Effects of dietary supplementation of *Saccharomyces cerevisiae* fermentation product to sows and their offspring on growth and meat quality

Y. B. Shen,* V. Fellner,* I. Yoon,† and S. W. Kim*[1]

*North Carolina State University, Raleigh 27695 and †Diamond V, Cedar Rapids, IA 52405

ABSTRACT: This study evaluated the effects of long term dietary supplementation of *Saccharomyces cerevisiae* fermentation product (SCFP) in the diets for sows and offspring on growth performance, intestinal morphology, volatile fatty acid production, and carcass characteristics of offspring. Newly weaned pigs (n = 256) were allotted to 4 treatments based on a 2 × 2 factorial arrangement. Each treatment had 8 pens with 8 pigs per pen. First factor was maternal dietary effects (no SCFP, or SCFP at 12.0 and 15.0 g/d through gestation and lactation, respectively) and the second factor was dietary supplementation of SCFP to offspring (no SCFP, or SCFP at 0.2 and 0.1% for nursery and finisher, respectively). Pigs were on a 6-phase feeding program with assigned diets from nursery to slaughter. Body weights (BW) and feeder weights were measured at the end of each phase. On d 5 after weaning, 1 pig per pen was euthanized to evaluate intestinal morphology and volatile fatty acid production. At 115 kg of BW, 1 pig from each pen was slaughtered to measure carcass characteristics. Feeding diets with SCFP to sows or to their offspring had no effect on BW, overall average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed (G:F) ratio during the nursery or finisher period. Feeding SCFP to sows tended to increase (P = 0.098) cecal butyric acid production in their offspring. Pigs with SCFP tended to have a greater (P = 0.084) concentration of acetic acid but a reduced (P = 0.054) propionic acid in colon digesta than pigs without SCFP regardless of maternal feeding regimen. Loin marbling scores were greater (P = 0.043) in pigs with SCFP than those without SCFP regardless of maternal feeding regimen. Overall, supplementation of SCFP in sow diets did not affect growth performance or intestinal morphology of their offspring. Supplementation of SCFP in diets of offspring from nursery to slaughter had little effect on growth performance. However, inclusion of SCFP from nursery to slaughter improved marbling score possibly by increased acetic acid and butyric acid production in the large intestine.

Key words: carcass characteristic, pig, *Saccharomyces cerevisiae* fermentation product, volatile fatty acids

Transl. Anim. Sci. 2017.1:45–53
doi:10.2527/tas2016.0005

INTRODUCTION

The use of antibiotics has long played an important role in animal production as subtherapeutic enhancements against animal illness and disease (Barton, 2000). The inclusion of antibiotics to gestation and lactation diets of sows has been shown to influence litters, resulting in larger pigs and a decreased incidence of piglet mortality (Soma and Speer, 1975). Subtherapeutic use of antibiotics during the weaning period has been applied to solve post-weaning problems (Barton, 2000). Concerns about the perceived risk of antibiotic resistance have led to a ban of subtherapeutic use of antibiotics in several European and Asian countries. Due to the restricted use of antibiotics in some regions, various products that can improve animal health including probiotics, prebiotics, and yeast products have gained tremendous attention. One of the hypothesized functions of these products is to enhance the growth of health benefiting microorganism in the gut environment with the goal of improving growth performance (Jadamus et al., 2001; Jadamus et al., 2002; Vahjen et al., 2002; Taras et al., 2006; Simon et al., 2007). The *Saccharomyces cerevisiae* fermentation products (SCFP) are the most

[1]Corresponding author: sungwoo_kim@ncsu.edu
Received September 9, 2016.
Accepted November 4, 2016.

widely researched within the sub-therapeutic antibiotics-alternative category. (van der Peet-Schwering et al., 2007; Shen et al. (2009) and 2011; Price et al., 2010).

The SCFP is a dried product produced via fermentation of an unmodified strain of *Saccharomyces cerevisiae,* containing organic acids, polyphenols, nucleotides, B-vitamins, residual yeast cells, yeast cell wall fragments (β-glucans and mannan-oligosaccharides), and the media utilized during fermentation (Shen et al., 2011). Several studies have indicated that feeding SCFP enhanced growth performance, strengthened the immune system in nursery pigs, and improved the health and reproductive performance of sows (Kornegay et al., 1995; van der Peet-Schwering et al., 2007; Kim et al., 2008 and 2010; Shen et al. 2009 and 2011). However, very little information has been reported on the potential for SCFP to further affect the growth and/or health of their offspring. Therefore, this study was conducted to evaluate whether the long term dietary supplementation of SCFP to pigs weaned from sows fed SCFP would affect growth performance, intestinal morphology, volatile fatty acid production, and carcass characteristics.

MATERIALS AND METHODS

Experimental protocols were approved by the Institutional Animal Care and Use Committee at North Carolina State University (Raleigh, NC) and Texas Tech University (Lubbock, TX).

Animals and Design

Two hundred fifty six pigs weaned from 42 sows (Camborough-22, PIC) were used in this study. Pigs were allotted to a 2 × 2 factorial arrangement. The first factor was a sow diet with or without SCFP and the second factor was an offspring diet with or without SCFP. On d 5 before breeding, sows were allotted to 2 dietary treatments representing: (1) a basal diet without SCFP additive (n = 20) and (2) a basal diet with 12.0 g/d SCFP (Diamond V Original XPC^{TM}, Diamond V, Cedar Rapids, IA) through gestation and 15.0 g/d SCFP through lactation (n = 22) as suggested by Kim et al. (2008). After weaning, piglets from these sows were further assigned to a second factor with 2 dietary treatments in 6-phase feeding program. Pigs from within sow treatment were separated by sex and within sex pigs were randomly allotted to 2 offspring dietary treatments. Dietary treatments were: (1) basal diet without SCFP and (2) basal diet with 0.2 and 0.1% SCFP for phases 1 to 3 and phases 4 to 6, respectively. After weaning at 3 wk of age, phase 1 was 3 to 4 wk of age, phase 2 was 4 to 6 wk of age, and phase 3 was 6 to 9 wk of age. After phase 3, phase 4 was 9 to 17 wk of age, phase 5 was 17 to 23 wk of age, and phase 6 was 23 to 27 wk of age. Each treatment consisted of 8 pens with 8 pigs per pen. Gilts and barrows were equally distributed within each treatment and pen. Pigs were housed in pens (1.5 × 3.0 m) with plastic pleated flooring, steel feed bins, and stainless steel water nipples in a nursery building until the end of phase 3 (6 wks). From phase 4, pigs were housed in pens (2.5 × 3.8 m) with slatted concrete floors, stainless feed bins, and stainless steel water nipples in a finisher building until the end of the study [115 kg body weight (BW)]. Body weights and feeder weights were recorded at the end of each phase for a computation of growth performance.

Diets

Basal diets for all sows were corn and soybean based diets. Gestation diets contained 12.2% CP and 3.1 Mcal metabolizable energy (ME)/kg and lactation diets contained 19.2% crude protein (CP) and 3.3 Mcal ME/kg. Diets were formulated according to the nutrient requirements of sows (NRC, 1998). Dietary composition of sow diets was presented in our previous data (Shen et al., 2011). Sows were limit-fed during gestation, receiving 2 kg/d (as-fed basis) of the gestation diet. At 0800 h, sows received 12 g/d of their respective treatment top dressing from 5 d before breeding until farrowing. Top dressing was either (1) a mixture of corn and soybean meal to provide 15% CP that matches the CP concentration in Diamond V Original XPC or (2) Diamond V Original XPC. On d 109 of gestation, sows were moved into farrowing crates. After farrowing, sows were given ad libitum access to lactation diets. In addition, sows received 15 g/d of their respective treatment top dressing at 0800 h during lactation.

After weaning, pigs were fed based on a 6-phase feeding program from weaning to slaughter (Table 1). Corn and soybean meal were the major ingredients for the diets in all phases. Phase 1 and 2 also included dried whey, plasma protein, and fish meal in addition to corn and soybean meal. Diets were formulated according to the nutrient requirements (NRC, 1998). Nursery diets with SCFP supplementation (phase 1 to 3) contained 0.2% Diamond V Original XPC by replacing corn in basal diets and provided 3.29 to 3.34 Mcal ME/kg and 21.3 to 23.0% CP. Grower-finisher diets with SCFP supplementation (phase 4 to 6) contained 0.1% Diamond V Original XPC also by replacing corn in basal diets provided 3.36 to 3.40 Mcal ME/kg and 14.7 to 18.2% CP.

Gut Tissue and Digesta

On d 5 after weaning, 1 pig representing the mean BW of each pen was euthanized by carbon dioxide suffocation in a chamber followed by exsanguination for collection

Table 1. Dietary composition of basal nursery and finishing diets, as fed basis

Diets	Phase 1[1]	Phase 2[1]	Phase 3[1]	Phase 4[2]	Phase 5[2]	Phase 6[2]
Ingredient, %						
Corn grain	34.2	42.7	60.7	69.0	76.8	79.0
Soybean meal, dehulled	22.0	29.0	34.0	26.0	19.0	17.0
Dried whey	27.5	17.5	–	–	–	–
Plasma protein, APC-920	4.0	3.0	–	–	–	–
Fish meal, Menhaden	4.5	–	–	–	–	–
Vitamin-mineral premix[3]	4.0	3.0	2.0	2.0	1.4	1.4
Salt	0.45	0.35	0.25	0.30	0.15	0.15
Zinc Oxide	0.30	0.25	–	–	–	–
Dicalcium Phosphate	0.40	1.50	1.40	1.00	0.90	0.85
Limestone	0.70	0.70	0.70	0.70	0.75	0.60
Fat, vegetable oil	2.00	1.50	1.00	1.00	1.00	1.00
Total	100	100	100	100	100	100
Calculated composition						
DM, %	91.1	90.7	89.8	89.7	89.6	89.5
ME, Mcal/kg	3.30	3.29	3.34	3.36	3.37	3.38
CP, %	23.0	22.2	21.3	18.2	15.5	14.7
Lys, %	1.51	1.36	1.19	0.97	0.78	0.72
Ca, %	0.92	0.90	0.74	0.62	0.59	0.52
Available P, %	0.55	0.55	0.36	0.27	0.24	0.23
Total P, %	0.73	0.77	0.64	0.54	0.50	0.49

[1]Nursery diets with Saccharomyces cerevisiae fermentation product (SCFP; phases 1 to 3) contained 0.2% Diamond V Original XPC (Diamond V, Cedar Rapids, IA) by replacing corn in basal diets.

[2]Grower-finisher diets with SCFP (phases 4 to 6) contained 0.1% Diamond V Original XPC by replacing corn in basal diets.

[3]Provided the following per kg of the complete diet: manganese, 46.7 mg; iron, 75 mg; zinc, 103.8 mg; copper, 9.5 mg; iodide 0.72 mg; selenium, 0.23 mg; retinyl acetate, 2600 μg; cholecalciferol, 20.6 μg; D-α-tocopherol, 41.5 mg; menadione sodium bisulfate, 2.7 mg; vitamin B-12, 54.9 μg; riboflavin, 13.7 mg; niacin, 54.9 mg; and choline, 1650 mg.

of digesta and intestinal tissue. The entire gastrointestinal tract was carefully removed and dissected into duodenum, jejunum, ileum, cecum, colon, and rectum. The middle section of jejunum (3 cm) was collected and stored in 10% formaldehyde (Fisher Diagnostics, Middletown, VA) to determine villus height and crypt depth. Jejunum samples were fixed in 10% formaldehyde (Protocol Fisher Scientific) and then embedded in paraffin wax. Following hematoxylin and eosin staining, 10 well-oriented intact villus and associated crypt were measured in triplicate at 40× magnification using an Olympus microscope (Olympus Optical Company, Center Valley, PA). Digesta from colon (20 to 30 mL) and cecum (20 to 30 mL) was collected into plastic containers to determine volatile fatty acid (**VFA**) contents. Volatile fatty acids in digesta samples were quantified by gas liquid chromatography (model CP-3380; Varian, Walnut Creek, CA) according to Shen et al. (2009).

Slaughter and Carcass Measurements

At the conclusion of the study (approximately 115 kg of BW), 1 pig representing the median BW of each pen was selected and slaughtered at a local processing plant to determine carcass quality parameters. Before transport, all pigs were numbered by tattoo to identify their original treatment. Euthanization was facilitated by high pressure CO_2. Hot carcass weights were obtained after slaughter prior tochilling. Backfat thickness and longissimus muscle (LM) depth were determined by measuring midline fat thickness (for backfat including the skin) at the last rib. Weight and percent lean of LM were also determined. Percent lean was determined on the warm carcasses before chilling. The pH and temperature were obtained from the LM between the 10th and 11th rib after 24 h of chilling. The pH of the LM was determined using a portable pH meter (Model IQ140, IQ Scientific Instruments, Carlsbad, CA). Hunter L (luminescence), a (redness), and b (yellowness) values were obtained using a Minolta color recorder (MiniScan XE Plus, HunterLab, Reston, VA). The Japanese color scores were measured using a 6 disc standard color scale (scale 1 = light-colored pork to 6 = dark-colored pork) by 2 trained researchers (Ji et al., 2006). Results from the 2 scorers were averaged to obtain the color score. Firmness of LM was measured using a 1 to 5 standard scale based on the firmness of the loin and the bending ability by attempting to fold one end to the other (NPPC, 2000). The marbling scores of LM were measured using a 1 to 5 standard scale (scale 1 = traces

Table 2. Growth performance of pigs fed diets with or without *Saccharomyces cerevisiae* fermentation product (SCFP) from sows fed diets with or without SCFP

Maternal diet (MD)	Control[1]		SCFP[2]			*P*-value		
Offspring diet (OD)	Control[3]	SCFP[3]	Control[3]	SCFP[3]	SEM[4]	MD[5]	OD[6]	MD × OD
Initial BW, kg	6.07	6.11	6.09	6.08	0.11	0.992	0.958	0.924
BW, kg								
Phase 1	6.86	6.75	6.90	6.97	0.12	0.597	0.935	0.725
Phase 2	11.1	11.1	10.3	10.9	0.22	0.263	0.514	0.566
Phase 3	20.9	20.1	19.7	20.4	0.37	0.564	0.939	0.303
Phase 4	62.4	58.8	56.6	58.5	1.34	0.273	0.758	0.324
Phase 5	94.3	89.7	89.2	91.9	1.68	0.681	0.779	0.295
Phase 6	116.5	112.1	111.2	118.1	2.01	0.933	0.768	0.175
ADG, kg/d								
Phase 1	0.10	0.08	0.10	0.11	0.01	0.450	0.902	0.613
Phase 2	0.31	0.33	0.26	0.29	0.01	0.015	0.180	0.941
Phase 3	0.47	0.43	0.45	0.46	0.01	0.869	0.446	0.278
Phase 4	0.74	0.69	0.68	0.69	0.02	0.370	0.593	0.412
Phase 5	0.76	0.75	0.79	0.80	0.02	0.236	0.896	0.821
Phase 6	0.82	0.86	0.89	0.96	0.03	0.195	0.364	0.810
Phase 1 to 6	0.66	0.64	0.64	0.68	0.01	0.872	0.664	0.222
ADFI, kg/d								
Phase 1	0.17	0.19	0.26	0.24	0.01	0.012†	0.952	0.449
Phase 2	0.45	0.46	0.36	0.43	0.02	0.037†	0.186	0.244
Phase 3	0.96	0.84	0.95	0.88	0.02	0.689	0.015†	0.466
Phase 4	1.67	1.60	1.55	1.60	0.04	0.406	0.915	0.406
Phase 5	1.92	1.77	1.71	1.85	0.05	0.531	0.925	0.170
Phase 6	2.96	2.94	2.97	3.10	0.07	0.564	0.713	0.610
Phase 1 to 6	1.68	1.59	1.57	1.64	0.03	0.660	0.834	0.175
G:F								
Phase 1	0.50	0.30	0.39	0.48	0.06	0.818	0.683	0.246
Phase 2	0.68	0.74	0.72	0.67	0.02	0.573	0.901	0.115
Phase 3	0.49	0.50	0.47	0.52	0.01	0.822	0.144	0.498
Phase 4	0.45	0.43	0.44	0.43	0.00	0.725	0.388	0.764
Phase 5	0.40	0.43	0.47	0.44	0.01	0.090	0.880	0.128
Phase 6	0.28	0.29	0.30	0.32	0.01	0.225	0.502	0.982
Phase 1 to 6	0.40	0.41	0.41	0.41	0.01	0.283	0.372	0.832

[1]A corn soybean meal basal diet top-dressed with a corn-soybean meal mixture containing 15% crude protein (CP; 12.0 g/d during gestation and 15.0 g/d during lactation). This supplement was given to match the amount of crude protein from the SCFP supplement.

[2]*Saccharomyces cerevisiae* fermentation product (Diamond V Original XPC, Diamond V, Cedar Rapids, IA) was top-dressed at 12.0 g/d during gestation and 15.0 g/d during lactation.

[3]During 6 phase feeding program from nursery to slaughter, corn and soybean based diets were given to pigs. Nursery diets with SCFP (phase 1 to 3) contained 0.2% Diamond V Original XPC by replacing corn in basal diets. Grower-finisher diets with SCFP (phase 4 to 6) contained 0.1% Original XPC also by replacing corn in basal.

[4]Standard error of means.

[5]Effect from SCFP during gestation and lactation period.

[6]Effect from SCFP during nursery, grower and finishing period.

to 6: abundant) by 2 trained researchers (Jones et al., 1992; NPPC, 2000). Scores from the 2 researchers were averaged to obtain the color score.

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The study was a randomized complete block design with sex and dietary treatment for sows and pigs as fixed effects. Pen was the experimental unit. Least square means and standard errors were also obtained through SAS. Probability values less than 0.05 were used as the criterion for statistical significance and 0.10 as the criterion for tendency.

RESULTS

During phase 1, pigs from sows fed with SCFP had greater (P = 0.012) average daily feed intake (ADFI) compared with pigs from sows fed without SCFP

Table 3. Jejunal villus characteristics, microbial count in colon, and volatile fatty acid production in cecum and colon of nursery pigs fed diets with or without *Saccharomyces cerevisiae* fermentation product (SCFP) on offspring weaned from sows fed diets with or without SCFP[1]

Maternal diet (MD)	Control[2]		SCFP[3]			*P*-value		
Offspring diet (OD)	Control[4]	SCFP[4]	Control[4]	SCFP[4]	SEM[5]	MD[6]	OD[7]	MD × OD
Villus height, um								
Jejunum	366.4	433.8	409.8	374.4	7.5	0.587	0.276	0.001
VFA, mol % cecal digesta								
Acetic acid	58.6	60.4	56.0	58.1	0.01	0.305	0.414	0.950
Propionic acid	30.9	28.9	30.6	28.6	0.01	0.860	0.338	0.998
Isobutyric acid	0.426	0.388	0.604	0.395	0.001	0.531	0.404	0.563
Butyric acid	8.19	8.89	10.30	10.50	0.005	0.098	0.655	0.841
Valeric acid	1.26	0.89	1.66	1.67	0.002	0.127	0.634	0.618
Isovaleric acid	0.617	0.502	0.863	0.672	0.001	0.333	0.474	0.858
VFA, mol % colon digesta								
Acetic acid	58.9	61.5	56.4	60.8	0.01	0.432	0.084	0.641
Propionic acid	26.3	24.5	28.5	25.0	0.01	0.331	0.054	0.525
Isobutyric acid	1.20	1.20	0.87	0.98	0.001	0.201	0.810	0.770
Butyric acid	9.61	9.40	10.60	9.65	0.004	0.491	0.521	0.684
Valeric acid	2.14	1.66	2.36	2.02	0.001	0.306	0.156	0.802
Isovaleric acid	1.86	1.74	1.39	1.52	0.01	0.295	0.980	0.694

[1]Measured at d 5 after weaning.

[2]A corn soybean meal basal diet top-dressed with a corn-soybean meal mixture containing 15% crude protein (CP; 12.0 g/d during gestation and 15.0 g/d during lactation). This supplement was given to match the amount of crude protein from the SCFP supplement.

[3]*Saccharomyces cerevisiae* fermentation product (Diamond V Original XPC, Diamond V, Cedar Rapids, IA) was top-dressed at 12.0 g/d during gestation and 15.0 g/d during lactation.

[4]During 6 phase feeding program from nursery to slaughter, corn and soybean based diets were given to pigs. Nursery diets with SCFP (phase 1 to 3) contained 0.2% Diamond V Original XPC by replacing corn in basal diets. Grower-finisher diets with SCFP (phase 4 to 6) contained 0.1% Original XPC also by replacing corn in basal.

[5]Standard error of means.

[6]Effect from SCFP product during gestation and lactation period.

[7]Effect from SCFP during nursery, grower and finishing period.

(Table 2). However, during phase 2, pigs from sows fed without SCFP had greater average daily gain (ADG) and ADFI (P = 0.015 and P = 0.037) compared with sows fed SCFP. During phase 3, pigs fed a diet without SCFP supplementation had a greater (P = 0.015) ADG compared with pigs fed a diet with SCFP supplementation; however, at the end of the nursery (Phase 3) there were no differences in BW between the treatments. During phase 5, pigs from sows fed with SCFP tend to have a greater (P = 0.090) gain-to-feed (G:F) ratio compared with pigs from sows fed without SCFP. During the entire period, a long term dietary supplementation of SCFP in the diets for sows and offspring had little effect on BW, overall ADG, ADFI and G:F ratio.

On d 5 after weaning, dietary supplementation of SCFP in the diet for sows and offspring did not affect the height of villus in jejunum (Table 3). However, there was an interaction (P = 0.001) between 2 factors. The SCFP supplementation in offspring's diets increased the jejunal villus height in pigs from sows fed without SCFP but had the opposite effect on villus heights of pigs from sows fed with SCFP. On 5 d after weaning, pigs fed SCFP tended to have a greater (P = 0.084) concentration of acetic acid but a reduced (P = 0.054) propionic acid in colonal digesta than pigs fed without SCFP regardless of maternal feeding treatment. Offsping from sows fed SCFP tended to have a greater (P = 0.098) butyric acid concentration in cecal digesta compared with pigs from sows fed without SCFP. Loin marbling scores were greater (P = 0.043) in pigs fed with SCFP than those without SCFP regardless of maternal feeding treatment. (Table 4) However, all other carcass characteristics were unaffected by SCFP supplementations.

DISCUSSION

Positive effects of SCFP on growth performance have been reported by several researchers (van der Peet-Schwering et al., 2007; Shen et al., 2009; Price et al., 2010). Studies have been conducted to explore the mode of action by SCFP. Several different mechanisms have been proposed by different researchers (van der Peet-Schwering et al., 2007; Shen et al. (2009) and 2011; Price et al., 2010). A frequently referred mechanism is associated with the health promotion benefits of SCFP, such as improved gut morphology (Shen et

Table 4. Carcass characteristics of pigs fed diets with or without *Saccharomyces cerevisiae* fermentation product (SCFP) on offspring weaned from sows fed diets with or without SCFP[1]

Maternal diet (MD)	Control[2]		SCFP[3]			*P* value		
Offspring diet (OD)	Control[4]	SCFP[4]	Control[4]	SCFP[4]	SEM[5]	MD[6]	OD[7]	MD × OD
Carcass								
Hot carcass weight, kg	95.0	93.0	89.9	90.9	1.4	0.211	0.863	0.617
Backfat thickness[8], mm	18.9	18.7	18.4	20.6	0.7	0.602	0.452	0.367
Lean, %	52.5	52.2	52.5	52.0	0.3	0.831	0.502	0.848
LM								
LM depth, mm	57.9	56.2	55.6	57.7	0.6	0.749	0.907	0.150
pH of LM	5.64	5.66	5.76	5.72	0.04	0.305	0.948	0.707
Minolta L*	45.5	47.3	47.8	47.2	0.4	0.191	0.454	0.161
Minolta a*	11.4	10.8	11.2	12.0	0.3	0.411	0.938	0.260
Minolta b*	4.34	4.19	4.36	5.36	0.22	0.175	0.329	0.186
Japanese color score	3.42	3.42	3.31	3.37	0.06	0.505	0.813	0.779
Marbling score[9]	1.92	2.28	2.00	2.50	0.11	0.468	0.043	0.727
Firmness[10]	1.70	1.70	1.63	1.94	0.06	0.515	0.237	0.230

[1]Measured at d 5 after weaning.

[2]A corn soybean meal basal diet top-dressed with a corn-soybean meal mixture containing 15% crude protein (CP; 12.0 g/d during gestation and 15.0 g/d during lactation). This supplement was given to match the amount of crude protein from the SCFP supplement.

[3]*Saccharomyces cerevisiae* fermentation product (Diamond V Original XPC, Diamond V, Cedar Rapids, IA) was top-dressed at 12.0 g/d during gestation and 15.0 g/d during lactation.

[4]During 6 phase feeding program from nursery to slaughter, corn and soybean based diets were given to pigs. Nursery diets with SCFP (phase 1 to 3) contained 0.2% Diamond V Original XPC by replacing corn in basal diets. Grower-finisher diets with SCFP (phase 4 to 6) contained 0.1% Original XPC also by replacing corn in basal.

[5]Standard error of means.

[6]Effect from SCFP during gestation and lactation period.

[7]Effect from SCFP during nursery, grower and finishing period.

[8]Backfat thickness at 3 to 4 last rib.

[9]NPPC (2000) scale: 1 represents 1% marbling, 2 represents 2% marbling.

[10]NPPC (2000) firmness scale (1 to 5): 1 = very soft; 5 = very firm.

al., 2009; Price et al., 2010), enhanced digestibility (Kornegay et al., 1995; Shen et al., 2009), protection against pathogenic bacteria attachment (Kiarie et al., 2011), and modulation of the immune system (Shen et al., 2009; Jensen et al., 2007; Jensen et al., 2011). However, variation in the efficacy of SCFP has been reported in weanling pigs. Kornegay et al. (1995) reported inclusion of SCFP had no effect on ADG, ADFI and G:F ratio in nursery pigs. Jurgens (1995) also reported SCFP did not affect growth performance of neonatal pigs. Price et al. (2010) reported SCFP improved growth performance of pigs when pigs were infected with *Salmonella* and Kiarie et al. (2011) reported improved performance following an *E. coli* challenge. Therefore, one possible explanation for the variable effects of SCFP on growth performance would be the differences in terms of environmental challenge and microbial load conditions from study to study.

Significant reduction in villus height after weaning has been associated with reduced performance and high mortality (Cera et al., 1988; McCracken et al., 1999; Tang et al., 1999; Berkeveld et al., 2007). Intestinal villus and crypt integrity is critical for nutrient absorption and a successful and rapid transition from liquid diet to solid diet for newly weaned pigs. Positive effects of SCFP on gut morphology have been reported by several researchers. Shen et al. (2009) reported villus height and villus:crypt ratio were increased by SCFP. Gao et al. (2008) also reported beneficial effect of SCFP on gut morphology in broiler chicken. A decreased population of pathogenic bacteria in the gut has been proposed to be the reason of improved intestinal morphology (Mourão et al., 2006). van der Peet-Schwering et al. (2007) reported that SCFP had little effect on intestinal morphology although growth performance was improved. Interestinly, supplementing SCFP to pigs increased jejunum villus height in pigs from control fed sows, but reduced villus height from SCFP fed sows leading to an interaction. One possible explanation for variable results would be different doses of SCFP used in different studies. In this study, 0.2% SCFP was used during nursery period. van der Peet-Schwering et al. (2007) reported inclusion level of SCFP in their study was 0.125%. Those inclusion levels of SCFP in diets were relatively lower than the level reported by Shen et al. (2009). Shen et al. (2009) reported that 0.5% SCFP supplementation increased villus height and villus:crypt ratio. Based on a dose response study, Shen et al. (2009) showed the beneficial

effect of SCFP supplementation was maximized at a level of 0.5%. Therefore, a higher inclusion level maybe needed to affect intestinal morphology. Another factor for consideration was the relative impact of environmental challenge within the current study. Kiarie et al. (2011) reported SCFP reduced number of mucosa adherent *Escherichia coli*. Shen et al. (2009) suggested the enhanced intestinal morphology was partly due to decreased *Escherichia coli* colonization. Therefore, in an environment with a significant gut health challenge, the effect of dietary SCFP on intestinal morphology could be significantly more important.

Acetic acid and butyric acid concentrations in digesta tended to be increased by SCFP in this study (Table 3). The effect of SCFP supplementation on intestinal VFA production in pigs has not been reported. However, several ruminant and poultry-based studies support the rational of our results (Callaway and Martin, 1997; Sullivan and Martin, 1999; Miller-Webster et al., 2002). Callaway and Martin (1997) and Chen et al. (2016) reported the concentration of VFA was increased by SCFP in ruminants and broiler chickens, respectively. Miller-Webster et al. (2002) and Rubinelli et al. (2016) also reported increased VFA production by addition of SCFP to in vitro mixed ruminal and chicken cecal culture, respectively. Several hypotheses have been proposed to explain the effect of SCFP on increased production of ruminal VFA production (Nisbet and Martin, 1991; Callaway and Martin, 1997). One potential explanation could be related to the specific composition of SCFP (Lynch and Martin, 2002). Fermentation of *Saccharomyces cerevisiae* cell wall or other cell content could account for the increased acetic acid production (Lynch and Martin, 2002). Another possible mechanism by which that SCFP impacts VFA production may be through the utilization lactate, thus increasing pH in gastrointestinal tract and stabilizing the environment of the microflora. Nisbet and Martin (1991) proposed that SCFP increased the utilization of lactate, which in turn created a more stabilized rumen environment with higher pH. A stabilized rumen environment with higher pH induces the growth of cellulolytic bacteria and subsequently increases acetic acid production (Yoon and Stern, 1996). However, in swine few studies have revealed the effect of SCFP on utilization of lactate, the pH, and cellulolytic bacteria population at lower gastrointestinal tract. More research is needed to understand the mechanism of SCFP on VFA synthesis. Interestingly, a recent study showed the supplementation of SCFP increased *Lactobacillus* after *Salmonella* infection (Price et al., 2010). This indicated the potential role of SCFP on regulating VFA synthesis through modifying intestinal microflora in pigs.

Marbling score was increased by nursery to harvest SCFP supplementation. Our study is the first to report data on the improvement of intramuscular fat deposition in pork loin by SCFP. Several studies in ruminant animals have shown the effect of SCFP on fat metabolism (Piva et al., 1993; Kalmus et al., 2009). Piva et al. (1993) reported dietary inclusion of SCFP increased milk fat production. Kalmus et al. (2009) reported an increase in milk fat when cows received SCFP. The enhanced milk fat synthesis could be attributed to an increased ruminal production of acetic acid and butyric acid. Acetic acid and butyric acid are precursors of long chain fatty acid synthesis (Zambell et al., 2003). A clear relationship has been established in dairy cow between acetic acid or butyric acid and milk fat synthesis (Oldham and Emmans, 1988). Zambell et al. (2003) also reported that acetic acid and butyric acid are the major substrates for *de novo* lipogenesis in rat. In the current study, supplementation of SCFP in offspring diets increased acetic acid production in colonal digesta on d 5 after weaning. Maternal feeding of SCFP increased butyric acid production in cecal digesta on d 5 after weaning. Therefore, we speculate that the increased production of acetic and butyric acids is one potential reason for improved marbling score, although this needs to be further validated if the increased VFA in digesta continues as the pigs age.

As intramuscular fat deposition positively influences flavor, juiciness, and tenderness of pork loin, methods to increase marbling score have been extensively evaluated. In the past, research has been conducted to increase marbling through genetic selection (Hocquette et al., 2009). Numerous nutrition studies have attempted to increase intramuscular fat deposition in pigs (D'Souza et al., 2003; Guillerm-Regost et al., 2006; Gondret and Lebret, 2007) by manipulation of metabolism via feed restriction followed by re-feeding, overfeeding, and feeding diets deficient in vitamin A. However, most of these attempts are not practical in commercial animal production due to low growth efficiency, poor carcass quality, and animal welfare concerns. In this study, marbling score was increased by SCFP supplementation. Although the increase can be considered as small (0.3 to 0.5 units of marbling scores), this study provides a novel way to increase intramuscular fat deposition.

In summary, supplementing SCFP in sow diets did not affect growth performance, intestinal morphology, and carcass characteristics of their offspring. Supplementation of SCFP in pig diets from nursery to slaughter had little effect on growth performance. However, inclusion of SCFP to the diets fed from nursery to slaughter improved marbling score in pork loin which is potentially related to increased acetic and butyric acids production in the large intestine by inclusion of SCFP.

LITERATURE CITED

Barton, M. D. 2000. Antibiotic use in animal feed and its impact on human health. Nutr. Res. Rev. 13:279–299. doi:10.1079/095442200108729106

Berkeveld, M., P. Langendijk, H. M. G. van Beers-Schreurs, A. P. Koets, M. A. M. Taverne, and J. H. M. Verheijden. 2007. Intermittent suckling during an extended lactation period: Effects on piglet behavior. J. Anim. Sci. 85:3415–3424. doi:10.2527/jas.2007-0223

Callaway, E. S., and S. A. Martin. 1997. Effects of a Saccharomyces cerevisiae culture on ruminal bacteria that utilize lactate and digest cellulose. J. Dairy Sci. 80:2035–2044. doi:10.3168/jds.S0022-0302(97)76148-4

Cera, K. R., D. C. Mahan, R. F. Cross, G. A. Reinhart, and R. E. Whitmoyer. 1988. Effect of age, weaning and postweaning diet on small intestinal growth and jejunal morphology in young swine. J. Anim. Sci. 66:574–584. doi:10.2527/jas1988.662574x

Chen, C. Y., S. W. Chen, and H. T. Wang. 2016. Effect of supplementation of yeast with bacteriocin and lactobacillus culture on growth performance, cecal fermentation, microbiota composition, and blood characteristics in broiler chickens. Asian-Austalas. J. Anim. Sci. (in press). doi: 10.5713/ajas.16.0203

D'Souza, D. N., D. W. Pethick, F. R. Dunshea, J. P. Pluske, and B. P. Mullan. 2003. Nutritional manipulation increases intramuscular fat levels in the longissimus muscle of female finisher pigs. Aust. J. Agric. Res. 54:745–749. doi:10.1071/AR03009

Gao, J., H. J. Zhang, S. H. Yu, S. G. Wu, I. Yoon, J. Quigley, Y. P. Gao, and G. H. Qi. 2008. Effects of yeast culture in broiler diets on performance and immunomodulatory functions. Poult. Sci. 87:1377–1384. doi:10.3382/ps.2007-00418

Gondret, F., and B. Lebret. 2007. Does feed restriction and realimentation differently affect lipid content and metabolism according to muscle type in pigs (Sus scrofa)? Comp. Biochem. Physiol., Part A. Mol. Integr. Physiol. 147:375–382. doi:10.1016/j.cbpa.2007.01.023

Guillerm-Regost, C., I. Louveau, S. P. Sebert, M. Damon, M. M. Champ, and F. Gondret. 2006. Cellular and biochemical features of skeletal muscle in obese Yucatan minipigs. Obes. 14:1700–1707. doi:10.1038/oby.2006.195

Hocquette, J. F., F. Gondret, E. Baéza, F. Médale, C. Jurie, and D. W. Pethick. 2009. Intramuscular fat content in meat-producing animals: Development, genetic and nutritional control, and identification of putative markers. Anim. 4:303–319. doi:10.1017/S1751731109991091

Jadamus, A., W. Vahjen, K. Schäfer, and O. Simon. 2002. Influence of the probiotic strain Bacillus cereus var. toyoi on the development of enterobacterial growth and on selected parameters of bacterial metabolism in digesta samples of piglets. J. Anim. Physiol. Anim. Nutr. 86:42–54. doi:10.1046/j.1439-0396.2002.00336.x

Jadamus, A., W. Vahjen, and O. Simon. 2001. Growth behaviour of a spore forming probiotic strain in the gastrointestinal tract of broiler chickens and piglets. Arch. Anim. Nutr. 54:1–17.

Jensen, G. S., A. N. Hart, and A. G. Schauss. 2007. An anti-inflammatory immunogen from yeast culture induces activation and alters chemokine receptor expression on human natural killer cells and B lymphocytes in vitro. Nutr. Res. 27:327–335. doi:10.1016/j.nutres.2007.04.008

Jensen, G. S., K. A. Redman, K. F. Benson, S. G. Carter, M. A. Mitzner, S. Reeves, and L. Robinson. 2011. Antioxidant bioavailability and rapid immune-modulating effects after consumption of a single acute dose of a high-metabolite yeast immunogen: Results of a placebo-controlled double-blinded crossover pilot study. J. Med. Food 14:1002-1010. doi: 10.1089/jmf.2010-0174.

Ji, F., J. J. McGlone, and S. W. Kim. 2006. Effects of dietary humic substances on pig growth performance, carcass characteristics, and ammonia emission. J. Anim. Sci. 84:2482–2490. doi:10.2527/jas.2005-206

Jones, S. D. M., W. M. Robertson, and S. Talbot. 1992. Marbling standards for beef and pork. Agriculture and Agri-Food Canada Pub. No. 1879/E, Ottawa, ON.

Jurgens, M.H. 1995. Performance of weaning pigs fed diets containing yeast culture and/or an antibiotic. In: Research Investment Report. Natl. Pork Prod. Counc., DesMoines, IA. p. 417-422

Kalmus, P., T. Orro, A. Waldmann, R. Lindjärv, and K. Kask. 2009. Effect of yeast culture on milk production and metabolic and reproductive performance of early lactation dairy cows. Acta Vet. Scand. 51:32. doi:10.1186/1751-0147-51-32

Kiarie, E., S. Bhandari, M. Scott, D. O. Krause, and C. M. Nyachoti. 2011. Growth performance and gastrointestinal microbial ecology responses of piglets receiving Saccharomyces cerevisiae fermentation products after an oral challenge with Escherichia coli (K88). J. Anim. Sci. 89:1062–1078. doi:10.2527/jas.2010-3424

Kim, S. W., M. Brandherm, M. Freeland, B. Newton, D. Cook, and I. Yoon. 2008. Effects of yeast culture supplementation to gestation and lactation diets on growth of nursing piglets. Asian-Aust. J. Anim. Sci. 21:1011–1014.

Kim, S. W., M. Brandherm, B. Newton, D. R. Cook, I. Yoon, and G. Fitzner. 2010. Effect of supplementing Saccharomyces cerevisiae fermentation product in sow diets on reproductive performance in a commercial environment. Can. J. Anim. Sci. 90:229–232. doi:10.4141/CJAS09100

Kornegay, E. T., D. Rhein-Welker, M. D. Lindemann, and C. M. Wood. 1995. Performance and nutrient digestibility in weaning pigs as influenced by yeast culture additions to starter diets containing dried whey or one of two fiber sources. J. Anim. Sci. 73:1381–1389. doi:10.2527/1995.7351381x

Lynch, H. A., and S. A. Martin. 2002. Effects of Saccharomyces cerevisiae culture and Saccharomyces cerevisiae live cells on in vitro mixed ruminal microorganism fermentation. J. Dairy Sci. 85:2603–2608. doi:10.3168/jds.S0022-0302(02)74345-2

McCracken, B. A., M. E. Spurlock, M. A. Roos, F. A. Zuckermann, and H. R. Gaskins. 1999. Weaning anorexia may contribute to local inflammation in the piglet small intestine. J. Nutr. 129:613–619.

Miller-Webster, T., W. H. Hoover, M. Holt, and J. E. Nocek. 2002. Influence of yeast culture on ruminal microbial metabolism in continuous culture. J. Dairy Sci. 85:2009–2014. doi:10.3168/jds.S0022-0302(02)74277-X

Mourão, J. L., V. Pinheiro, A. Alves, C. M. Guedes, L. Pinto, M. J. Saavedra, P. Spring, and A. Kocher. 2006. Effect of mannan oligosaccharides on the performance, intestina morphology and cecal fermentation of fattening rabbits. Anim. Feed Sci. Technol. 126:107–120. doi:10.1016/j.anifeedsci.2005.06.009

National Research Council. 1998. Nutrient Requirements of Swine, 10th ed. Washington, DC: National Academic Press.

Nisbet, D. J., and S. A. Martin. 1991. Effect of a Saccharomyces cerevisiae culture on lactate utilization by the ruminal bacterium Selenomonas ruminantium. J. Anim. Sci. 69:4628–4633. doi:10.2527/1991.69114628x

NPPC. 2000. In: Berg, E. P., editor, Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Counc, Des Moines, IA. p. 1–38.

Oldham, J. D., and G. C. Emmans. 1988. Prediction of responses to protein and energy yielding nutrients. In: P. C. Garnsworthy, editor, Nutrition and Lactation in the Dairy Cow. Butterworths, London. p. 76–96. doi:10.1016/B978-0-408-00717-7.50010-1

Piva, G., S. Belladonna, G. Fusconi, and F. Sicbaldi. 1993. Effects of yeast on dairy cow performance, ruminal fermentation, blood components, and milk manufacturing properties. J. Dairy Sci. 76:2717–2722. doi:10.3168/jds.S0022-0302(93)77608-0

Price, K. L., H. R. Totty, H. B. Lee, M. D. Utt, G. E. Fitzner, I. Yoon, M. A. Ponder, and J. Escobar. 2010. Use of Saccharomyces cerevisiae fermentation product on growth performance and microbiota of weaned pigs during Salmonella infection. J. Anim. Sci. 88:3896–3908. doi:10.2527/jas.2009-2728

Rubinelli, P., S. Roto, S. A. Kim, S. H. Park, H. O. Pavlidis, D. McIntyre, and S. C. Ricke. 2016. Reduction of Salmonella Typhimurium by fermentation metabolites of Diamond V Original XPC in an in vitro anaerobic mixed chicken cecal culture. Font. Vet. Sci. 3:83. doi:10.3389/fvets.2016.00083

Shen, Y. B., J. A. Carroll, I. Yoon, R. D. Mateo, and S. W. Kim. 2011. Effects of supplementing Saccharomyces cerevisiae fermentation product to sow diets on performance of sows and nursing piglets. J. Anim. Sci. 89:2462–2471. doi:10.2527/jas.2010-3642

Shen, Y. B., X. S. Piao, S. W. Kim, L. Wang, P. Liu, I. Yoon, and Y. G. Zhen. 2009. Effects of yeast culture supplementation on growth performance, intestinal health, and immune response of nursery pigs. J. Anim. Sci. 87:2614–2624. doi:10.2527/jas.2008-1512

Simon, O., W. Vahjen, and D. Taras. 2007. Potentials of probiotics in pig nutrition. Feed Mix. 15:25–27.

Soma, J. A., and V. C. Speer. 1975. Effects of pregnant mare serum and chlortetracycline on the reproductive efficiency of sows. J. Anim. Sci. 41:100–105. doi:10.2527/jas1975.411100x

Sullivan, H. M., and S. A. Martin. 1999. Effects of a Saccharomyces cerevisiae culture on in vitro mixed ruminal microorganism fermentation. J. Dairy Sci. 82:2011–2016. doi:10.3168/jds.S0022-0302(99)75438-X

Tang, M., B. Laarveld, A. G. Van Kessel, D. L. Hamilton, A. Estrada, and J. F. Patience. 1999. Effect of segregated early weaning on postweaning small intestinal development in pigs. J. Anim. Sci. 77:3191–3200. doi:10.2527/1999.77123191x

Taras, D., W. Vahjen, M. Macha, and O. Simon. 2006. Performance, diarrhea incidence, and occurrence of Escherichia coli virulence genes during long-term administration of a probiotic Enterococcus faecium strain to sows and piglets. J. Anim. Sci. 84:608–617. doi:10.2527/2006.843608x

Vahjen, W., A. Jadamus, and O. Simon. 2002. Influence of a probiotic Enterococcus faecium strain on selected bacterial groups in the small intestine of growing turkey poults. Arch. Anim. Nutr. 56:419–429.

van der Peet-Schwering, C. M. C., A. J. M. Jansman, H. Smidt, and I. Yoon. 2007. Effects of yeast culture on performance, gut integrity, and blood cell composition of weaning pigs. J. Anim. Sci. 85:3099–3109. doi:10.2527/jas.2007-0110

Yoon, I. K., and M. D. Stern. 1996. Effects of Saccharomyces cerevisiae and Aspergillus oryzae cultures on ruminal fermentation in dairy cows. J. Dairy Sci. 79:411–417. doi:10.3168/jds.S0022-0302(96)76380-4

Zambell, K., M. D. Fitch, and S. E. Fleming. 2003. Acetate and butyrate are the major substrates for de novo lipogenesis in rat colonic epithelial cells. J. Nutr. 133:3509–3525.