	14.97	13.48	0.619	0.58	0.50
6 week	13.78	10.43	11.67	10.10	0.459	0.01	0.25
BGL[6)] (mg/dL)							
Initial	93.29	93.29	93.29	93.29	-	-	-
2 week	98.83	94.83	98.67	96.17	1.382	0.72	0.76
4 week	100.33	97.17	96.00	102.50	1.911	0.73	0.18
6 week	104.33	103.33	97.17	104.17	2.612	0.80	0.51

1)Least squares means for five observations per treatment.
2)B0, 0% barley was supplemented in each phase; B10, barley 10%; B20, barley 20%; B30, barley 30%.
3)Standard error of means.
4)Lin. (linear), Quad. (quadratic).
5)Blood urea nitrogen.
6)Blood glucose level.

barley supplementation when inclusion level was relatively low. Kornegay [43] found the negative correlation between the inclusion level of dietary fiber and nutrient digestibility and there were researches reporting decreased DM and energy digestibility in pigs fed a diet containing high level of barley [44,45]. In the previous findings, the piglets were weaned before day 21, but piglets in the present study were weaned at day 28.

In general, BUN was the indicator for determination of amino acid utilization by pigs and it was directly related to intake of protein and protein quality [46]. Thus, the high level of BUN indicated that excessive amino acids were metabolized and circulated in the blood. In the current study, the BUN concentration of weaning pigs at 2 week and 4 week did not affected by dietary treatments. The result of BUN in the current study was similar to the result of Yoo et al. [47] that milk by-products level in weaning pig's diet had no influence on the BUN in weaning pigs. However, the BUN concentration in 6 week decreased linearly as barley supplementation level increased. Considering the diet formulation of phase III diets, there were no milk by-products and barley inclusion level increased by corn and SBM decreased. It should be noted that the BUN concentration can vary depending on the excessive nitrogen or amino acids and amino acid imbalance. Thus, the linear decrease of BUN at 6 week could be due to the improvement of the amino balance for weaning pigs fed barley in corn-SBM based diet.

https://doi.org/10.5187/jast.2019.61.2.77

Diarrhea incidence

The effect of barley supplementation on diarrhea incidence in weaning pigs was shown in Table 7. In all phases, diarrhea incidence was decreased linearly as the inclusion level of barley increased, resulting in linear response (linear, $p < 0.01$).

Schulman [48] demonstrated that weaning could cause gastric changes increasing counts of *E. coli*, resulting in severe diarrhea and growth depth. However, many researchers indicated that these negative effects of weaning on gastric condition could be decreased by the supplementation of fiber sources and prebiotics [49–51]. Soluble fiber, highly included in barley, improves the volume and bulk of intestinal contents and it may cause increased water-holding capacity and viscosity causing low moisture content of feces [52]. Moreover, the supplementation of fiber source as prebiotics was associated with inhibiting harmful bacterial activity [53]. Fermented barley β-glucans increased short-chain fatty acids and low digesta pH, thus it helps to the production of beneficial bacteria at the expense of acid-sensitive *Enterobacteria* spp. [32] and killed *Salmonella* and *E. coli* bacteria in the gastrointestinal tract [54]. The β-glucans in barley have been shown to have prebiotic properties [32] and it could affected positively the diarrhea incidence of weaned pigs. In the present study, although the diarrhea incidence was improved by barley supplementation in phase I, ADG was decreased linearly. It should be noted that the growth rate of pigs within 7 days postweaning can vary depending on weaning weight, weaning stress, nutrient digestibility or availability, and diarrhea.

Table 7. Effect of varying levels of barley supplementation on diarrhea incidence in weaning pigs[1)]

	Treatment[2)]				SEM[3)]	*p*-value[4)]	
	B0	B10	B20	B30		Linear	Quad
Diarrhea incidence[5)]							
Phase I	1.9	1.8	1.5	1.2	0.09	0.01	0.39
Phase II	0.9	0.7	0.7	0.4	0.07	0.01	0.77
Phase III	0.8	0.6	0.5	0.2	0.05	0.01	0.67

1)Least squares means for seven replications per treatment.

2)B0, 0% barley was supplemented in each phase; B10, barley 10%; B20, barley 20%; B30, barley 30%.

3)Standard error of means.

4)Lin. (linear), Quad. (quadratic).

5)Diarrhea incidence: 0 (no occurrence) to 4 (all pigs diarrhea); Data were measured by average total diarrhea incidence during each phases.

Table 8. Effect of varying levels of barley supplementation on economic analysis in weaning pigs[1)]

	Treatment[2)]				SEM[3)]	*p*-value[4)]	
	B0	B10	B20	B30		Lin.	Quad.
Phase I (0 to 2 weeks)							
Cost of feed/kg ($)	0.99	0.86	0.74	0.61	-	-	-
Weight gain per head (kg)	3.42	2.97	2.47	2.47	0.124	0.01	0.30
Feed intake per head (kg)	4.31	4.19	3.62	3.97	1.153	0.09	0.25
Feed cost / 1 kg ($)	1.26	1.23	1.09	1.00	0.029	0.01	0.59
Phase II (2 to 4 weeks)							
Cost of feed/kg ($)	0.68	0.65	0.60	0.56	-	-	-
Weight gain per head (kg)	5.38	4.87	5.24	5.62	0.201	0.53	0.27
Feed intake per head (kg)	10.19	9.64	9.85	9.54	2.255	0.35	0.76
Feed cost / 1 kg ($)	1.31	1.28	1.13	0.95	0.042	0.01	0.17
Phase III (4 to 6 weeks)							
Cost of feed/kg ($)	0.53	0.53	0.54	0.54	-	-	-
Weight gain per head (kg)	8.13	8.20	8.18	8.98	0.286	0.25	0.46
Feed intake per head (kg)	15.54	14.77	14.50	15.60	5.062	0.95	0.06
Feed cost / 1 kg ($)	0.98	0.94	0.94	0.93	0.026	0.29	0.56
Total feed cost / 1 kg ($)	1.18	1.15	1.05	0.96	0.022	0.01	0.32

1)A total of 112 crossbred pigs were fed from average initial body weight 7.04 ± 1.39 kg.

2)B0, 0% barley was supplemented in each phase; B10, barley 10%; B20, barley 20%; B30, barley 30%.

3)Standard error of means.

4)Lin. (linear), Quad. (quadratic).

Thus, this result could partly be attributed that the positive effect for high digestible milk by-product intake affect strongly to the growth rate of phase I than the negative effect for the diarrhea incidence.

Economic analysis

To evaluate the effects of barley supplementation on the cost of feed and productivity, the economic analyses were conducted at end of growth trial (Table 8). The feed cost/1 kg BW was reduced significantly as the inclusion level of barley increased in phase I and II. Although there was no significant difference, feed cost / 1 kg BW in phase III was also improved numerically in pigs fed the diet containing a high level of barley and low level of milk by-product.

Consequently, there were no detrimental effects of barley supplementation up to 30% replace to milk by-product on growth performance, nutrient digestibility, and blood profiles. Feed cost per weight gain and diarrhea incidence were improved clearly when the pigs fed the diet containing a high level of barley.

Competing interests

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

Funding sources

This research was supported by "Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ011617)" Rural Development Administration, Korea .

Acknowledgements

Not applicable.

Availability of data and material

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

Authors' contributions

Conceptualization: Kim YY, Lee GI.
Data curation: Hong JS, Jo YY.
Methodology: Hong JS, Jin KY.
Software: Jeong JH, Jin XH.
Validation: Jin KY, Jang JC.
Investigation: Sin DW, Kang HG.
Writing - original draft: Jin KY.
Writing - review & editing: Kim YY, Hong JS.

Ethics approval and consent to participate

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 (SNU-IACUC; SNU-160513-2).

ORCID

Kyung Young Jin	https://orcid.org/0000-0003-1182-9271
Jin Su Hong	https://orcid.org/0000-0002-3401-3024
Dong Wook Sin	https://orcid.org/0000-0002-3789-4840
Hyo Kon Kang	https://orcid.org/0000-0001-7226-875X
Yun Young Jo	https://orcid.org/0000-0003-0969-9877
Geon Il Lee	https://orcid.org/0000-0003-0412-2905
Xing Hao Jin	https://orcid.org/0000-0003-4942-9142
Jae Cheol Jang	https://orcid.org/0000-0001-9843-3186
Jae Hark Jeong	https://orcid.org/0000-0001-9611-3787
Yoo Yong Kim	https://orcid.org/0000-0001-8121-3291

References

1. Mahan DC. Efficacy of dried whey and its lactalbumin and lactose components at two dietary lysine levels on postweaning pig performance and nitrogen balance. J Anim Sci. 1992;70:2182-7.
2. Woyengo TA, Beltranena E, Zijlstra RT. Nonruminant nutrition symposium: controlling feed cost by including alternative ingredients into pig diets: a review. J Anim Sci. 2014;92:1293-305.
3. Li S, Sauer WC, Huang SX, Gabert VM. Effect of beta-glucanase supplementation to hulless barley- or wheat-soybean meal diets on the digestibilities of energy, protein, beta-glucans, and amino acids in young pigs. J Anim Sci. 1996;74:1649-56.
4. Hongtrakul K, Goodband RD, Behnke KC, Nelssen JL, Tokach MD, Bergstrom JR, et al. The effects of extrusion processing of carbohydrate sources on weanling pig performance. J Anim Sci. 1998;76:3034-42.
5. Kim BG, Lee JH, Jung HJ, Han YK, Park KM, Han IK. Effect of partial replacement of soybean meal with palm kernel meal and copra meal on growth performance, nutrient digestibility and carcass characteristics of finishing pigs. Asian-Australas J Anim Sci. 2001;14:821-30.
6. Campbell GL, Classen HL, Thacker PA, Rossnagel BG, Grootwassink JW, Salmon RE. Effect of enzyme supplementation on the nutritive value of feedstuffs. 7th Western Nutrition Conference; Saskatoon, SK, Canada; 1986.
7. Aaman P, Graham H. Analysis of total and insoluble mixed-linked (1–3), (1–4)-beta-D-glucans in barley and oats. J Agric Food Chem. 1987;35:704-9.
8. Johnson IT, Gee JM. Effect of gel-forming gums on the intestinal unstirred layer and sugar transport in vitro. Gut. 1981;22:398-403.

https://doi.org/10.5187/jast.2019.61.2.77

9. Huff GR, Huff WE, Farnell MB, Rath NC, Solis de Los Santos F, Donoghue AM. Bacterial clearance, heterophil function, and hematological parameters of transport-stressed turkey poults supplemented with dietary yeast extract. Poult Sci. 2010;89:447-56.
10. Jensen BB. The impact of feed additives on the microbial ecology of the gut in young pigs. J Anim Feed Sci. 1998;7 Suppl 1:45-64.
11. Yin YL, Baidoo SK, Schulze H, Simmins PH. Effects of supplementing diets containing hulless barley varieties having different levels of non-starch polysaccharides with β-glucanase and xylanase on the physiological status of the gastrointestinal tract and nutrient digestibility of weaned pigs. Livest Prod Sci. 2001;71:97-107.
12. Committee on Animal Nutrition, Subcommittee on Swine Nutrition, National Research Council. Nutrient requirements of swine. 10th ed. Washington, DC: National Academy Press; 1998.
13. Kim BG, Lee JW, Stein HH. Energy concentration and phosphorus digestibility in whey powder, whey permeate, and low-ash whey permeate fed to weanling pigs. J Anim Sci. 2012;90:289-95.
14. Hermes RG, Molist F, Ywazaki M, Nofrarias M, Gomez de Segura A, Gasa J, et al. Effect of dietary level of protein and fiber on the productive performance and health status of piglets. J Anim Sci. 2009;87:3569-77.
15. AOAC, Cunniff P. Official methods of analysis of AOAC international. 16th ed. Washington, DC: Association of Official Analytical Chemists; 1995.
16. Graham PL, Mahan DC, Shields RG Jr. Effect of starter diet and length of feeding regimen on performance and digestive enzyme activity of 2-week old weaned pigs. J Anim Sci. 1981;53:299-307.
17. Cera, KR, Mahan DC, Reinhart GA. Effects of dietary dried whey and corn oil on weanling pig performance, fat digestibility and nitrogen utilization. J Anim Sci. 1988;66:1438-45.
18. Goodband RD, Hines RH. The effect of barley particle size on starter and finishing pig performance. J Anim Sci. 1987;65 Suppl 1:317.
19. Lepine AJ, Mahan DC, Chung YK. Growth performance of weanling pigs fed corn-soybean meal diets with or without dried whey at various L-lysine. HCl levels. J Anim Sci. 1991;69:2026-32.
20. Mahan DC. Evaluating two sources of dried whey and the effects of replacing the corn and dried whey component with corn gluten meal and lactose in the diets of weanling swine. J Anim Sci. 1993;71:2860-6.
21. Cheeke PR, Stangel DE. Lactose and whey utilization by rats and swine. J Anim Sci. 1973;37:1142-6.
22. Shi XS, Noblet J. Effect of body weight and feed composition on the contribution of hindgut to digestion of energy and nutrients in pigs. Livest Prod Sci. 1994;38:225-35.
23. Davidson MH, McDonald A. Fiber: forms and functions. Nutr Res. 1998;18:617-24.
24. Touchette KJ, Crow SD, Allee GL, Newcomb MD. Weaned pigs respond to lactose (day 0–14 postweaning). J Anim Sci. 1995;73 Suppl 1:70.
25. Stephas EL, McMurty MR, DeGregorio RM, Miller BL. Performance of piglets fed phase II starters differing in lactose level. J Anim Sci. 1996;74 Suppl 1:52.
26. Graham H, Fadel JG, Newman CW, Newman RK. Effect of pelleting and β-glucanase supplementation on the ileal and fecal digestibility of a barley-based diet in the pig. J Anim Sci. 1989;67:1293-8.
27. Li S, Sauer WC, Huang SX, Gabert VM. Effect of beta-glucanase supplementation to hulless barley-or wheat-soybean meal diets on the digestibilities of energy, protein, beta-glucans, and amino acids in young pigs. J Anim Sci. 1996;74:1649-56.
28. Jensen MS, Knudsen KEB, Inborr J, Jakobsen K. Effect of β-glucanase supplementation on pancreatic enzyme activity and nutrient digestibility in piglets fed diets based on hulled and hulless barley varieties. Anim Feed Sci Technol. 1998;72:329-45.
29. Canh TT, Sutton AL, Aarnink AJA, Verstegen MWA, Schrama JW, Bakker GCM. Dietary carbohydrates alter the fecal composition and pH and the ammonia emission from slurry of growing pigs. J Anim Sci. 1998;76:1887-95.
30. Hoberg A. Cereal non-starch polysaccharides in pig diets - influence on digestion site, gut environment and microbial populations [Ph.D. dissertation]. Uppsala (Sweden): Swedish University of Agricultural Sciences; 2003.
31. Campbell GL, Bedford MR. Enzyme applications for monogastric feeds: a review. Can J Anim Sci. 1992;72:449-66.
32. O'Connell JM, Sweeney T, Callan JJ, O'Doherty JV. The effect of cereal type and exogenous enzyme supplementation in pig diets on nutrient digestibility, intestinal microflora, volatile fatty acid concentration and manure ammonia emissions from finisher pigs. Anim Sci. 2005;81:357-64.
33. Knudsen KB, Eggum BO. The nutritive value of botanically defined mill fractions of barley: 3. The protein and energy value of pericarp, testa, germ, aleuron, and endosperm rich decortication fractions of the variety Bomi. J Anim Phys Anim Nutr. 1984;51:130-48.
34. Bell JM, Shires A, Keith MO. Effect of hull and protein contents of barley on protein and energy digestibility and feeding value for pigs. Can J Anim Sci. 1983;63:201-11.

35. Pettersson A, Lindberg JE. Ileal and total tract digestibility in pigs of naked and hulled barley with different starch composition. Anim feed Sci technol. 1997;66:97-109.
36. Lynch MB, Sweeney T, Callan JJ, O'Doherty JV. Effects of increasing the intake of dietary β-glucans by exchanging wheat for barley on nutrient digestibility, nitrogen excretion, intestinal microflora, volatile fatty acid concentration and manure ammonia emissions in finishing pigs. Animal. 2007;1:812-9.
37. Crampton EW, Ness OM. A meal mixture suitable as the entire ration to be self-fed dry to pigs weaned at ten days of age. J Anim Sci. 1954;13:357-64.
38. Frobish LT, Hays VW, Speer VC, Ewan RC. Effect of fat source and level on utilization of fat by young pigs. J Anim Sci. 1970;30:197-202.
39. Allee GL, Baker DH, Leveille GA. Fat utilization and lipogenesis in the young pig. J Nutr. 1971;101:1415-21.
40. Lawrence NJ, Maxwell CV. Effect of dietary fat source and level on the performance of neonatal and early weaned pigs. J Anim Sci. 1983;57:936-42.
41. Cera KR, Mahan DC, Reinhart GA. Evaluation of various extracted vegetable oils, roasted soybeans, medium-chain triglyceride and an animal-vegetable fat blend for postweaning swine. J Anim Sci. 1990;68:2756-65.
42. Qureshi MS. Relationship of pre- and postpartum nutritional status with reproductive performance in Nili-Ravi buffaloes under the conventional farming system in NWFP, Pakistan [Ph.D. dissertation]. Faisalabad (Pakistan): University of Agriculture Faisalabad; 1998.
43. Kornegay ET. Feeding value and digestibility of soybean hulls for swine. J Anim Sci. 1978;47:1272-80.
44. Bowland JP. Comparison of several wheat cultivars and a barley cultivar in diets for young pigs. Can J Anim Sci. 1974;54:629-38.
45. Wu JF, Ewan RC. Utilization of energy of wheat and barley by young swine. J Anim Sci. 1979;49:1470-7.
46. Eggum BO. Blood urea measurement as a technique for assessing protein quality. Br J Nutr. 1970;24:983-8.
47. Yoo SH, Hong JS, Yoo HB, Han TH, Jeong JH, Kim YY. 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. Asian-Australas J Anim Sci. 2018;31:696-704.
48. Schulman A. Effect of weaning on the pH changes of the contents of the piglet stomach and duodenum. Nord Vet Med. 1973;25:220-5.
49. Muralidhara KS, Sheggeby GG, Elliker PR, England DC, Sandine WE. Effect of feeding lactobacilli on the coliform and lactobacillus flora of intestinal tissue and feces from piglets. J Food Prot. 1977;40:288-95.
50. Mitchell, IDG, Kenworthy R. Investigations on a metabolite from lactobacillus bulgaricus which neutralizes the effect of enterotoxin from Escherichia coli pathogenic for pigs. J Appl Microbiol. 1976;41:163-74.
51. Cherbut C, Albina E, Champ M, Doublier JL, Lecannu G. Action of guar gums on the viscosity of digestive contents and on the gastrointestinal motor function in pigs. Digestion. 1990;46:205-13.
52. Metzler BU, Mosenthin R. A review of interactions between dietary fiber and the gastrointestinal microbiota and their consequences on intestinal phosphorus metabolism in growing pigs. Asian-Australas J Anim Sci. 2008;21:603-15.
53. Gibson GR, Beatty ER, Wang X, Cummings JH. Selective stimulation of bifidobacteria in the human colon by oligofructose and inulin. Gastroenterology. 1995;108:975-82.
54. Mikkelsen LL, Naughton PJ, Hedemann MS, Jensen BB. Effects of physical properties of feed on microbial ecology and survival of Salmonella enterica serovar typhimurium in the pig gastrointestinal tract. Appl Environ Microbiol. 2004;70:3485-92.

https://doi.org/10.5187/jast.2019.61.2.77