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

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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

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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

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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 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 sixty 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™, 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.

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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 CO₂. Hot carcass weights were obtained after slaughter prior to chilling. 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 1. Dietary composition of basal nursery and finishing diets, as fed basis

| Ingredient, % | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 |
|---------------|---------|---------|---------|---------|---------|---------|
| 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 premix³ | 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     |

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.
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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) | Offspring diet (OD) | Control$^1$ | SCFP$^2$ | Control$^1$ | 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   |

1A 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.

3During 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.

4Standard error of means.

5Effect from SCFP during gestation and lactation period.

6Effect 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

| Maternal diet (MD) | Offspring diet (OD) | Control | SCFP | SEM | P-value | MD | OD | MD × OD |
|-------------------|---------------------|---------|------|-----|---------|----|----|--------|
| Maternal diet (MD) | Offspring diet (OD) | Control | SCFP | SEM | P-value | MD | OD | MD × OD |
| Jejunum Villus height, um | | 366.4 | 433.8 | 409.8 | 374.4 | 0.01 | 0.587 | 0.276 | 0.001 |
| VFA, mol % cecal digesta | | | | | | | | | |
| Acetic acid | 58.6 | 60.4 | 56.0 | 58.1 | 0.01 | 0.432 | 0.084 | 0.641 |
| Propionic acid | 30.9 | 28.9 | 30.6 | 28.6 | 0.01 | 0.331 | 0.054 | 0.525 |
| Isobutyric acid | 0.426 | 0.388 | 0.604 | 0.395 | 0.001 | 0.201 | 0.810 | 0.770 |
| Butyric acid | 8.19 | 8.89 | 10.30 | 10.50 | 0.005 | 0.491 | 0.521 | 0.684 |
| Valeric acid | 1.26 | 0.89 | 1.66 | 1.67 | 0.002 | 0.306 | 0.156 | 0.802 |
| Isovaleric acid | 0.617 | 0.502 | 0.863 | 0.672 | 0.001 | 0.295 | 0.980 | 0.694 |
| 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 | 0.004 | 0.491 | 0.521 | 0.684 |
| Butyric acid | 9.61 | 9.40 | 10.60 | 9.65 | 0.004 | 0.306 | 0.156 | 0.802 |
| Valeric acid | 1.86 | 1.74 | 1.39 | 1.52 | 0.01 | 0.295 | 0.980 | 0.694 |
| Isovaleric acid | | | | | | | | | |

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 \((P = 0.015 \text{ and } P = 0.037)\) 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 colonic digesta than pigs fed without SCFP regardless of maternal feeding treatment. Offspring 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
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 0.5% SCFP supplementation increased villus height and villus:crypt ratio. Based on a dose response study, Shen et al. (2009) showed the beneficial

### 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

| Maternal diet (MD) | Control<sup>2</sup> | SCFP<sup>3</sup> | Control<sup>4</sup> | SCFP<sup>4</sup> | SEM<sup>5</sup> | MD<sup>6</sup> | OD<sup>7</sup> | MD × OD |
|-------------------|------------------|-----------------|------------------|----------------|-----------|-------------|-------------|---------|
| Offspring diet (OD) |                  |                 |                  |                 |           |             |             |         |
| Control           | 95.0             | 93.0            | 89.9             | 90.9            | 1.4       | 0.211       | 0.863       | 0.617   |
| SCFP              | 89.9             | 90.9            |                   |                 |           |             |             |         |
| SEM               |                  |                 |                   |                 |           |             |             |         |
| P value           |                  |                 |                   |                 |           |             |             |         |
| Hot carcass weight, kg | 95.0             | 93.0            | 89.9             | 90.9            | 1.4       | 0.211       | 0.863       | 0.617   |
| Backfat thickness<sup>8</sup>, 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<sup>9</sup> | 45.5             | 47.3            | 47.8             | 47.2            | 0.4       | 0.191       | 0.454       | 0.161   |
| Minolta a<sup>9</sup> | 11.4             | 10.8            | 11.2             | 12.0            | 0.3       | 0.411       | 0.938       | 0.260   |
| Minolta b<sup>9</sup> | 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<sup>9</sup> | 1.92             | 2.28            | 2.00             | 2.50            | 0.11      | 0.468       | 0.043       | 0.727   |
| Firmness<sup>10</sup> | 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.
effect of SCFP supplementation was maximized at a level of 0.5%. Therefore, a higher inclusion level may be needed to affect intestinal morphology. Another factor for consideration was the relative impact of environmental challenge within the current study. Kiariie 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 rationale 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 colonic 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 (Hocquet 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.
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