Effects of Extrusion Conditions of Corn and Soybean Meal on the Physico-Chemical Properties, Ileal Digestibility and Growth of Weaned Pig

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ABSTRACT : Two experiments were conducted to evaluate the effects of different extrusion conditions of corn and soybean meal on physico-chemical properties, ileal digestibility of amino acid and growth performance in weaned pigs. In Expt. 1, to compare physico-chemical properties and ileal digestibility of extruded corn and soybean meal, ground corn (2 mm screen) and soybean meal were separately extruded in four different conditions: (1) no preconditioning, low water supply (3.0 l/min) (NCLW), (2) no preconditioning, high water supply (7.0 l/min) (NCHW), (3) preconditioning (steam 3.0 l/min) with low water supply (3.0 l/min) (CLW), and (4) preconditioning (steam 3.0 l/min) plus high water supply (7.0 l/min) (CHW). Twenty-five cannulated pigs (L × Y × D, 7.62 kg BW for soybean meal, 8.80 kg BW for corn) were employed to determine nutrients digestibility of the extruded feedstuffs. In Expt. 2, a total of 90 pigs (L × Y × D, 9.18 kg BW) were used for a 28 d feeding trial to compare growth performance of pigs as affected by different extrusion conditions. Before mixing, corn and soybean meal were blended and extruded by the same conditions as described in Expt. 1.

Corn extruded with NCLW showed the highest ($p < 0.05$) degree of gelatinization (DG), compared to the lowest values observed for NCHW. Extrusion of corn with preconditioning (CLW and CHW) increased ($p < 0.05$) the DG as compared to the extrusion condition of NCHW. Extruded SBM with NCLW showed the lowest ($p < 0.05$) degree of texturization among treatments. The ileal digestibility of GE in SBM was higher with NCHW and CHW as compared to NCLW. The ileal digestibility of CP was lower in extruded corn, but was higher in extruded SBM, compared to untreated sample. Lysine digestibility of extruded corn(except corn with NCHW) was in general significantly improved. Extrusion of SBM resulted in no improvements in ileal digestibility of amino acids, but extruded SBM with NCLW had lower lysine digestibility compared to other treatments. In growth responses, pigs fed a diet with CLW had higher, but not significant, average daily gain (ADG) than other treatments during first 2 weeks. From d 15 to 28, pigs fed a diet with CHW had significantly less ($p < 0.05$) average daily feed intake (ADFI) than others except NCHW. In conclusion, the proper extrusion condition for corn and SBM in terms of ileal digestibility of amino acids and growth performance of weaning pigs seems to be the combination of preconditioning and a low water supply (3.0 l/min).

(**Key Words**: Extrusion Condition, Corn, Soybean Meal, Ileal Digestibility, Growth Performance, Weaned Pigs)

INTRODUCTION

The process of extrusion cooking involves heating, pressurization, and shearing. Extrusion affects cereal grains by rupturing the semi-crystalline structure of starch granules, which cause gelatinization and thus, improves utilizability by animals (Bjorck et al., 1985; Mills et al., 1993). Herkelman et al. (1990) suggested that extrusion of corn improved energy utilization but did not affect the utilization of lysine or N by pigs. Richert et al. (1992) also reported that extrusion of corn and sorghum improved performance for d 0 to 10 after weaning of piglets, but reduced growth performance if fed for the entire nursery period. Extrusion affects soybean products

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as well, by destroying trypsin inhibitors and other antinutritional factors present in soybeans, and by rupturing the oil cells of soybeans, allowing the oil to be reabsorbed into the product, which increases digestibility and reduces the antigenicity of less refined soy products (Li et al., 1991; Mills et al., 1993).

In addition, the processing condition during extrusion can alter the effect of extrusion on the nutritional values and/or physicochemical properties of feedstuffs. Moisture content, as one of first variables during extrusion, is critical to the extrudate, which is related to the friction, shearing, and temperature in the extruder (Hancock, 1992). Chiang and Johnson (1977) reported that gelatinization of wheat starch increased as extrusion temperature was increased from 65 to 110℃, but only when the starch was preconditioned to 18 to 27% moisture. Gomez and Aguilera (1984) also demonstrated improved gelatinization of corn starch with reduced moisture contents. Moist extrusion can result in better nutritional values of feedstuffs than dry extrusion (Decuypere et al., 1981; Walker et al., 1986b; Li et al., 1991; Friesen et al., 1993).

Information, however, is still lacking for the effects of different extrusion conditions on the nutritional values of feedstuffs. Therefore, this study was conducted to investigate the effects of different extrusion conditions (water input levels and with or without preconditioning) of corn and soybean meal, which are major feed ingredients, on physico-chemical properties, ileal digestibility of energy, protein and amino acid and growth performance of weaned pigs.

MATERIALS AND METHODS

Experimental design, animal and feed

For ileal digestibility, a total of 25 cannulated pigs (L × Y × D, 7.62 kg BW for soybean meal, 8.80 kg BW for corn) were used in individual metabolism cages, with 5 replications/treatment. The cannula and surgical procedure used in this study were made according to the method suggested by Walker et al. (1986a). The pigs were given four days of convalescent and adjustment period prior to the test diets. On the fifth and sixth days post-surgery, digesta samples were collected. The samples were frozen immediately at −20℃, freeze dried (Ilsin Engineering Co., Korea), ground with a 1 mm mesh Wiley mill, and stored in a refrigerator until analysis. Ground corn (2 mm) and soybean meal (3 mm) were separately extruded with a semi-moist type extruder (Millbank®, Single Screw, New Zealand) as follows; 1) no preconditioning, low water supply (3.0 l/min) (NCLW), 2) no preconditioning, high water supply (7.0 l/min) (NCHW), 3) preconditioning (steam 3.0 l/min) with low water supply (3.0 l/min) (CLW), and 4) preconditioning (steam 3.0 l/min), high water supply (7.0 l/min) (CHW). Steam and water input were mechanically controlled, thus extrusion temperatures varied from 125 to 150℃ according to the consistent throughput of extrudates by about 1,500 kg/h. All extrudates were ground and mixed with other ingredients as shown in table 1.

Table 1. Experimental diets for metabolic trial in nursery pigs

	Corn	Soybean meal
Ingredient (%):		
Corn	63.94	–
Soybean meal	–	50.00
Lactose	25.00	35.00
Corn starch	–	7.44
Dicalcium phosphate	3.43	2.74
Soybean oil	2.00	2.00
Limestone	0.95	0.68
Salt	0.50	0.50
Vit. premix[1]	0.25	0.20
Min. premix[2]	0.124	0.11
Antibiotic[3]	1.00	1.00
Biotin	0.50	–
Choline chloride	0.965	–
Potassium chloride	1.00	–
Se premix[4]	0.08	0.09
Folic acid	0.0005	–
Chromic oxide	0.25	0.25
Total	100.00	100.00
Chemical composition[5] (%):		
Crude protein	5.56	24.00
Calcium	1.00	1.00
Phosphorus	0.90	0.90

[1] Supplied per kilogram of diet: 5,513 IU of vitamin A, 551 IU of vitamin D_3, 22 IU of vitamin E, 2.2 mg of vitamin K (as menadione), 5.5 mg of riboflavin, 13.8 mg of pantothenic acid (as d-calcium pantothenate), 30.3 mg of niacin, 551 mg of choline, and 0.03 mg of vitamin B_{12}.

[2] Supplied per kilogram of diet: 100 mg of Mn, 100 mg of Fe, 100 mg of Zn, 40 mg of Ca, 264 mg of Cu, 3.0 mg of I, 1.0 mg of Co, and 0.03 mg of Se.

[3] Supplied per kilogram of diet: 110 mg of chlortetracycline, 110 mg of sulfathiazole, and 55 mg of penicillin.

[4] Se premix: Se 198.4 mg/kg.

[5] Calculated value.

For a feeding trial with the extrudates, a total of 90 pigs (L × Y × D, 9.18 kg BW) were allotted on the basis of sex to five treatments with 3 replications of 6 animals/pen. Corn and soybean meal were blended and extruded with the above conditions. Production rate was constant (about 1,800 kg/h) and cooking temperatures were from 130 to 135℃. Pigs were housed in 2.5 × 1.5 m pens with concrete floors, one nipple water and a feeder per pen, and had free access to water and feed during the experimental period (28 days). All diets were fed as mash form, and the formulas and chemical composition of experimental diets were presented in table 2.

Table 2. Formula and chemical composition of basal diet for feeding trial

Ingredients (%)	% of diet
Corn	54.00
Soybean meal (46%)	34.87
Tricalcium phosphate	1.89
Salt	0.10
Vit. mixture[1]	0.20
Min. mixture[2]	0.24
Soybean oil	3.18
Milk replacer	3.00
Spray dry plasma protein	1.50
Fumaric acid	0.20
Choline chloride	0.23
Colistin[3]	0.20
Tyrosine[4]	0.10
Sulfathiazole[5]	0.10
L-lysine	0.07
DL-methionine	0.12
Total	100.00
Chemical composition[6] (%):	
Crude protein	21.95
Metabolizable energy (kcal/kg)	3,360
Lysine	1.30
Methionine + Cystine	0.80
Calcium	0.84
Phosphorus	0.72

[1] Supplied per kg diet: 8,000 IU vitamin A, 2,500 IU vitamin D_3, 30 IU vitamin E, 3 mg vitamin K, 1.5 mg thiamin, 10 mg riboflavin, 2 mg vitamin B_6, 40 μg vitamin B_{12}, 30 mg pantothenic acid, 60 mg niacin, 0.1 mg biotin, 0.5 mg folic acid.

[2] Supplied per kg diet: 200 mg Cu, 100 mg Fe, 150 mg Zn, 60 mg Mn, 1 mg I, 0.5 mg Co, 0.3 mg Se.

[3,4,5] Supplied 20 mg colistin, 100 mg tyrosine, 200 mg sulfathiazole per kg.

[6] Calculated value.

Chemical and statistical analysis

Proximate analysis were conducted by the methods of AOAC (1990), and chromium was measured by an atomic absorption spectrophotometer (Shimadzu®, AA 625, Japan). Amino acids were determined, following acid hydrolysis in 6N HCl at 110℃ for 16 hrs (Mason, 1984), using an automatic analyzer (LKB® 4150 alpha, Pharmacia Instr. Co., England). The gross energy of diet was measured by an adiabatic bomb calorimeter (Parr®, USA). The degree of gelatinization (Wooton et al., 1971) in corn, and texturization (Harper, 1981) in soybean meal were also determined.

Statistical analysis were carried out by Duncan's multiple range test (Duncan, 1955), using the General Linear Model (GLM), and the procedure of SAS program (1985).

RESULTS AND DISCUSSION

Gelatinization and texturization

The degree of gelatinization (DG) for corn and texturization (DT) for SBM were presented in table 3. The DG of corn was significantly ($p < 0.05$) affected by extrusion conditions. Corn extruded with NCLW, at the highest temperature (150℃) in the end of barrel, showed the highest ($p < 0.05$) DG, whereas corn extruded with NCHW, having a lower temperature (125℃), had the lowest DG compared to other treatments. But, extrusion of corn with preconditioning (CLW and CHW) increased ($p < 0.05$) the DG as compared to the extrusion condition of NCHW.

However, the trend of DT for SBM extrusion, was different from that of DG for corn extrusion under the same conditions. As the input levels of moisture (water and/or steam) were increased, the temperature in the barrel was also increased, resulting an improved ($p < 0.05$) DT of SBM. Among different extrusion conditions, except NCLW, there were no significant differences ($p > 0.05$) in the DT of SBM. Results obtained from this study are consistent with previous reports which demonstrated improved gelatinization (Chiang and Johnson, 1977; Gomez and Aguiler, 1984; Bjorck, 1985), and texturization (Owusu-Ansah et al., 1984; Chinnaswamy and Hanna, 1990) during extrusion cooking. Temperature and moisture content are critical to the degree of extrusion cooking. Mercier and Feillet (1975) adjusted the moisture content of corn starch to 22% and measured the effect of temperatures from 70 to 225℃. Maximum expansion was achieved between 170 and 200℃. Chiang and Johnson (1977) also previously indicated that the gelatinization of wheat starch increased as extrusion temperature was increased from 65 to 110℃, but only when starch was preconditioned to $\geq 18\%$ moisture. In the present study, temperature was only a second variable. Temperature in barrel was highest (150℃) when a low amount of water (3.0 l/min) was added as compared with others. Therefore, it exerted an improved DG. Interestingly, for SBM extrusion, the barrel temperature slightly increased when the input level of water was increased, resulting in a improved DT.

Table 3. The effect of different extrusion condition of corn and soybean meal on the gelatinization and texturization

Item \ Treatment[1]	NCLW	NCHW	CLW	CHW
Corn				
Temp. in barrel (℃)[2]	150	120	130	125
Gelatinization (%)[3]	75.71 ± 1.24^{a}	54.59 ± 1.50^{c}	62.34 ± 1.16^{b}	61.10 ± 1.51^{b}
Soybean meal				
Temp. in barrel (℃)[2]	135	140	145	150
Texturization (%)[3]	4.55 ± 0.26^{b}	6.58 ± 0.22^{a}	6.30 ± 0.01^{a}	6.06 ± 0.23^{a}

[1] NCHW: no conditioning, low water supply (3.0 ℓ/min).
NCHW: no conditioning, High water supply (7.0 ℓ/min).
CLW: conditioning (steam 3.0 ℓ/min) plus low water supply (3.0 ℓ/min).
CHW: conditioning (steam 3.0 ℓ/min) plus high water supply (7.0 ℓ/min).

[2] Temperature in the last barrel when samples were taken, which was second variable.

[3] Means ± SE with different superscript in the same row are different ($p < 0.05$).

Ileal digestibilities of nutrients

The ileal digestibilities of gross energy (GE), crude protein (CP), and amino acids of extruded corn and SBM are presented in tables 4 and 5, respectively.

There were no significant differences ($p > 0.05$) among treatments in GE digestibility of corn, even though corn extruded with NCLW showed the highest DG. However, CP digestibility of corn extruded at the condition of NCLW was significantly higher ($p < 0.05$) than those of other extruded corn. SBM extruded by CHW, had the highest digestibility of GE among treatments, with significant differences ($p < 0.05$) compared to SBM unextruded or extruded with NCLW. The CP digestibilities of SBM extruded with NCHW, CLW or CHW were higher ($p < 0.05$) than those of unextruded or extruded SBM with NCLW.

There were interactions in CP digestibilities of corn and SBM (control vs extrusion, E-1,3 vs E-2,4, E-1,2 vs E-3,4), and in GE digestibility of SBM (E-1,3 vs E-2,4).

For amino acids, even though the average digestibilities of essential amino acids (AEAA), average non-essential amino acids (ANEAA), and total amino acids (TAA) of corn were not significantly ($p > 0.05$) different from each other, lysine digestibility was generally improved when corn was extruded, and showed a significant difference ($p < 0.05$) between unextruded and extruded corn with NCLW, CLW or CHW. The digestibility of threonine was significantly higher ($p < 0.05$) in extruded corn with CLW than that with CHW. For NEAA, there were inconsistent trends in ileal digestibility when corn was extruded, showing alternatively an increase or decrease. There were also interactions in amino acids digestibilities of corn between treatments (control vs extrusion: Lys, Pro, Ala,; E-1, 3 vs E-2, 4: Leu, Ala; E-1, 2 vs E-3, 4: Val, Asp, Glu, Pro, Gly, Ala, Tyr) as shown in table 4. When SBM was extruded with NCLW, the digestibility of amino acids generally decreased with a significant difference ($p < 0.05$) between unextruded and extruded with NCLW for ANEAA and TAA. As compared to unextruded SBM, the digestibilities of several EAA decreased significantly ($p < 0.05$) when SBM was extruded with NCLW for Thr, Phe and Val, with NCHW for Thr, with CLW for Met, Leu, and Phe and with CHW for Met. However, the digestibilities of His and Lys in extruded SBM were generally improved ($p < 0.05$) over those of an unextruded SBM except extruded with NCLW. For NEAA there were inconsistent digestibilities among treatments. There were also interactions in digestibilities of amino acids between extruded and unextruded SBM (Val, Met, Leu, Phe, His, Glu, Ala and Tyr), between water levels (Phe, Glu, Pro and ANEA) and between with and without preconditioning (Thr, Lys, Asp, Ser, Gly and ANEAA).

The extrusion of corn did not generally improve the ileal digestibilities of energy and CP in the diet of weaned pigs. Even though extruded corn with NCLW showed the highest DG, the difference in energy digestibility was not significant compared to other treatments. But, Lys digestibility was generally improved when corn was extruded with preconditioning. This result is not in agreement with the report of Herkelman et al. (1990), who found that extrusion improved ($p < 0.05$) energy utilization, but did not affect the utilization of lysine in corn fed to growing pigs. Unlikely corn, extrusion of SBM with adequate moisture generally improved the digestibilities of energy and CP but not those of amino acids when compared to those observed for unextruded SBM. But extrusion with low moisture (NCLW) reduced the ileal digestibilities of amino acids mostly in SBM. In addition, the digestibilities of several amino acids such as His and Lys were improved when SBM was extruded with preconditioning. Hancock (1992) suggested that raising moisture content of the extruded material tended

Table 4. Ileal digestibilities of corn as affected by different extrusion conditions

Treatment	Control	NCLW (E-1)	NCHW (E-2)	CLW (E-3)	CHW (E-4)	SE
GE	84.48	85.43	83.23	84.15	84.10	0.31
CP	74.22^{ab}	80.87^{a}	70.43^{b}	67.78^{b}	67.76^{b}	4.32
Amino acids						
Thr	71.30^{ab}	68.29^{ab}	78.39^{ab}	79.28^{a}	66.36^{b}	7.23
Val	80.93	83.63	86.76	83.32	79.20	4.91
Met	88.35	84.52	92.32	77.63	86.16	9.82
Ile	80.20	79.03	90.25	67.86	79.82	14.99
Leu	84.73	77.62	88.24	82.80	87.01	7.63
Phe	83.32	78.23	82.36	79.91	67.96	12.09
His	74.06	64.87	68.33	71.41	71.21	8.70
Lys	70.20^{c}	80.01^{a}	73.53^{bc}	76.82^{ab}	77.88^{ab}	3.51
Arg	77.26	80.31	79.48	84.70	86.00	6.76
AEAA	78.93	77.39	82.18	78.08	78.29	5.03
Asp	76.97^{ab}	85.45^{a}	83.04^{ab}	79.10^{ab}	75.81^{b}	5.28
Ser	80.95	80.94	83.65	83.32	84.40	3.75
Glu	89.36^{bc}	86.52^{c}	90.04^{abc}	93.60^{ab}	94.46^{a}	2.91
Pro	88.11^{a}	79.14^{ab}	79.56^{ab}	61.39^{b}	58.84^{b}	13.64
Gly	64.91	65.69	70.14	66.93	57.00^{b}	4.73
Ala	86.25^{a}	76.51^{a}	83.68^{a}	61.01^{b}	80.74^{a}	6.43
Tyr	76.35^{ab}	70.00^{ab}	54.66^{b}	84.49^{a}	93.34^{a}	17.91
ANEAA	80.41	77.75	77.82	75.69	77.80	4.16
ATAA	79.58	77.55	80.28	77.04	78.07	4.03

Probability	THR	VAL	MET	ILE	LEU	PHE	HIS	LYS	ARG	EAA
Con. vs Ext.	NS*	NS	NS	NS	NS	NS	NS	0.003	NS	NS
E-1,3 vs E-2,4	NS	NS	NS	NS	0.071	NS	NS	NS	NS	NS
E-1,2 vs E-3,4	NS	0.091	NS	NS	NS	NS	NS	NS	NS	NS

Probability	ASP	SER	GLU	PRO	GLY	ALA	TYR	NEAA	CP	GE
Con. vs Ext.	NS	NS	NS	0.029	NS	0.009	NS	NS	0.046	NS
E-1,3 vs E-2,4	NS	NS	NS	NS	NS	0.001	NS	NS	0.044	NS
E-1,2 vs E-3,4	0.021	NS	0.001	0.013	0.024	0.012	0.010	NS	0.028	NS

Abbreviations: see table 3 (Control = unextruded corn).
GE: gross energy; CP: Crude protein.
AEAA: average essential amino acid.
ANEAA: average non-essential amino acid.
ATAA: average total amino acid; SE: standard error.
* Not significant.
** Values with different superscript in the same row are different ($p < 0.05$).

Table 5. Ileal digestibilities of soybean meal as affected by different extrusion conditions

	Control	NCLW (E-1)	NCHW (E-2)	CLW (E-3)	CHW (E-4)	SE
GE	72.60^{bc}	71.75^{c}	77.75^{ab}	76.39^{abc}	78.20^{a}	0.80
CP	75.39^{b}	75.38^{b}	80.74^{a}	80.76^{a}	83.48^{a}	2.80
Amino acids						
Thr	74.72^{a}	60.39^{c}	68.76^{b}	79.22^{a}	75.29^{a}	4.08
Val	81.03^{a}	66.61^{b}	72.86^{ab}	73.93^{ab}	72.11^{ab}	7.44
Met	87.71^{a}	80.74^{ab}	77.97^{ab}	66.32^{c}	69.63^{bc}	7.78
Ile	74.74	77.05	78.16	74.44	79.13	9.48
Leu	81.35^{a}	75.28^{ab}	78.23^{ab}	70.99^{b}	73.95^{ab}	6.28
Phe	85.36^{a}	68.01^{bc}	80.19^{ab}	62.77^{c}	77.93^{ab}	8.36
His	56.07^{b}	66.13^{a}	68.17^{a}	75.45^{a}	67.67^{a}	6.46
Lys	83.47^{b}	82.97^{b}	84.96^{ab}	88.78^{a}	86.43^{ab}	2.99
Arg	87.36^{ab}	86.31^{b}	90.27^{a}	89.01^{ab}	87.96^{ab}	2.26
AEAA	79.09^{a}	73.72^{b}	77.73^{ab}	75.65^{ab}	76.68^{ab}	3.17
Asp	80.55^{b}	72.99^{c}	74.98^{c}	87.41^{a}	80.21^{b}	3.03
Ser	81.79^{a}	75.33^{b}	83.33^{a}	85.04^{a}	81.58^{a}	2.74
Glu	88.47^{b}	90.27^{b}	92.50^{a}	88.06^{b}	94.00^{a}	1.53
Pro	78.58^{abc}	69.04^{c}	85.87^{ab}	74.44^{bc}	90.24^{a}	8.26
Gly	65.53^{a}	54.67^{b}	63.21^{a}	69.58^{a}	70.27^{a}	5.37
Ala	78.33^{a}	52.86^{b}	64.81^{b}	61.99^{b}	56.29^{b}	8.21
Tyr	63.08^{b}	72.54^{ab}	80.61^{ab}	80.60^{ab}	87.44^{a}	14.08
ANEAA	76.62^{a}	69.67^{b}	77.90^{a}	78.16^{a}	80.00^{a}	3.73
ATAA	78.01^{a}	71.95^{b}	77.81^{a}	76.75^{a}	78.13^{a}	3.11

Probability	THR	VAL	MET	ILE	LEU	PHE	HIS	LYS	ARG	AEAA
Con. vs Ext.	NS*	0.020	0.002	NS	0.047	0.006	0.001	NS	NS	NS
E-1,3 vs E-2,4	NS	NS	NS	NS	NS	0.003	NS	NS	NS	NS
E-1,2 vs E-3,4	0.001	NS	0.007	NS	NS	NS	NS	0.021	NS	NS

Probability	ASP	SER	GLU	PRO	GLY	ALA	TYR	ANEAA	CP	GE
Con. vs Ext.	NS	NS	0.002	NS	NS	0.001	0.001	NS	0.004	NS
E-1,3 vs E-2,4	NS	NS	0.001	0.001	NS	NS	NS	0.012	0.008	0.056
E-1,2 vs E-3,4	0.001	0.008	NS	NS	0.001	NS	NS	0.009	0.008	NS

Abbreviations: see table 3 (Control = unextruded SBM) and table 4.

* Not significant.

** Values with different superscript in the same row are different ($p < 0.05$).

to decrease friction, shearing, and extrusion temperature. He also suggested that a compromise with pre-extrusion moisture concentrations of 18 to 25% and extrusion temperatures of 120 to 170℃ seemed to result in a high degree of gelatinization and minimal protein damage in cereal grains. For SBM cooking, since the moisture supply for the NCLW treatment was low (less than 18%) in the present study, it could not prevent protein damage by friction and shearing in the barrel. Many researchers suggested that moist extrusion could result in an improved nutrient digestibility of feed ingredients (Decuypere et al., 1981; Walker et al., 1986; Li et al., 1991; Friesen et al., 1993), compared to dry extrusion.

Growth performance

The effect of differently extruded diets on post-weaning performance respones was presented in table 6. For d 0 to 14 period, pigs fed the extruded diet with CLW had higher ADG (5.9% improvement over the unextruded diet), even though there were no significant differences among extrusion conditions. From d 15 to 28, pigs fed diets containing corn-SBM extruded with CHW had significantly less ($p < 0.05$) ADFI than others, except NCHW. For the overall period (28 d), there were no siginificant ($p > 0.05$) differences in ADG, ADFI and G/F ratio among pigs fed the differently extruded corn-SBM diets. No improvement of growth performance was obtained from extrusion of corn and SBM in weaning pigs, which is consistent with the previous results of Cunningham (1959), Aumaitre (1972), Lindemann et al. (1986) and den Hartog et al. (1988). However, Friesen et al. (1993) reported that early weaned pigs fed moist extruded soybean meal had a similar ADG to pigs fed a milk diet but had an increased ADG over pigs fed dry extruded soybean meal. Richert et al. (1992) used weaning pigs, averaging 21 d of age with 6 kg initial weight in their experiment and concluded that extruded corn and sorghum improved performance from 0 to 10 postweaning, but reduced growth performance if fed for the entire nursery period. The present data would support this conclusion because this experiment was performed using weaning pigs, averaging 9.2 kg of initial weight. Another factor which can alter the effect of extrusion of feedstuffs is the extrusion method itself, especially if the feedstuffs are extruded separately or simultaneously. Recently, Deluca et al. (1995) indicated in a weaning pig study that extrusion of the individual ingredients (corn, soybean, soybean meal) improved overall pig performance, whereas extrusion of the blends did not improve performance. However in grower pig study, Hancock et al. (1991) reported that the combined extrusion of sorghum and soybeans together was more beneficial than extruding those ingredients separately. Since corn and SBM mixture was extruded together in the present study, it possibly resulted in a reduced extrusion effect due to a slight lower temperature in the barrel as compared to the extrusion of corn and SBM separately.

Table 6. Effects of various extrusion conditions on growth pefomance of weaned pigs

Treatment	Control	NCLW	NCHW	CLW	CHW	SE
d 0 to 14						
ADG (g)	387	375	389	410	380	13.9
ADFI (g)	607	623	624	647	623	12.8
G/F (g/kg)	636	600	622	632	606	12.1
d 15 to 28						
ADG (g)	533	524	469	520	489	10.1
ADFI (g)	937^{a}	937^{a}	848^{ab}	924^{a}	826^{b}	16.4
G/F (g/kg)	569	560	552	564	592	9.4
d 0 to 28						
ADG (g)	460	449	429	465	434	9.4
ADFI (g)	772	780	736	786	724	12.5
G/F (g/kg)	595	577	582	591	599	6.6

Probability	d 0 to 14			d 15 to 28			d 0 to 28		
	ADG	ADFI	G/F	ADG	ADFI	G/F	ADG	ADFI	G/F
Con. vs ext.	NS*	NS	NS	NS	NS	NS	NS	NS	NS
LW vs HW	NS	NS	NS	0.061	0.007	NS	NS	NS	NS
NC vs C	NS	NS	NS	NS	NS	NS	NS	NS	NS

[ab] Means with different superscript in the same row differ ($p < 0.05$).

* Not significant.

** Abbreviations: see table 3.

In conclusion, on the basis of data on ileal digestibility and growth performance, processing conditions during moist extrusion of corn and SBM (preconditioning plus water, 3 l/min) were considered to be one of the most critical factors affecting the quality of extruded diets for weaning pigs.

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