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The effects of synbiotics-glyconutrients on growth performance, nutrient digestibility, gas emission, meat quality, and fatty acid profile of finishing pigs

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Abstract

Glyconutrients help in the body's cell communication. Glyconutrients and synbiotics are promising options for improving immune function. Therefore, we hypothesized that combining synbiotics and glyconutrients will enhance pig nutrient utilization. 150 pigs (Landrace × Yorkshire × Duroc), initially weighing 58.85 ± 3.30 kg of live body weight (BW) were utilized to determine the effects of synbiotics-glyconutrients (SGN) on the pigs' performance, feed efficiency, gas emission, pork traits, and composition of fatty acids. The pigs were matched by BW and sex and chosen at random to 1 of 3 diet treatments: control = Basal diet; TRT1 = Basal diet + SGN 0.15%; TRT2 = Basal diet + SGN 0.30%%. The trials were conducted in two phases (weeks 1–5 and weeks 5–10). The average daily gain was increased in pigs fed a basal diet with SGN (p = 0.036) in weeks 5–10. However, the apparent total tract digestibility of dry matter, nitrogen, and gross energy did not differ among the treatments (p > 0.05). Dietary treatments had no effect on NH_3, H_2S, methyl mercaptans, acetic acids, and CO_2 emissions (p > 0.05). Improvement in drip loss on day 7 (p = 0.053) and tendency in the cooking loss were observed (p = 0.070) in a group fed basal diets and SGN at 0.30% inclusion level. The group supplemented with 0.30% of SGN had higher levels of palmitoleic acid (C16:1), margaric acid (C17:0), omega-3 fatty acid, omega-6 fatty acid, and ω-6: ω-3 ratio (p = 0.034, 0.020, 0.025, 0.007, and 0.003, respectively) in the fat of finishing pigs. Furthermore, group supplemented with 0.30% of SGN improved margaric acid (C17:0), linoleic acid (C18:2n6c), arachidic acid (C20:0), omega 6 fatty acid, omega-6 to omega-3 ratio, unsaturated fatty acid, and monounsaturated fatty acid (p = 0.037, 0.05, 0.0142, 0.036, 0.033, 0.020, and 0.045, respectively) in the lean tissues of finishing pigs compared to pigs fed with the control diets. In conclusion, the combination of probiotics, prebiotics, and glyconutrients led to higher average daily gain, improved the quality of pork, and more favorable fatty acid composition. Therefore, these results contributed to a better understanding of the potential of SGN combinations as a feed additive for pigs.

Keywords: Finishing pigs, Glyconutrient, Performance, Prebiotic, Probiotic

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Availability of data and material
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Authors' contributions
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Ethics approval and consent to participate
The experimental procedure was reviewed and accepted by Dankook University's Institutional Animal Care and Use Committee (IACUC) with IACUC #DK-2-2128.

INTRODUCTION

The pig industry faces the challenge of meeting global demand for pork, which is expected to grow by 19% from 2019 to 2029 [1]. This must be achieved while also ensuring the production of affordable and high-quality pork that meets consumer preferences and expectations. Pig meat quality and nutritional value are significantly influenced by fatty acid composition in both adipose tissue and muscle [2]. There are numerous ways that fatty acids affect pig's meat quality and nutritional value, including melting point, firmness, flavor, oxidative stability, and shelf life. A high level of saturated fatty acids (SFA) increases fat melting point and firmness, and a high level of polyunsaturated fatty acids (PUFAs) decreases them [3]. PUFAs also contribute to meat flavor, but they are more prone to oxidation, which can cause rancidity and off-flavors [2]. Dietary composition significantly influences pork quality and nutritional value, particularly through its impact on intramuscular fat content and lipid profile, despite the influence of genetics [4]. Moreover, since the feed cost represents 65%–75% of the overall production cost in swine production [5,6], efforts to lower feed costs are a primary concern for boosting the pig industry's competitiveness. Therefore, improving feed efficiency is essential for the profitability of pig production [7,8]. By improving feed conversion into body weight gain, less feed is required per unit of meat produced, which lowers production costs and increases profits for pig farmers. There are many factors contributing to optimal feed efficiency, including genetics, diet, feed, management, housing, and environment [9]. One of the key factors in improving feed efficiency is maintaining a healthy gastrointestinal tract for optimal metabolic utilization of dietary nutrients. Thus, a healthy gut facilitates or enhances feed digestion and nutrient absorption [7,10]. Gut health affects nutrient absorption and digestion by influencing the metabolic activity and stability of the gut microbiome, the production and secretion of digestive enzymes, and the function and integrity of the gut immune system [7,11].

The use of synbiotic-glyconutrient (SGN) combinations as a feed additive has gained popularity in recent years due to their positive effects on gut health and growth performance in other livestock species [12–15]. Glyconutrients and synbiotics are substances that can improve the meat quality of pigs by influencing their gut microbiota and fatty acid composition. According to a study by Núñez-Benítez et al. [12], a standardized mixture of SGN as a feed additive in steers fed a finishing diet improved ruminal fermentation, microbial protein synthesis, and carcass traits. Additionally, a study by Chang et al. [16] found that probiotic-friendly pig production improved meat quality and physicochemical characteristics of pigs by reducing drip loss, cooking loss, shear force, and pH value of pork. Moreover, in lambs, the addition of synbiotics and glyconutrients combination enhanced growth, energy, and carcass weight [13].

In our study, we used a SGN mixture composed of probiotics (*Lactiplantibacillus plantanum, Bacillus subtilis, and Saccharomyces cerevisiae*), prebiotics (yeast cell wall β-glucans), and glyconutrients (simple sugars) [12,17]. *L. plantarum* is a probiotic bacteria known for its beneficial effects on gut health and immunity [18]. *B. subtilis* is another probiotic that has been shown to improve digestive function and reduce pathogenic bacteria in the gut [19]. While *S. cerevisiae* is a yeast commonly used as a probiotic in animal feeds due to its ability to improve nutrient utilization and gut health [20]. Yeast cell wall β-Glucans, a type of prebiotic, act as a source of soluble fiber that feeds the beneficial bacteria in the gut [21]. The glyconutrients in this combination include simple sugars with anti-inflammatory and antimicrobial properties, and are believed to improve cell function and overall health [14]. However, there is inadequate investigation on the effects of this combination on finishing pigs.

We expect that the pigs fed the SGN combination will have improved feed efficiency, with higher average daily gain (ADG), lower feed conversion ratio (FCR), and higher nutrient digestibility

compared to the control group. We also anticipate that the treatment will result in a reduction in gas emissions and improvement in meat quality, with a more favorable fatty acid composition. Therefore, the aim of the study was to examine the effects of a standardized SGN combination on growth performance, nutrient digestibility, gas emission, meat quality, and fatty acid profile of finishing pigs.

MATERIALS AND METHODS

Animals and ethics

The experimental procedure was reviewed and accepted by the Dankook University's Institutional Animal Care and Use Committee (IACUC) with IACUC #DK-2-2128. The study was carried out at the Dankook Unversity's pig research farm (Gongju, Korea).

Animals, diets, and sampling

During 10 weeks of the trial, 150 finishing pigs in total (Landrace × Yorkshire × Duroc) initially weighing 58.85 ± 3.30 kg of live body weight (BW) were selected based on BW and sex. Then they were assigned into 30 experimental pens in a completely randomized block design (ten pens for each treatment; with five pigs for each pen; three females and two males per pen). Slatted floors and environmentally controlled rooms were used to house the pigs. Diets based on the corn-soybean meal (Table 1), were created in order to meet or exceed NRC [22] guidelines. The combination of synbiotic and glyconutrient was sourced from Maxcell Global (Seoul, Korea), containing *L. plantarum, B. subtilis, and S. cerevisiae* of 1×10^7 CFU/g, with yeast cell wall β-glucans of 5% from *S. cerevisiae*, and 7% of glyconutrients composed of N-acetylglucosamine, D-xylose, and Fucose. A synbiotic is a combination of probiotics and prebiotics [17]. Probiotics are beneficial bacteria that contribute to a host's health and it's well-being when given sufficient amounts [23]. Prebiotics are non-digestible feed supplements that help promote the multiplication of beneficial microbiota in the gut [24]. Glyconutrients are simple sugars which act as cell integrity promoters, improving health and energy efficiency [14]. Pigs were fed to three different diets (CON, basal diets; TRT1, CON + SGN 0.15%; and TRT2, CON + SGN 0.30%) in phase I and phase II (weeks 1 to 5 and weeks 5 to 10, respectively). During the trial, feed and water were freely available to the pigs.

Samples collection, processing, and calculations

Growth performance

In order to calculate the ADG, BW of every individual pig was recorded on days 1, 35, and 70. In addition, the consumed and remained feeds (per pen) were noted for the calculation of average daily feed intake (ADFI), and ultimately the amount of ADG and ADFI were taken to calculate the FCR.

Apparent total tract digestibility

The 2 g/kg of chromium oxide (Cr_2O_3) as indigestible marker were mixed with diets seven days before fecal sample collection in order to determine the ATTD of nitrogen (N), dry matter (DM), and gross energy (GE) of pigs. At the completion of the trial, we have selected one gilt and one barrow per each pen for fresh fecal sample collection. The samples were obtained by massaging a pig's rectum. The samples were directly put into a chilled box. Later on, we transported the samples to the lab, and kept at a temperature of −20℃ until they were examined by trained personnel. Following 72 hours of drying at 70℃, samples were finely powdered and sieved through a 1-mm screen. The AOAC [25] methods were applied to assess the digestibility of DM, N, and GE. The

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Table 1. Experimental diet ingredient composition (as-fed basis)

Raw material	Phase1 (%)	Phase2 (%)
Corn	63.71	68.91
Soybean meal	19.84	11.90
Rapeseed meal	3.00	4.00
DDGS (corn)	5.00	7.00
Tallow	3.40	3.10
Molasses	2.00	2.00
Limestone	1.24	1.27
MDCP	0.53	0.37
Salt	0.30	0.30
DL-Methonine	0.04	-
L-Lysine H_2SO_4	0.41	0.45
L-Threonine	0.06	0.07
L-Tryptophan (10%)	0.17	0.33
Vit/Min premix[1)]	0.20	0.20
Phytase	0.05	0.05
Carbohydrase	0.05	0.05
Total	100.00	100.00
Analyzed values		
Moisture	12.90	12.98
CP	16.74	14.41
EE	5.71	5.64
Fiber	2.95	2.89
Ash	5.07	4.72
NSP	120.55	116.40
NDF	10.17	10.80
ADF	2.98	3.09
Ca	0.69	0.66
P	0.42	0.38
Na	0.15	0.16
Cl	0.28	0.28
K	0.83	0.71
Lysine	1.0164	0.8560
Methionine	0.3241	0.2629
Threonine	0.6729	0.5864
Tryptophan	0.1961	0.1771
Met + Cys	0.6204	0.5329

[1)]Provided per kg diet: Fe, 100 mg as ferrous sulfate; Cu, 17 mg as copper sulfate; Mn, 17 mg as manganese oxide; Zn, 100 mg as zinc oxide; I, 0.5 mg as potassium iodide; and Se, 0.3 mg as sodium selenite. Provided per kilograms of diet: vitamin A, 10,800 IU; vitamin D_3, 4,000 IU; vitamin E, 40 IU; vitamin K_3, 4 mg; vitamin B_1, 6 mg; vitamin B_2, 12 mg; vitamin B_6, 6 mg; vitamin B_{12}, 0.05 mg; biotin, 0.2 mg; folic acid, 2 mg; niacin, 50 mg; D-calcium pantothenate, 25 mg.

DDGS, dried distillers grains solubles; MDCP, monodicalcium phosphate; CP, crude protein; EE, ether extract; NSP, non-starch polysaccharides; NDF, neutral-detergent fiber; ADF, acid-detergent fiber; Met, methionine; Cyst, cystine.

analysis of ATTD was conducted using the method utilized in the previous research of Munezero and Kim [26]. A UV absorption spectrophotometric measurement was performed to measure chromium levels (UV-1201, Shimadzu, Kyoto, Japan). A sample of 2 grams of faecal and feed was

analyzed using an oxygen bomb calorimeter (Parr, 6400 Instrument Company, Moline, IL, USA). Moreover, in order to calculate the protein, the N was assessed by using Kjeltec 8600 (Foss Tecator AB, Hoeganaes, Sweden).

Gas emission

At the end of weeks 5 and 10 of the study, fecal samples were collected from one gilt and one barrow per pen to measure the concentration of methyl mercaptans, acetic acid, H_2S, NH_3, and CO_2. A plastic box (2.6 liters) was filled with 300g of collected faeces and covered with adhesive plaster to allow fermentation for 24 hours at 25 degree Celsius. Before measurement, each box with a sample was agitated around 30 seconds to homogenize the sample. The level of gas emission was determined by using a GV100 (Gastec, Seoul, Korea).

Meat quality

When pigs attained 110 kg of an average weight, they were sacrificed at a nearby abattoir. In order to ensure that the samples were chilled, the carcasses were kept at 2°C for 24 hours. The sample was taken around the ribs positioned at 10th to 11th. Before testing, meat samples were put at the temperature of 26°C. The color, marbling, and firmness scores were performed at room temperature in accordance with NPPC [27] Standards. The panel had 10 trained personnel who had all been briefed to estimate the sensory features of color, marbling, and firmness. Using a Model CR410 Chromameter, the values of lightness (L*), redness (a*), and yellowness (b*) of each sample were examined immediately after it was cut (Konica Minolta Sensing, Osaka, Japan). Simultaneously, using the pH meter, the pH of each sample were recorded (Model77p, Istek, Seoul, Korea). The water-holding capacity (WHC) was determined using the method described by Sureshkumar et al. [28]. A meat sample was compressed and the region with moisture was drawn and assessed by the use of digitizing area line sensor (MT10S; M.T. Precision, Sinyoung Choukki, Bucheon, Korea). Then we calculated the WHC values, a ratio with lower value indicates a higher WHC). The area of longissimus muscle (LM) was measured by tracing the LM surface at the 10th rib with the previously mentioned digitizing area line sensor. 3g of meat was sampled to determine the drip loss utilizing the plastic bag technique described by Sureshkumar et al. [29], and cook loss was determined as outlined by Sullivan [30].

Fatty acid profile

Samples were collected to examine the fatty acid composition at the end of the experiment (week 10). In brief, a crude fat extractor was used to collect the sample, which was then placed in a cellulose cup. The sample was then mixed to a 5 mL of n-hexane. After that, BF-3 Methanol (3 mL) and 1 ml of extraction sample were added, homogenized, and reacted at 100℃ for 1 hour. Following the reaction, 2 ml of saturated saline and 2 mL of Hexane were added, homogenized, and then purified. A Gas Chromatography-FID (Agilent, Santa Clara, USA) was used to analyze the hexane layer (upper layer) in the distribution solution after 30 minutes.

Statistical analysis

Statistical analysis was performed with General Linear Model procedure of the SAS software (SAS Institute, Cary, NC, USA) using the Tukey's honest significance test. The pen was taken as the experimental unit. The outcomes from the analysis were illustrated as mean and the standard error of the mean (SEM) values. A p-value < 0.05 was considered significant.

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RESULTS

Growth performance

Data and results recorded from week 1 to week 10 are shown in Table 2. In weeks 5 to 10, ADG increased (p = 0.036) as SGN supplementation increased in finishing diets. Finishing pigs supplemented with 0.3% SGN demonstrated higher ADG than other groups. However, the inclusion of SGN in the pigs' diet did not affect BW gain, ADFI, and FCR (p > 0.05) throughout the experiment.

Apparent total tract digestibility

Table 3 summarizes effects of SGN on ATTD of finishing pigs. SGN supplementation had no effects on ATTD parameters (DM, N, or GE; p > 0.05).

Gas emissions

Table 4 presents the gas emission results from finishing pigs. The inclusion of SGN to the finishing pig's diets had no significant change on NH_3, H_2S, methyl mercaptans, acetic acids, and CO_2

Table 2. The effect of synbiotic-glyconutrient supplementation on growth performance in finishing pigs

Items	CON[1)]	TRT1	TRT2	SEM	*p*-value
BW (kg)					
Week 0	53.85	53.85	53.84	0.01	0.807
Week 5	81.12	81.68	81.78	0.43	0.520
Week 10	111.14	113.50	113.95	0.98	0.124
Initial–week 5					
ADG (g)	779	795	798	12	0.512
ADFI (g)	2,377	2,403	2,400	22	0.664
FCR	3.054	3.024	3.009	0.030	0.564
Week 5–10					
ADG (g)	858[b]	909[ab]	919[a]	16	0.036
ADFI (g)	2,907	3,005	3,027	42	0.128
FCR	3.391	3.308	3.295	0.035	0.138
Overall					
ADG (g)	819	852	859	14	0.126
ADFI (g)	2,642	2,704	2,713	29	0.205
FCR	3.231	3.175	3.162	0.028	0.224

[1)]CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.

[a,b]Means in the same row with different superscripts differ significantly (p < 0.05).

Table 3. The effect of synbiotic-glyconutrient supplementation on apparent total tract digestibility in finishing pigs

Items (%)	CON[1)]	TRT1	TRT2	SEM	*p*-value
Week 10					
Dry matter	68.69	69.17	69.54	1.58	0.929
Nitrogen	64.11	65.41	65.88	1.58	0.722
Gross energy	70.41	71.57	71.64	1.51	0.813

CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.

Table 4. The effect of synbiotic-glyconutrient supplementation on gas emission in finishing pigs

Items (ppm)	CON[1)]	TRT1	TRT2	SEM	*p*-value
Week 5					
NH_3	6.0	5.8	5.8	0.4	0.857
H_2S	4.68	5.08	4.65	0.31	0.582
Methyl mercaptans	7.5	7.8	7.5	1.1	0.976
Acetic acid	12.0	12.8	12.0	1.4	0.913
CO_2	14,775.0	14,675.0	14,525.0	349.6	0.881
Week 10					
NH_3	7.3	7.3	6.3	0.8	0.564
H_2S	6.60	6.53	6.40	0.40	0.940
Methyl mercaptans	7.8	7.5	7.3	0.8	0.901
Acetic acid	12.5	12.3	12.3	1.1	0.983
CO_2	16,675.0	16,475.0	16,225.0	379.3	0.716

[1)]CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.
NH_3, ammonia; H_2S, hydrogen sulfide; CO_2, carbon dioxide.

emission throughout the trial ($p > 0.05$).

Meat quality

Table 5 presents the results of the meat color (lightness, redness, and yellowness), WHC, LM area, cooking loss, drip loss, and sensory features. Pigs fed a diet containing 0.3% SGN has indicated a significant lower drip loss than that of other diet-fed pigs on d 7 ($p = 0.053$). Moreover, due a diet containing 0.3% SGN, the cooking loss tended to improve ($p = 0.070$). Nevertheless, the significant effects of WHC, longissimus muscle area, meat color, and sensory features were not found ($p > 0.05$).

Table 5. The effect of synbiotic-glyconutrient supplementation on meat quality in finishing pigs

Items	CON[1)]	TRT1	TRT2	SEM	*p*-value
Water holding capacity (%)	48.40	49.67	50.94	3.54	0.881
Longissimus muscle area (mm^2)	6,552.39	6,853.80	6,861.49	377.80	0.809
Meat color					
L*	51.79	51.13	51.71	0.33	0.345
a*	32.97	32.81	32.68	0.25	0.720
b*	6.16	6.02	6.05	0.13	0.751
Cooking loss (%)	32.25	31.86	30.74	0.39	0.070
Drip loss (%)					
d1	7.86	7.76	7.50	0.43	0.837
d3	14.04	13.89	12.82	0.50	0.233
d5	19.66	19.51	19.31	0.19	0.463
d7	24.44[a]	23.76[ab]	24.04[b]	0.14	0.053
Sensory evaluation					
Color	3.16	3.13	3.31	0.20	0.778
Marbling	3.34	3.34	3.28	0.09	0.845
Firmness	3.31	3.28	3.25	0.10	0.901

[1)]CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.
[a,b]Means in the same row with different superscripts differ significantly ($p < 0.05$).

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Fatty acid profiles in fat of finishing pigs

The effects of SGN supplementation on fatty acid profiles in the fat of finishing pigs are listed in Table 6. The increased levels of palmitoleic acid (C16:1), margaric acid (C17:0), omega-3 fatty acid (ω-3 FA), omega-6 fatty acid (ω-6 FA), and ω-6: ω-3 ratio (p = 0.034, 0.020, 0.025, 0.007, and 0.003, respectively) were observed in the fat of finishing pigs fed on 0.3% of SGN compared with pigs fed the control diets. Moreover, the SGN tended to increase the concentration of heneicosylic acid (C21:0) and PUFA / SFA in the fat of finishing pigs (p = 0.0813 and 0.0877, respectively).

Fatty acid profiles in the lean tissues of finishing pigs

The impact of SGN addition on the fatty acid profiles in finishing pig lean is illustrated in Table 7. SGN tended to increase the concentration of lauric acid (C12:0), palmitic acid (C16:0), and omega 3 fatty acid in the lean of finishing pig (p = 0.094, 0.091, and 0.094 respectively). Furthermore, increased levels of margaric acid (C17:0), linoleic acid (C18:2n6c, LA), arachidic acid (C20:0),

Table 6. The effect of synbiotic-glyconutrient supplementation on fatty acid profile in finishing pig's fat

Items (%)	CON[1)]	TRT1	TRT2	SEM	*p*-value
C16:0	20.64	22.97	24.17	1.02	0.238
C16:1	1.75[b]	2.20[ab]	2.25[a]	0.11	0.034
C17:0	0.14[b]	0.47[ab]	0.48[a]	0.07	0.020
C17:1	0.10	0.18	0.24	0.06	0.406
C18:0	10.85	11.10	14.48	1.12	0.112
C18:1,T	19.00	20.33	20.29	5.81	0.725
C18:1,C	22.96	33.43	44.13	7.85	0.241
C18:2N6T	11.91	16.56	17.46	1.82	0.147
C18:3N3	0.53	0.77	0.91	0.11	0.125
C20:0	0.24	0.25	0.28	0.05	0.834
C20:1	0.86[b]	0.99[b]	1.20[a]	0.10	0.109
C20:2	0.60	0.61	0.61	0.04	0.945
C20:3N6	0.06	0.08	0.09	0.01	0.259
C21:0	0.11	0.17	0.18	0.02	0.087
C20:3N3	0.08	0.09	0.10	0.01	0.454
C22:1N9	0.01	0.03	0.03	0.01	0.298
C23:0	0.05	0.08	0.08	0.01	0.316
ω-3 FA	0.53[b]	0.85[ab]	0.91[a]	0.07	0.025
ω-6 FA	11.9[b]	16.65[ab]	17.57[a]	0.84	0.007
ω-6: ω-3	18.2[b]	22.28[ab]	22.74[a]	0.61	0.003
ΣSFA	40.48	34.42	33.58	3.35	0.347
ΣUSFA	59.51	65.57	66.41	2.53	0.191
ΣMUFA	46.34	47.29	47.40	2.64	0.953
ΣPUFA	13.17	18.27	19.00	1.87	0.133
MUFA/SFA	1.14	1.37	1.41	0.08	0.107
PUFA/SFA	0.32	0.53	0.56	0.07	0.088
TOTAL FATTY ACIDS	100.0	100.00	100.00	0.00	-

[1)]CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.

[a,b]Means in the same row with different superscripts differ significantly (p < 0.05).

ΣSFA, sum of saturated fatty acids; ΣUSFA, sum of unsaturated fatty acids; ΣMUFA, sum of monounsaturated fatty acids; ΣPUFA, sum of polyunsaturated fatty acids; MUFA/SFA, ratio of monounsaturated fatty acids and saturated fatty acids; PUFA/SFA, ratio of polyunsaturated fatty acid and saturated fatty acids.

Table 7. The effect of synbiotic-glyconutrient supplementation on fatty acid profile in finishing pig's lean

Items (%)	CON[1)]	TRT1	TRT2	SEM	*p*-value
C10:0	0.01	0.03	0.03	0.01	0.388
C12:0	0.02	0.04	0.07	0.01	0.094
C14:0	1.41	1.43	1.53	0.04	0.106
C16:0	22.07	22.96	23.05	0.28	0.091
C16:1	3.12	3.13	3.25	0.06	0.303
C17:0	0.01[b]	0.03[ab]	0.04[a]	0.01	0.037
C17:1	0.01	0.03	0.03	0.01	0.351
C18:0	10.96	11.28	11.36	0.14	0.189
C18:1,t	41.84	42.05	42.39	0.28	0.435
C18:1,c	3.80	4.18	4.48	0.23	0.198
C18:2N6C, LA	12.44[b]	13.29[ab]	13.54[a]	0.26	0.052
C18:3N3, ALA	0.45	0.51	0.60	0.06	0.237
C20:0	0.01[b]	0.03[ab]	0.04[a]	0.004	0.014
C20:1	0.69	0.75	0.80	0.06	0.424
C20:2	0.44	0.49	0.53	0.04	0.356
C21:0	0.27	0.37	0.40	0.04	0.158
ω-3 FA	0.45	0.51	0.60	0.04	0.094
ω-6 FA	12.44[b]	12.96[ab]	13.62[a]	0.24	0.036
ω-6: ω-3	22.44[b]	25.59[ab]	28.39[a]	0.95	0.033
ΣSFA	36.37	35.30	34.95	0.76	0.439
ΣUSFA	63.62[b]	65.04[ab]	66.69[a]	0.54	0.020
ΣMUFA	50.16[b]	51.28[ab]	53.83[a]	0.81	0.045
ΣPUFA	13.46	14.86	15.86	0.73	0.132
MUPA/SFA	1.37	1.43	1.57	0.09	0.325
PUFA/SFA	0.40	0.42	0.44	0.02	0.306
TOTAL FATTY ACIDS	100.00	100.00	100.00	0.00	-

[1)]CON, basal diet; TRT1, basal diet + SGN 0.15%; TRT2, basal diet + SGN 0.30%.

[a,b]Means in the same row with different superscripts differ significantly ($p < 0.05$).

FA, fatty acid; LA, linoleic acid; ALA, alpha-linolenic acid; ΣSFA, sum of saturated fatty acids; ΣUSFA, sum of unsaturated fatty acids; ΣMUFA, sum of monounsaturated fatty acids; ΣPUFA, sum of polyunsaturated fatty acids; MUFA/SFA, ratio of monounsaturated fatty acids and saturated fatty acids; PUFA/SFA, ratio of polyunsaturated fatty acid and saturated fatty acids.

omega 6 fatty acid, omega-6 to omega-3 ratio, unsaturated fatty acid, and monounsaturated fatty acid ($p = 0.037$, 0.052, 0.014, 0.036, 0.033, 0.020, and 0.045, respectively) were observed in the lean of finishing pigs fed diets containing 0.3% of SGN.

DISCUSSION

The actions of this combination are recognized to improve cell communication, which enhances immune responses, mediates inflammation, and reduces cellular stress in general [14]. Our findings indicated that finishing pigs fed SGN-supplemented diets improved ADG in the period of 5–10 weeks. Similarly, an increased growth performance has been observed in SGN supplemented group in poultry and nursery pigs [31,32]. Possibly, synbiotics and glyconutrients may have improved finishing pig growth by modulating the gut microbiota, enhancing intestinal barrier function, and regulating immune responses. Moreover, glyconutrients can increase energy efficiency and health

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by aiding in the reduction of inflammation and microbial growth [14,33]. In addition, Lee et al. [34] and Chu et al. [35] have demonstrated that pigs fed synbiotic-supplemented diets achieved comparable growth rates as pigs fed antibiotic-supplemented diets. In a disease challenge model, Guerra-Ordaz et al. [36] discovered that synbiotics can improve ADG, but not ADFI and Gain: Feed. There is a possibility that the higher ADG observed in a SGN group is due to a numerically higher ADFI in comparison to the control group.

A lot of attention has been paid to how probiotics and prebiotics help digest nutrients [37,38]. This study did not find any significant effect on nutrient digestibility of DM, N, and GE. It could be possible that SGN have a differential effect on the digestibility of different nutrients, such as protein, fat, and fiber, which was not detected by the overall digestibility measurement used in this study. Currently, there is no research on the impact of glyconutrients on nutrient digestibility in pigs. Similarly, a diet supplemented with *Enterococcus faecium* and inulin for growing pigs did not impact the digestibility of DM, GE, and N [39]. Moreover, Weiss et al. [40] concluded that *Pediococcus acidilactici* and oligofructose together had no effect on the ileal DM and crude protein digestibility in piglets. In contrast, combining probiotics from bacteria with prebiotics showed higher digestibility of DM and N in weaning pigs [34]. Increased organic matter digestion with probiotic and prebiotic supplementation is largely due to increases in neutral detergent fiber digestion [41]. The differences in our results compared to other research findings could be due to the different breeds and stages of pigs used in these studies.

It is thought that changes in gut microbiota affect the composition of feces as well as the amount of gases released from manure. Emissions of harmful gases like NH3, H2S, and other gaseous compounds originating from the livestock industry contribute to environmental pollution and have detrimental impacts on the health of both humans and animals [42]. NH_3, H_2S, methyl mercaptans, and acetic acid have not been affected with probiotic and prebiotic inclusion between treatments in the study conducted by Yun et al. [43]. Although Higgins et al. [44] reported that probiotic supplementation could reduce the NH_3 content of broiler excreta, the combination of synbiotic and glyconutrient had no effect on NH_3, H_2S, methyl mercaptans, acetic acids, or CO_2. Perhaps, the microbiome of pigs in the SGN group has not been able to be positively manipulated in a way that can affect noxious gas emissions. Moreover, this could be due to the low sensitivity of the gas measurement method or the high variability of gas production among individual pigs. Furthermore, more accurate and reliable methods of gas emission measurement should be employed to evaluate the environmental impact of SGN in pig diets.

The quality of meat and carcass traits determines taste, tenderness, juiciness, and overall consumer acceptance. Our study showed positive outcomes for cooking and drip loss parameters. SGN may have improved finishing pig pork quality by altering their fatty acid profile and increasing the content of beneficial omega-3 fatty acids, which have positive effects on human health. Consistent with our findings, Zhu et al. [45] found that adding maternal probiotics increased cooking yield and reduced drip loss. Following slaughter, the production of lactic acid through the glycolysis process reduces pH, which is related to drip loss and shear force [46]. According to earlier research, adding *L. plantarum* ZJ316 to piglets' diets increased meat quality by raising the pH_{45min} value [47], and adding *B. coagulans* had a positive impact on meat quality by reducing drip loss [48]. In the study conducted by Zhu et al. [45], maternal synbiotics increased redness while decreasing lightness in the *longissimus thoracis* muscle. Dietary probiotic consumption has been observed to increase redness but not whiteness [49]. These variations may be related to the feeding stage, the type, and the dose of probiotics or synbiotics and components of glyconutrients applied. Therefore, it would be beneficial to conduct further studies to determine the optimum dosage and absorption mechanism of this combination to gain a deeper understanding of its effects on pig meat quality.

The focus on meat fatty acid composition arises primarily from the desire to produce healthier meat with a higher ratio of polyunsaturated to saturated fatty acids and a more favorable balance between n-6 and n-3 polyunsaturated fatty acids [50]. The fatty acid profile of pork influences its nutritional value, organoleptic properties, and eating quality [2,45,51]. There are several essential fatty acids in pork, including myristic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, and linoleic acid [52]. However, fatty acid imbalances can even be harmful to consumers [53]. Pigs store dietary fatty acids in tissues without further modification [54]. Pork, being the most consumed meat globally, often has a high omega-6 (n-6) to omega-3 (n-3) fatty acid ratio due to conventional feeding methods, resulting in its limited availability as a source of n-3 fatty acids [55]. Currently, animal husbandry relies on grain-fed systems, leading to a high intake of omega-6 fatty acids which causes an imbalance between omega-6 and omega-3 [56]. People with this imbalance are more likely to develop cardiovascular disease, inflammation, diabetes, and autoimmune diseases [57]. Furthermore, the increase in linoleic acid could stimulate lipid oxidation in pork, and have a hypocholesterolemic effect and thus slowing the development of atherosclerosis for the consumer [58]. Also, in the body, linoleic acid elongates and desaturates to form C20:4n6, a precursor to pro-inflammatory compounds that can be harmful to health [59]. This prompted a call to rebalance their ratio in the feeds supplied to the animals. Employing nutritional strategies to improve meat fatty acid composition is a beneficial approach. Our study showed that supplementing finishing pigs' diets with the combination of probiotics, prebiotics, and glyconutrients increased the amount of palmitoleic acid (C16:1), margaric acid (C17:0), omega-3 fatty acid, omega-6 fatty acid, and ω-6: ω-3 ratio in fat of the pig meat. In addition, the higher levels of margaric acid (C17:0), linoleic acid (C18:2n6c), arachidic acid (C20:0), omega 6 fatty acid, omega-6 to omega-3 ratio, unsaturated fatty acid, and monounsaturated fatty acid were observed in the lean of finishing pigs. SGN may have improved fatty acid profiles in pigs due to their prebiotic and probiotic effects, which induce the production of short-chain fatty acids and other metabolites that regulate lipid metabolism. Similarly, probiotics such as *Lactobacillus amylovorus* and *Enterococcus faecium* have also been found to boost the C18:2n6c, monounsaturated fatty acids, and PUFA content in pork [54]. Furthermore, our results are constant with a study conducted by Chang et al. [16] who found that omega 3 and 6 fatty acids were significantly higher in the supplemented probiotic group. The addition of probiotics may improve the primary fatty acids content in offspring muscle, resulting in favorable changes in the gut microbiome [60]. Variations in flavor were related to the variability in fatty acid composition [61]. The addition of SGN increased the C16:1 level, which suggests that these additives might improve pork flavor. There is insufficient evidence to confirm that dietary prebiotics and probiotic supplementation effectively alter tissue fatty acid profiles. For example, longissimus dorsi muscle fatty acid profile did not change following the addition of inulin and horse chestnuts [62]. However, the inclusion of inulin into rabbit diets has resulted in an increase in linoleic acid and omega-3-PUFA levels, as well as a decrease in the indices of atherogenicity and thrombogenicity [63]. The probiotics, prebiotics, and simple sugars used in this study likely altered the gut microbiota, which could explain the positive results found. Consequently, this led to an increase in the content of beneficial fatty acids in pork.

CONCLUSION

Results of this experiment indicated that supplementing a diet containing 0.3% SGN improved growth performance, meat quality, and fatty acid profile in both lean and fat tissues. However, the SGN addition had no effect on ATTD and gas emissions of finishing pigs as we expected. The use of SGN combinations as feed additives could lead to improved feed efficiency, higher ADG,

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and improved meat quality. Nevertheless, this study failed to demonstrate an interaction between synbiotics and glyconutrients when this combination was mixed in the pigs' diet. Therefore, our team is developing a robust approach to elucidate more deeply the interaction between synbiotics and glyconutrients and their roles in the health and productivity of livestock.

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