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Response of growing pig in dietary sucrose supplementation on growth performance, nutrient digestibility, fecal score, and serum cortisol

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Abstract

Sucrose is a common disaccharide sugar that is used in pig diet mainly as an energy source as well as to improve the palatability of diet. This study investigated the effects of dietary sucrose supplementation on the growth performance, nutrient digestibility, fecal score, and serum cortisol of growing pigs. A total of 96 growing pigs were randomly allocated into three treatment groups (8 repetitions per treatment, 4 pigs per pen). Dietary treatments included: control (CON), basal diets; treatment 1 (TRT1), basal diet with 0.75% sucrose; and treatment 2 (TRT2), basal diet with 1% sucrose. Dietary sucrose supplementation tended to improve ($p < 0.10$) the average daily gain compared to CON group. Moreover, increased ($p < 0.05$) feed intake was found in the sucrose supplemented group compared to the CON group. In comparison to the CON diet the nutrient digestibility of energy tended to increase ($p < 0.10$) by sucrose supplemented diet. Fecal score was not altered through dietary sucrose supplementation. Decreased ($p < 0.05$) serum cortisol was found in both the 0.75% sucrose and 1% sucrose supplemented diet than the CON diet. In conclusion, sucrose can be a suitable feed ingredient for growing pigs as it can improve the palatability of diet as well as feed intake, energy digestibility and reduce stress through reducing serum cortisol.

Keywords: diet, growing pig, growth performance, palatability, sucrose

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Introduction

Worldwide pork production experienced a significant increase of approximately 31%, growing from 96 million metric tons in 2001 to almost 126 million metric tons by 2020 (FAO, 2021). Achieving optimal growth rates in commercial pig production requires appropriate feed intake, which is achieved through the supplementation of various feed additives in pig diets. Pigs can detect all five basic tastes, which include umami, sweet, bitter, sour, and salty (Roura et al., 2008). These taste perceptions are linked to various nutrients; for instance, umami taste is attributed to L-amino acids and peptides, whereas the sweetness sensation is triggered by simple carbohyd-rates (Chaudhari et al., 2009; Bachmanov et al., 2014). The classification of sugars includes a wide range of carbohydrates, polyols, and sweeteners. These substances are recognized by the taste receptor family 1 subunits 2 and 3 (T1R2 or T1R3) located within the oral cavity and gastrointestinal tract (GIT) of pigs (Daly et al., 2021). Pigs are inherently drawn to and prefer the flavors of sucrose, glucose, lactose, and sodium saccharin in solutions.

Sucrose is a disaccharide consisting of glucose and fructose, is a usual carbohydrate source found in numerous feed ingredients. Over time, pigs have developed a trait that signals a preference for high energy and carbohydrate-rich nutrients (Guzmán-Pino et al., 2015). Earlier studies have affirmed that sucrose stands as the most favored carbohyd-rate in pigs, and provides the greatest sweet intensity among all carbohydrates (Glaser et al., 2000). Sucrose improves the taste and energy content of feed, making consumption a more enjoyable experience for pigs. Consequently, it has been incorporated as an additive in pig diets to boost feed consumption (Roura et al., 2008; Roura and Tedó, 2009). Additionally, stress in animals are often assessed through serum cortisol levels, has substantial implications on pig performance. It is a critical factor affecting pig performance, as chronic stress can lead to poor growth and health problems (Lee et al., 2016). The effects of administering low doses of sucrose to growing pigs, especially regarding their feed consumption, growth rates, nutrient absorption, and levels of stress-related hormones in the blood, remain underexplored. This experiment focus on key performance indicators such as feed intake, growth performance and feed conversion ratio, together with the markers for gut health (nutrient digestibility, fecal score) and stress (serum cortisol level).

Materials and Methods

The Animal Care and Use Committee at Dankook University authorized the research protocol (approval code: DK-1-2226). The committee ensured that the study was done accordance with ethical principles and guidelines for animal research, which also conform to the requirements of the Canadian Council on Animal Care or the Guide for the Care and Use of Laboratory Animals.

Experiment animals, diets, and housing

A total of 96 growing pigs [(Yorkshire × Landrace) × Duroc] with an average body weight of 24.17 ± 0.24 kg were randomly allocated into three treatment group for four-weeks long feeding trial (8 replications per treatment, 4 pigs per pen). Dietary treatments were, control (CON), basal diets; treatment 1 (TRT1), basal diet with 0.75% sucrose; and treatment 2 (TRT2), basal diet with 1% sucrose. The basal diet was formulated following the guideline of National Research Council (NRC, 2012) (Table 1). Food grade sucrose (16.736 MJ·kg) was used in this experiment (CJ CheilJedang Co., Ltd., Korea). The basal diet was prepared at first, and then the treatment sucrose was mixed with it. By exchanging the same amount of corn for sucrose, the diet was adjusted. All the experimental animals were housed in an environmentally controlled house with clean plastic floor. During the feeding trial, both the room temperature and relative humidity were maintained at 25℃ and 60% respectively. To ensure *ad libitum* feed and water consumption, each pen was equipped with stainless steel self-feeders and nipple drinking systems.

Table 1. Composition of growing pig diets (as fed-basis).

Components	Amount
Ingredients (%)	
Corn	76.10
Soybean meal	19.10
Animal fat	1.80
Dicalcium phosphate	1.30
Limestone	0.71
Salt	0.20
Methionine	0.07
Lysine	0.49
Mineral premix[y]	0.10
Vitamin premix[z]	0.10
Choline	0.03
Total	100.00
Calculated value (%)	
Metabolizable energy ($MJ \cdot kg^{-1}$)	14
Crude protein	15.70
Crude fat	4.70
Crude fibre	2.50
Ash	4.50
Calcium	0.66
Phosphorus	0.56
Lysine	1.12
Methionine	0.32
Threonine	0.58
Tryptophan	0.05
Arginine	0.94
Alanine	0.85
Aspartate	1.50
Cysteine	0.28
Glutamic acid	2.80
Glycine	0.62
Proline	1.00
Serine	0.74
Tyrosine	0.50

[y] Provided per kg diet: Fe, 100 mg as ferrous sulphate; Cu, 17 mg as copper sulphate; 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.

[z] 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.

Sample collection and measurement

The body weight of individual animals were measured at the start and end of the feeding trial. The amount of feed consumed was estimated on a per-pen basis. Using the data of feed intake and body weight, average daily gain, average daily feed intake, and feed conversion ratio were calculated.

At the final week of the feeding trial, chromium oxide (Cr_2O_3, 0.2%) was mixed with the experimental diet of each treatment to measure the digestibility of dry matter, nitrogen, and digestible energy. After feeding the chromium oxide mixed diet for seven days, fecal samples were collected on the last day of the feeding trial through rectal messages from two random pigs (one male and one female) in every pen. These collected samples were then pooled together by pen basis and stored at -20℃ in a freezer until analysis. Before drying the fecal sample in the oven, they were thawed. Fecal sample were dried in an oven at 70℃ for three days. The dried samples were finely milled to a consistency that would allow them to pass through a 1 mm sieve. Chromium concentrations were assessed employing UV absorption spectrophotometry (UV-1201, Shimadzu Corp., Japan). The gross energy content of the samples was determined with a bomb calorimeter (Parr 6100; Parr Instrument Co., USA). Analysis of dietary dry matter (DM; method 930.15), crude protein (CP; method 968.06) adhered to the protocols specified by Association of Official Analytical Chemists International (AOAC International, 2005). Apparent total tract digestibility (%), ATTD = $[1 - \{(Nf \times Cd) / (Nd \times Cf)\}] \times 100$, where Nf is the concentration of the fecal (% DM), Nd is the diet concentration of the element (% DM), Cd is the chromium concentration in the diet (% DM), and Cf denotes the chromium concentration in feces (% DM).

Fecal scores were assessed and recorded daily at 08:00 and 20:00 during weeks 1 and 4. Two trained personnel was assigned to check the fecal score. The evaluation was based on the mean value of five pigs within each pen, using a 5-grade scoring system (Gao et al., 2023). The scoring criteria are as follows: 1 = compact, dry pellets in a small, firm mass; 2 = firm, shaped stool that retains firmness and softness; 3 = soft, shaped, and moist feces that maintain form; 4 = tender, shapeless feces that conform to the container's shape; 5 = fluid, watery feces that can be poured. Scores were noted on a pen-by-pen basis.

At the end of the feeding trial, blood samples were obtained from two randomly chosen pigs in each replication pen. The blood was collected using a 5 mL K3EDTA (tripotassium ethylene diamine tetraacetic acid) Vacuum tube (Becton Dickinson Vacutainer Systems, USA) by puncturing the anterior vena cava. To separate the blood plasma, the samples were centrifuged at a force of 4,000 g for 15 min at a temperature of 4℃. The serum samples were then preserved at -2 0℃ until further analysis. To measure serum cortisol concentrations, a solid-phase cortisol radioimmunoassay (RIA) kit (Coat-A-Count TKCO, Diagnostic Products Corp., USA) was used.

Statistical analysis

All recorded data were statistically analyzed using a randomized complete block design and analyzed by analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS software (version 9.2, SAS Institute Inc., USA). The pen was considered as an experimental unit. The standard error of the means was shown to express the data variability. In the result, $p < 0.05$ were considered as statistically significant, whereas $p < 0.10$ was considered as trend.

Results

The effect of dietary sucrose supplementation on the growth performance of growing pigs are shown in Table 2. In the present research, the inclusion of sucrose in the diet showed a trend towards an increase ($p < 0.10$) in the average daily gain compared to the control diet. Feed intake was increased ($p < 0.05$) in sucrose supplemented diet compared to the control diet. Feed conversion ratio was not changed through the supplementation of sucrose in growing pig diet.

Table 2. Growth performance of growing pigs offered sucrose in diets.

Items	CON	TRT1	TRT2	SEM	p-value
Initial body weight (kg)	24.20	24.14	24.16	0.86	0.987
Final body weight (kg)	43.13	43.32	44.12	0.87	0.708
Week 0 - 4					
ADG (g)	676b	685ab	713a	5.60	0.0934
ADFI (g)	1,578b	1,619a	1,621a	7.77	0.0298
FCR	2.336	2.365	2.275	0.01	0.1423

CON (control), basal diets; TRT1 (treatment 1), basal diet with 0.75% sucrose; TRT2 (treatment 2), basal diet with 1% sucrose; SEM, standard error of the mean; ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ratio.
a, b: Means in the same row with different superscript differ significantly ($p < 0.05$). Means were calculated using 12 replicates (10 birds per replicate) per treatment.

The effects of dietary sucrose supplementation on the nutrient digestibility of growing pigs are shown in Table 3. Sucrose supplement showed a tendency to increase ($p < 0.10$) the digestibility of energy compared to the control diet. However, digestibility of dry matter and nitrogen was not affected in different treatment diet.

Table 3. Nutrient digestibility in growing pigs offered sucrose in diets.

Items (%)	CON	TRT1	TRT2	SEM	p-value
Dry matter	75.30	76.57	76.12	0.56	0.6290
Nitrogen	73.65	74.08	75.49	0.49	0.2895
Digestible energy	73.80b	76.10ab	76.17a	0.42	0.0823

CON (control), basal diets; TRT1 (treatment 1), basal diet with 0.75% sucrose; TRT2 (treatment 2), basal diet with 1% sucrose; SEM, standard error of the mean.
a, b: Means in the same row with different superscript differ significantly ($p < 0.05$). Means were calculated using 12 replicates (10 birds per replicate) per treatment.

Dietary supplementation of sucrose up to 1% did not show any significant difference ($p > 0.05$) in the fecal score of growing pigs (Table 4). Additionally, Supplementation of dietary sucrose at 0.75% and 1% significantly decreased ($p < 0.05$) the serum cortisol level compared to the control diet (Table 4).

Table 4. Fecal score and blood cortisol level in growing pigs with different dose of sucrose in diets.

Items	CON	TRT1	TRT2	SEM	p-value
Fecal score[z]					
Week 1	3.28	3.27	3.22	0.02	0.9800
Week 4	3.17	3.25	3.26	0.02	0.4868
Blood cortisol					
Cortisol ($\mu g \cdot L^{-1}$)	31.11a	28.78b	28.51b	0.43	0.0488

CON (control), basal diets; TRT1 (treatment 1), basal diet with 0.75% sucrose; TRT2 (treatment 2), basal diet with 1% sucrose; SEM, standard error of the mean.

[z] Fecal scoring can be categorized as follows: 1, hard, dry pellet-like feces; 2, firm, shaped stool; 3, soft, moist stool that holds its form; 4, soft, shapeless stool that conforms to the shape of its container; 5, watery, pourable liquid consistency.

a, b: Means in the same row with different superscript differ significantly ($p < 0.05$). Means were calculated using 12 replicates (10 birds per replicate) per treatment.

Discussion

The voluntary feed intake by pigs is a determinant of the nutrient intake levels and plays a crucial role in the effectiveness of pig production (Hossain et al., 2024). A broad range of factors determine the feed intake in pigs, including their thermal, social, and physical environment, health status, taste preferences, and dietary composition. As pigs can distinguish the five basic tastes - umami, sweet, bitter, sour, and salty (Roura, 2011), the sweet taste of sucrose likely has a crucial role in influencing voluntary feed intake. Consequently, the observed increase in feed intake in this study can be attributed to the added sucrose, enhancing the palatability of the diet, and prompting a higher voluntary feed intake in growing pigs. This aligns with Guzmán-Pino et al. (2015), who found that weaning pigs showed a higher initial feed intake with a 2% sucrose-supplemented diet. Guzmán-Pino et al. (2015) found that long-term exposure to 16% sucrose and 16% maltodextrin decreased feed intake and weight gain in weaned pigs despite the higher intake of low doses of sucrose. The result from our research is in alignment with the studies conducted by Guzmán-Pino et al. (2015) and McLaughlin et al. (1983), who explained the idea that pigs naturally exhibit a preference for sweet-tasting substances. Early studies that examined anatomical and behavioral features relevant to pig taste and preferences also found a strong preference for glucose and sucrose, which wasn't easily matched by non-caloric sweeteners like saccharin (Roura and Fu, 2017). Another study indicated that glucose sensing in the upper GIT might elicit endocrine responses determining feed intake (Duca et al., 2021). The hunger-satiety cycle appears to be regulated by a network of chemosensory cells in the GIT that express taste and nutrition receptors (Roura and Fu, 2017). This is how the palatability of sucrose enhance the feed intake in pig. On the other hand, pigs consume feed to meet the requirement of the first limiting nutrient, typically energy-yielding nutrients. When the dietary available energy content is reduced, pigs tend to maintain energy intake by consuming more feed (Nyachoti et al., 2004). This might explain why higher amounts of dietary sucrose decrease feed intake (Guzmán-Pino et al., 2015). Additionally, Beech et al. (1991) noted that sucrose inclusion in growing pig diet increased fat deposition but had no effect on protein deposition compared with the wheat-based control. The improved body weight gain in this study was due to the synergistic effect of increased feed intake and improved energy digestibility.

Our study demonstrated a trend towards energy digestibility when the diet of growing pigs was supplemented with 1% sucrose, consistent with previous findings (Beech et al., 1991). Sucrose is a simple disaccharide, and it is readily hydrolyzed by the enzyme sucrase in the small intestine into monosaccharides glucose and fructose. These monosaccharides are absorbed more quickly than complex carbs, which helps explain the increased energy digestibility found in our study (Sitrin, 2014). Notably, the apparent digestibility of sucrose in pigs has been reported to be as high as 98.3%, with no detectable carbohydrates found in the rectal contents of the pigs (Ly, 1992). This efficient digestion and absorption process ensures that a higher proportion of consumed energy is available for use by the pig. Upon absorption, the monosaccharides glucose and fructose are rapidly transported to the liver via the Na^+-glucose cotransporter SGLT1 and the facilitative transporters GLUT2 and GLUT5 (Koepsell, 2020). In the liver and other cells, these sugars undergo extensive metabolic transformations. Glucose is primarily used for energy production, initially converted into glucose-6-phosphate by the enzyme hexokinase before being further metabolized through the glycolysis pathway to generate adenosine triphosphate (ATP) (Nakrani et al., 2023). Simultaneously, fructose is primarily metabolized in the liver, where it's converted into fructose-1-phosphate by the enzyme fructokinase. This molecule then feeds into the glycolysis pathway, also leading to ATP production. Additionally, fructose metabolism contributes to the synthesis of lipids and cholesterol (Muriel et al., 2021). These metabolic pathways provide the energy and building blocks necessary for pig growth and development. However, the dietary supplementation of sucrose appears to improve the energy digestibility in growing pigs through its effects on carbohydrate digestion, monosaccharide absorption, and subsequent energy metabolism.

Fecal score, an indicator of gastrointestinal health and diet digestibility, remained unchanged between the control and sucrose-supplemented groups. This observation suggests that the addition of 1% sucrose to the basal diet does not have a disruptive effect on gut health, or the digestibility of the feed in growing pigs. Similar result was found in a previous study, where dietary supplementation of sugar beet pulp did not change the diarrhoea score in pigs (Yan et al., 2017). Lei et al. (2017) suggest that addition of sweetener in weaning pig diet prevent the diarrhoea score. Sucrose is a simple carbohydrate, and it is highly digestible in monogastric animals, such as pigs. This high digestibility means that the sucrose is predominantly absorbed in the small intestine, leaving little to be fermented in the hindgut (Ly, 1992). However, 1% sucrose in this study may have minimal impact on the gut environment and thus the fecal score.

Commercially raised pigs often face numerous stressors that adversely affect their health and overall productivity (Choe, 2018). Such stressors can lead to economic losses due to increased mortality rates, decreased weight gain, and degraded meat quality (Giergiel et al., 2021). Under stressful conditions, physiological responses such as changes in heart rate, blood pressure, and animal behavior are commonly observed (Choe, 2018). According to Martínez-Miró et al. (2016), cortisol is the main glucocorticoid and a key biomarker for stress in pigs. Our findings suggest that dietary supplementation with 1% sucrose in the basal diet of growing pigs significantly reduces serum cortisol levels, which is indicative of a decreased stress response in these animals. Similar result was found in the previous study conducted on growing pigs, where sweet molasses was supplemented to the animals (Singh et al., 2020). Gyllenhammer et al. (2014) noted that consuming a high-sugar diet for 3 weeks resulted in lower cortisol levels compared to a low-sugar diet in human. The gut-brain axis symbolizes the two-way interaction that occurs between the GIT and the central nervous system (Carabotti et al., 2015). Sucrose, as a readily digestible carbohydrate, could affect this communication pathway. By modulating the gut microbiota, which in turn influences the gut-brain axis, sucrose could potentially impact the regulation of the hypothalamic-pituitary-adrenal (HPA) axis, the system responsible for cortisol production (Foury et al., 2011; Morais et al., 2021). Sucrose, being a simple carbohydrate, could rapidly increase blood glucose levels, leading to an increase in insulin secretion. Insulin helps transport tryptophan - a precursor for serotonin, to the brain

(Tagliamonte et al., 1976). Serotonin is a neurotransmitter which is involved in the regulation of mood and stress (Bamalan et al., 2023). Thus, sucrose supplementation could potentially increase serotonin production, aiding in stress management and thereby reducing cortisol levels in this study. However, the proposed mechanisms need to be validated by further research. Additionally, the long-term impact of sucrose supplementation on the metabolic health of the pigs and their gut microbiome should be explored to ensure that the strategy does not inadvertently lead to other health issues such as obesity or gut dysbiosis.

Conclusion

The addition of sucrose tended to improve average daily gain. The increased feed intake and tendency to improve energy digestibility is the cause of improved growth performance in this study. Additionally, the reduction in serum cortisol indicates that sucrose supplementation may have a stress-reducing effect on growing pigs. In summary, the inclusion of sucrose up to 1% in the diet of growing pigs showed positive trends in improving growth performance, feed intake, energy digestibility, and reducing serum cortisol levels.

Data Availability Statement

The data presented in this study are available upon reasonable request to the corresponding author.

Conflict of Interests

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

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