RESEARCH ARTICLE

J Anim Sci Technol 2024;66(1):115-124
https://doi.org/10.5187/jast.2023.e24

JAST
Journal of Animal Science and Technology
pISSN 2672-0191 eISSN 2055-0391

Effects of dietary supplementation of illite on growth performance, nutrient digestibility, and meat-carcass grade quality of growing-finishing pigs

Madesh Muniyappan[#], Sureshkumar Shanmugam[#] and In Ho Kim*

Department of Animal Resource & Science, Dankook University, Cheonan 31116, Korea

Check for updates

Received: Oct 6, 2022
Revised: Jan 29, 2023
Accepted: Feb 24, 2023

[#]These authors contributed equally to this work.

***Corresponding author**
In Ho Kim
Department of Animal Resource & Science, Dankook University, Cheonan 31116, Korea.
Tel: +82-41-550-3652
E-mail: inhokim@dankook.ac.kr

ORCID
Madesh Muniyappan
https://orcid.org/0000-0002-4677-9350
Sureshkumar Shanmugam
https://orcid.org/0000-0002-3632-3114
In Ho Kim
https://orcid.org/0000-0001-6652-2504

Competing interests
Not applicable.

Funding sources
The Department of Animal Resource & Science was supported through the Research-Focused Department Promotion & Interdisciplinary

Abstract

This study investigated the impact of clay mineral 'illite' (IL) on the growth performance, apparent total tract digestibility, and meat-carcass grade quality in growing-finishing pigs. One hundred fifty pigs were divided into two groups with fifteen pens/group and five pigs/pen, a control group that was fed with a corn-soybean meal-based diet and IL treated group were fed a meal-based diet supplemented with 0.5% IL. Compared to the control, IL supplementation increased average daily feed intake (ADFI) and reduce gain to feed ratio (G:F) in the pigs during days 43 to 70 and 99 to 126 and increased dry matter during days 42 and 126, and backfat thickness on day 98 ($p<0.05$). The drip loss was reduced on day 7, meat firmness tended to increase with dietary IL supplementation. In summary, dietary 0.5% IL supplementation improved ADFI, nutrient utilization of dry matter, and firmness and reduced G:F and drip loss of growing-finishing pigs.

Keywords: Backfat thickness, Growing-finishing pigs, Growth performance, Illite, Meat quality, Nutrient digestibility

INTRODUCTION

Feeds are not only the source of nutrients but also contain a number of contaminants that may enter the food chain via animal products. Therefore, to diminish the penetration of such substances into the animal body and subsequent contamination of animal products. During the last few decades, various studies have suggested that the use of un-convention feed supplements such as feed adsorbents is the most promising and economical approach to address this issue [1–3]. Recently studies also suggested that adsorbents (a variety of clays, bentonites, zeolites, phyllosilicates, and synthetic aluminosilicates) can prevent or reduce the mycotoxicosis bioavailability and its detrimental effects on animals because of their binding effect with aflatoxins, zearalenone and the ammonium, [4,5]. Clay minerals are a phyllosilicate that joins tetrahedral sheets to octahedral sheets. Clay minerals is swine nutrition are used in particular due to their absorption/adsorption properties significantly contributing to the health of the swine [1]. Clay minerals bind noxious compounds and expel them from the body of animals

Convergence Research Projects as a part of the University Innovation Support Program for Dankook University in 2022.

Acknowledgements
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-RS-2023-00275307).

Availability of data and material
Upon reasonable request, the datasets of this study can be made available by the corresponding author.

Authors' contributions
Conceptualization: Muniyappan M.
Data curation: Muniyappan M.
Formal analysis: Muniyappan M.
Methodology: Muniyappan M, Kim IH.
Software: Muniyappan M, Shanmugam S, Kim IH.
Investigation: Kim IH.
Writing - original draft: Muniyappan M, Shanmugam S.
Writing - review & editing: Muniyappan M, Shanmugam S, Kim IH.

Ethics approval and consent to participate
The trial protocols was approved (DK-1-1934) by the Animal Care and Use Committee of Dankook University, Cheonan, Korea.

[2,3]. The most well-known are montmorillonite, illite (IL), biotite, diatomite, quartz porphyry, and clinoptilolite. Phyllosilicate minerals including zeolite, kaolinite, bentonite, and vermiculite, have positive effects for on livestock [6,7], due to the specific structures of porous layers and high ion-exchange capacity [8]. Clay minerals were shown to reduce mycotoxins, such as aflatoxin B_1 and zearalenone, in pigs diets [9]. The dietary supplementation of clay improved the growth performance and nutrient digestibility of pigs [10]. In addition, dietary anion supplementation showed beneficial effects on growth performance and meat quality in growing-finishing pigs [11,12]. A commercial phyllosilicate mineral additive is available under the trade name of IL (SeobongBiobestech Seoul, Korea). To the best of our knowledge, no information about the impact of IL on growing-finishing pigs was available. In this study, we evaluate the effects of supplementation of IL on growth performance, total tract digestibility, and meat quality in growing-finishing pigs.

MATERIALS AND METHODS

Animal ethics

The Dankook University Institutional Animal Care and Use Committee approved (DK-4-1516) the protocols for this experiment.

Source of Anion

The IL was prepared by seobongBiobestech (Seoul, Korea), the main components of this product was shown in Table 1, which is provided by the Korea Chemical Institution.

Experimental design, animals, and housing

One hundred and fifty pigs ([Landrace × Yorkshire × Duroc]with an initial body weight of 25.42 ± 3.23 kg) were randomly allocated to two groups with fifteen pens/group and five pigs/pen. The trial dietary groups consisted of a corn-soybean meal-based basal diet 0, (control) 0.5% IL for 126 days. The basal diet composition was formulated in order to meet the requirements according to the National Research Council recommendation [13] (Table 2). Each pen was equipped with a stainless steel self-feeder and a nipple drinker. Room temperature was kept at 27℃.

Table 1. Composition for illite supplementation[1)]

Ingredients	%[2)]
SiO_2	64.60
Al_2O_3	20.80
Fe_2O_3	3.05
FeO	0.46
MgO	2.30
CaO	0.53
Na_2O	2.60
K_2O	0.40
TiO_2	0.15
Ignition loss	4.74

[1)]Provided by SeobongBiobestech Co., Ltd., Seoul, Korea.

[2)]Provided by the Korea Chemical Institution, Daejeon, Korea.

https://doi.org/10.5187/jast.2023.e24

Table 2. Composition of finishing pig diets (as fed basis)

Ingredients	Content
Corn	76.73
Soybean meal (48%)	15.32
Tallow	2.52
Molasses	2.00
Dicalcium phosphate	1.15
Limestone	0.81
Salt	0.30
Methionine (99%)	0.07
Lysine	0.48
Threonine (99%)	0.14
Tryptophan (99%)	0.05
Mineral mix[1)]	0.20
Vitamin mix[2)]	0.20
Choline (25%)	0.03
Total	100.00
Calculated value	
Crude protein (%)	14.00
Calcium (%)	0.60
Phosphorus (%)	0.55
Lysine (%)	1.00
Methionine (%)	0.30
Threonine (%)	0.65
Tryptophan (%)	0.20
Metabolizable energy (kcal/kg)	3300
Crude fat (%)	5.38
Fiber (%)	2.34
Ash (%)	3.26

[1)]Provided per kg diet: Fe, 115 mg as ferrous sulfate; Cu, 70 mg as copper sulfate; Mn, 20 mg as manganese oxide; Zn, 60 mg as zinc oxide; I, 0.5 mg as potassium iodide; and Se, 0.3 mg as sodium selenite.

[2)]Provided per kilograms of diet: vitamin A, 13,000 IU; vitamin D_3, 1,700 IU; vitamin E, 60 IU; vitamin K_3, 5 mg; vitamin B_1, 4.2 mg; vitamin B_2, 19 mg; vitamin B_6, 6.7 mg; vitamin B_{12}, 0.05 mg; biotin, 0.34 mg; folic acid, 2.1 mg; niacin, 55 mg; D-calcium pantothenate, 45 mg.

Sampling and measurements

Pigs were weighed on days 0, 42, 70, 98, and 126 as well as the feed consumption was also recorded on a pen basis to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F = ADFI / ADG).

The fresh fecal samples were collected (about 300 g) from each pen during the end of the trial and were -dried and finally ground to pass through a 1-mm sieve for the measurement of dry matter, nitrogen, and energy. The two groups diets and feces samples were determined following the procedures of Association of Official Analytical Chemists [14].

Carcass traits

Two pigs per pen were selected randomly from each treatment at days 0, 14, 28, 42, 56, 70, 84, 98, 112, and 126 experiment period to determine the backfat thickness and at week 18 of the experiment, lean meat percentage (LMP) measurements were measured using a real-time ultrasound instrument (Piglog 105, SFK Technology, Herlev, Denmark).

Meat quality traits

One pig per pen was selected for slaughter based on the average body weight. One piece of the right loin sample was removed between 10th and 11th ribs after chilling at 2℃ for at least 24 h. The meat samples were thawed at ambient temperature prior to evaluation. The carcass was placed at 4℃ for a 24-h chilling period. The meat color containing L*, a*, and b* were determined by Chen et al. [1]. Minolta colorimeter (CR- 410, Konica Minolta Sensing, Osaka, Japan); firmness, color, and marbling values were assessed as reported by NPPC standards [15]. Drip loss was evaluated utilizing about 5g of meat sample as reported by the plastic bag method described by Honikel [16]. The weight of each sample was taken before and after cooking to determine cooking loss, which was defined as the cooked weight divided by uncooked weight multiplied by Sullivan et al. [17]. The thiobarbituric acid reactive substances (TBARS), was determined according to Witte et al. [18]. The quality of pork carcasses was graded using the method described by Muniyappan et al. [19].

Statistical Analysis

All data were analyzed by the student's *t*-test for unpaired data with pen as trial unit (SAS software version 9.2; SAS Institute, Cary, NC, USA). Variability in the data is expressed as the standard error of the means, and a probability level of $p < 0.05$ were considered to be statistically significant and the tendency was declared at $0.05 \le p < 0.10$.

RESULTS

Growth performance

The effect of supplementation of IL to basal diet on growth performance of growing-finishing pig is presented in Table 3. Dietary inclusion of IL increased ($p < 0.05$) ADFI and decreased G:F was observed during 43 to 70 and 99–126 days compared with the pigs fed control diet. However, body weight and ADG were similar among the diet groups.

Apparent total tract digestibility

The effect of IL supplementation on the nutrition digestibility of growing-finishing pig is presented in Table 4. On days 48 and 126, dietary inclusion of IL increased ($p < 0.05$) dry matter digestibility compared with the control. Dietary treatments did not influence nitrogen and energy.

Carcass traits

The data presented in Table 5 shows the result of backfat thickness and LMP. Dietary supplementation of IL in diets had shown significant ($p < 0.05$) improvement in backfat thickness during the day 98. However, LMP were not significantly different among the diet groups.

Meat quality

A decrease ($p < 0.05$) drip loss of pigs supplemented with IL was observed compared with the control. Furthermore, the supplementation of IL resulted in trends to increase of the firmness ($p < 0.10$). No impact of dietary treatments was found on other meat quality parameters (TBARS, meat color, cooking loss, sensory evaluation, Marbling) (Table 6).

Carcass grade

Table 7 shows the results of the effects of dietary inclusion of IL on carcass grade. We observed

https://doi.org/10.5187/jast.2023.e24

Table 3. Effect of dietary illite supplementation on growth performance in growing - finishing pig

Items	CON[1)]	IL	SEM	*p*-value
Body weight (kg)				
Initial	24.5	24.5	0.01	0.988
Day 42	50.4	50.9	0.30	0.767
Day 70	70.5	71.3	0.20	0.711
Day 98	92.4	93.4	0.30	0.822
Day 126	115.9	116.7	0.60	0.822
Day 0 to 42				
ADG (g)	616	629	7.00	0.555
ADFI (g)	1588[b]	1642[a]	18.00	0.222
G:F	0.388	0.383	0.002	0.511
Day 43 to 70				
ADG (g)	718	729	8.00	0.581
ADFI (g)	2141[b]	2287[a]	33.00	0.022
G:F	0.336[a]	0.319[b]	0.003	< .0001
Day 71 to 98				
ADG (g)	782	788	10.00	0.850
ADFI (g)	2538	2524	22.00	0.844
G:F	0.308	0.312	0.004	0.563
Day 99 to126				
ADG (g)	839	834	12.00	0.872
ADFI (g)	2735[b]	2843[a]	35.00	0.012
G:F	0.305[a]	0.295[b]	0.002	0.001
Overall				
ADG (g)	725	732	5.00	0.766
ADFI (g)	2201	2224	13.00	0.677
G:F	0.330	0.329	0.001	0.810

[1)]CON, basal diet; IL, 0.5% illite.

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

ADG, average daily gain; ADFI, average daily feed intake, G:F; gain to feed ratio.

Table 4. Effect of dietary illite supplementation on apparent total tract nutrient digestibility in growing - finishing pig

Items (%)	CON[1)]	IL	SEM	*p*-value
Day 42				
Dry matter	76.61	77.95	1.02	0.018
Nitrogen	74.58	74.50	1.41	0.980
Energy	75.40	75.10	1.41	0.903
Day 126				
Dry matter	73.04	74.99	0.65	0.043
Nitrogen	72.28	72.38	0.76	0.871
Energy	73.88	74.36	0.50	0.620

[1)]CON, basal diet; IL, 0.5% illite.

Table 5. Effect of dietary illite supplementation on backfat thickness in growing - finishing pig

Items	CON[1)]	IL	SEM	p-value
Back fat thickness (mm)				
Initial	6.00	6.10	0.07	0.563
Day 14	6.50	6.70	0.09	0.394
Day 28	7.20	7.30	0.08	0.465
Day 42	7.80	8.00	0.08	0.369
Day 56	9.30	9.50	0.09	0.393
Day 70	11.10	11.10	0.09	0.953
Day 84	12.80	13.10	0.12	0.207
Day 98	14.40[b]	15.00[a]	0.13	0.020
Day 112	16.30	16.70	0.15	0.162
Day 126	18.70	18.90	0.24	0.655
Lean muscle percentage (%)				
Day 126	55.9	55.4	0.30	0.240

[1)]CON, basal diet; IL, 0.5% illite.

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

Table 6. Effect of dietary illite supplementation on the meat quality of growing-finishing pigs

Item	CON[1)]	IL	SEM	p-value
TBARS	3.69	3.74	0.29	0.925
Meat color				
L*	55.16	55.69	1.58	0.766
a*	16.05	16.52	0.72	0.584
b*	6.14	6.23	0.66	0.903
Sensory evaluation				
Color	3.2	2.9	0.2	0.189
Firmness	3.1	3.3	0.2	0.088
Marbling	2.6	2.3	0.2	0.435
Cooking loss (%)	30.3	30.7	0.9	0.795
Drip loss (%)				
d1	1.39	1.75	0.66	0.616
d3	2.61	2.98	0.59	0.591
d5	4.07	3.94	0.50	0.853
d7	5.75[a]	5.56[b]	0.01	< .0001

[1)]CON, basal diet; IL, 0.5% illite.

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

TBARS, thiobarbituric acid reactive substances.

Table 7. Effect of dietary illite supplementation on carcass grade in growing - finishing pig

Items	CON[1)]	IL	SEM	p-value
Back fat thickness (mm)	19.2	19.5	0.9	0.574
Carcass weight (kg)	87.7	86.8	0.4	0.447
Carcass grade				
1+	21	22	-	-
1	38	41	-	-
2	16	12	-	-

[1)]CON, basal diet; IL, 0.5% illite.

 https://doi.org/10.5187/jast.2023.e24

no significant difference (p > 0.05) in carcass weight and backfat thickness among treatments. We found that 1% carcass grade was higher in pigs fed supplemented with IL.

DISCUSSION

Previous studies which investigated supplementation of non-conventional feed additives like clays, synthetic aluminosilicates, phyllosilicates, bentonites, and zeolites have decreased mycotoxicosis impact on livestock farms due to its binding capability with aflatoxins, zearalenone, and ammonium [11,20]. Dietary inclusion of zeolite particles might stimulate the lining of the gut and gastrointestinal tract and afterward promote swine health conditions [8]. In the current study, the inclusion of IL significantly improved ADFI and decreased G: F compared with the control, and this finding was similar to previous reports [11]. Kwon et al. [21] showed that Biotite V supplementation to pigs' diets had significantly increased ADFI and G:F. Thacker [6] also reported that dietary inclusion of zeolite increased ADG and ADFI of finishing pigs. Trckova et al. [22] found that adding 1% of kaolin enhanced pigs' growth performance. Similarly, Song et al. [7] and Xia et al. [23] reported a significant increase in the growth performance due to dietary supplementation of 0.15%, 0.3%, or 0.6% silicate minerals. The improvement in the growth performance of pigs due to the aluminosilicate minerals, clay has been proven to have anti-bacterial and anti-inflammatory activities [8,12]. In addition, it has been reported that aluminosilicate mineral was beneficial to the gut health of animals [10]. In the present study, supplementation of 0.5% IL significantly increased digestibility of dry matter which was consistent with the report of Li and Kim [24] who reported that dietary inclusion aluminosilicate minerals increased apparent total tract retention of dry matter in pigs. The positive impacts of aluminosilicate minerals on nutrient digestibility may be attributed to the effects of aluminosilicate minerals on gastrointestinal development and the concomitant increase in digestive enzyme secretion [20,25]. As reported by Chen et al. [1] and Yan et al. [11] in which pigs fed clay minerals (sericite and Biotite V) had greater apparent total tract digestibility of dry matter, and energy in pigs compared with those fed the control dietary treatment. In contrast, Chen et al. reported a did not observe significant effects on nutrient utilization due to the inclusion of clay minerals [2]. The contradictory results were due to diet complexity, inclusion level of minerals, age, and the health status of the pigs.

Pigs backfat thickness is one of the important forecasts of meat-carcass lean and quality [26]. The impact of backfat thickness has a reflection on LMP and helps in evaluating meat quality [27]. Furthermore, Boyd et al. [28] found that the backfat thickness is a significant parameter to determine enough energy in pig within a short span of time. The inclusion of anion did not influence on LMP and backfat thickness in finishing pigs [11]. In this study, the inclusion of IL could improve backfat thickness in growing-finishing pigs during day 98. These results agree with Chen et al. [1] report that dietary supplementation of aluminosilicate minerals increases backfat thickness in growing-finishing pigs.

Recently, different meat characteristics (pH, color, and firmness) have been employed to separate fresh pork into quality groups in the pork industry. Previous studies also suggested that supplementation of zeolites could alter tissue mineral concentration in poultry and pigs because of its ability to absorb metal ions [1]. Meat color is a major indicator of pork quality as it influences customers' choices [29]. Therefore, it is proper to suggest that the improved firmness observed in the current study might be due to its liking of the metabolism or interaction with those metal ions and subsequently alter the mineral distribution in tissue [30–32]. Similarly, Yan et al. [11] reported that pigs fed IL had significant effects on firmness and drip loss than those fed diets compared with the control. In contrast, Thacker [6] found that dietary clays did not influence meat quality and carcass grade of pigs fed diets compared with the control. In our study, IL supplementation had no significant effects on carcass weight and backfat thickness compared with control. However, in this current study, we found that "1%" carcass grade increased in pigs fed with IL inclusion compared with the control. Therefore, as limited studies were conducted to evaluate the effects of IL clay series on meat quality and carcass grade of pigs, no related reference is available to compare this effect. Further study is still necessary to evaluate its effect on meat quality.

CONCLUSION

Our study demonstrated that pigs fed diet supplementation with 0.5% IL could be beneficial to enhance the daily feed intake, nutrient utilization of dry matter, and to reduce G:F and meat quality of drip loss in growing-finishing pigs.

REFERENCES

1. Chen YJ, Kwon OS, Min BJ, Shon KS, Cho JH, Kim IH. The effects of dietary Biotite V supplementation on growth performance, nutrients digestibility and fecal noxious gas content in finishing pigs. Asian-Australas J Anim Sci. 2005;18:1147-52. https://doi.org/10.5713/ajas.2005.1147
2. Chen YJ, Kwon OS, Min BJ, Son KS, Cho JH, Hong JW, et al. The effects of dietary Biotite V supplementation as an alternative substance to antibiotics in growing pigs. Asian-Australas J Anim Sci. 2005;18:1642-5. https://doi.org/10.5713/ajas.2005.1642
3. Daković A, Tomašević-Čanović M, Dondur V, Rottinghaus GE, Medaković V, Zarić S. Adsorption of mycotoxins by organozeolites. Colloids Surf B Biointerfaces. 2005;46:20-5. https://doi.org/10.1016/j.colsurfb.2005.08.013
4. Abdel-Wahhab MA, Nada SA, Khalil FA. Physiological and toxicological responses in rats fed aflatoxin-contaminated diet with or without sorbent materials. Anim Feed Sci Technol. 2002;97:209-19. https://doi.org/10.1016/S0377-8401(01)00342-X
5. Abbès S, Ouanes Z, ben Salah-Abbès J, Houas Z, Oueslati R, Bacha H, et al. The protective effect of hydrated sodium calcium aluminosilicate against haematological, biochemical and pathological changes induced by Zearalenone in mice. Toxicon. 2006;47:567-74. https://doi.org/10.1016/j.toxicon.2006.01.016
6. Thacker PA. Performance of growing-finishing pigs fed diets containing graded levels of biotite, an alumninosilicate clay. Asian-Australas J Anim Sci. 2003;16:1666-72. https://doi.org/10.5713/ajas.2003.1666
7. Song M, Liu Y, Soares JA, Che TM, Osuna O, Maddox CW, et al. Dietary clays alleviate diarrhea of weaned pigs. J Anim Sci. 2012;90:345-60. https://doi.org/10.2527/jas.2010-3662
8. Guo L, Liu Y, Han J, Zhu H, Wang X. Effects of Biotite V supplementation on growth performance and the immunological responses of weaned pigs after an Escherichia coli lipopolysaccharide challenge. Livest Sci. 2017;195:112-7. https://doi.org/10.1016/j.livsci.2016.12.003
9. Fu JC, Chen Q, Du J, Shi BM, Shan AS. Effectiveness of maifanite in reducing the detrimental effects of aflatoxin B1 on hematology, aflatoxin B1 residues, and antioxidant enzymes activities of weanling piglets. Livest Sci. 2013;157:218-24. https://doi.org/10.1016/j.livsci.2013.06.032
10. Subramaniam MD, Kim IH. Clays as dietary supplements for swine: a review. J Anim Sci Biotechnol. 2015;6:38. https://doi.org/10.1186/s40104-015-0037-9
11. Yan L, Han DL, Meng QW, Lee JH, Park CJ, Kim IH. Effects of anion supplementation

 https://doi.org/10.5187/jast.2023.e24

on growth performance, nutrient digestibility, meat quality and fecal noxious gas content in growing-finishing pigs. Asian-Australas J Anim Sci. 2010;23:1073-9. https://doi.org/10.5713/ajas.2010.90609

12. Yan L, Lee JH, Meng QW, Kim IH. Evaluation of the Anion® supplementation on growth performance, nutrient digestibility, blood characteristics and faecal noxious gas content in weaning pigs. J Appl Anim Res. 2011;39:36-40. https://doi.org/10.1080/09712119.2011.565568
13. NRC [National Research Council]. Nutrient requirements of swine. 11th rev. ed. Washington, DC: National Academies Press; 2012.
14. AOAC [Association of Official Analytical Chemists] International. Official methods of analysis of AOAC International. 17th ed. Washington, DC: AOAC International; 2000.
15. NPPC [National Pork Producers Council]. Pork composition and quality assessment procedures. Des Moines, IA: National Pork Producer's Council; 2000.
16. Honikel KO. Reference methods for the assessment of physical characteristics of meat. Meat Sci. 1998;49:447-57. https://doi.org/10.1016/S0309-1740(98)00034-5
17. Sullivan ZM, Honeyman MS, Gibson LR, Prusa KJ. Effects of triticale-based diets on finishing pig performance and pork quality in deep-bedded hoop barns. Meat Sci. 2007;76:428-37. https://doi.org/10.1016/j.meatsci.2006.12.002
18. Witte VC, Krause GF, Bailey ME. A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. J Food Sci. 1970;35:582-5. https://doi.org/10.1111/j.1365-2621.1970.tb04815.x
19. Muniyappan M, Palanisamy T, Kim IH. Effect of microencapsulated organic acids on growth performance, nutrient digestibility, blood profile, fecal gas emission, fecal microbial, and meat-carcass grade quality of growing-finishing pigs. Livest Sci. 2021;252:104658. https://doi.org/10.1016/j.livsci.2021.104658
20. Denli M, Blandon JC, Guynot ME, Salado S, Perez JF. Effects of dietary AflaDetox on performance, serum biochemistry, histopathological changes, and aflatoxin residues in broilers exposed to aflatoxin B1. Poult Sci. 2009;88:1444-51. https://doi.org/10.3382/ps.2008-00341
21. Kwon OS, Kim IH, Hong JW, Lee SH, Jung YK, Min BJ, et al. Effects of dietary germanium biotite in weaned, growing and finishing pigs. J Anim Sci Technol. 2003;45:355-68. https://doi.org/10.5187/JAST.2003.45.3.355
22. Trckova M, Vondruskova H, Zraly Z, Alexa P, Hamrik J, Kummer V, et al. The effect of kaolin feeding on efficiency, health status and course of diarrhoeal infections caused by enterotoxigenic Escherichia coli strains in weaned piglets. Vet Med. 2009;54:47-63. https://doi.org/10.17221/5/2009-VETMED
23. Xia MS, Hu CH, Xu ZR. Effects of copper bearing montmorillonite on the growth performance, intestinal microflora and morphology of weanling pigs. Anim Feed Sci Technol. 2005;118:307-17. https://doi.org/10.1016/j.anifeedsci.2004.11.008
24. Li J, Kim IH. Effects of dietary supplementation of sericite on growth performance, nutrient digestibility, blood profiles and fecal microflora shedding in growing pigs. Anim Feed Sci Technol. 2013;184:100-4. https://doi.org/10.1016/j.anifeedsci.2013.04.010
25. Liu JB, Xue PC, Cao SC, Liu J, Chen L, Zhang HF. Effects of dietary phosphorus concentration and body weight on postileal phosphorus digestion in pigs. Anim Feed Sci Technol. 2018;242:86-94. https://doi.org/10.1016/j.anifeedsci.2018.06.003
26. De Jong JA, Tokach MD, McKinney LJ, DeRouchey JM, Goodband RD, Nelssen JL, et al. Effects of corn particle size, complete diet grinding, and diet form on finishing pig growth performance, caloric efficiency, carcass characteristics, and economics. In: Swine Day 2012:

report of progress 1074. Manhattan, KS: K-State Research an Extension; 2012. p. 316-24.
27. Sampath V, Shanmugam S, Park JH, Kim IH. The effect of black pepper (piperine) extract supplementation on growth performance, nutrient digestibility, fecal microbial, fecal gas emission, and meat quality of finishing pigs. Animals. 2020;10:1965. https://doi.org/10.3390/ani10111965
28. Boyd RD, Castro GC, Cabrera RA. Nutrition and management of the sow to maximize lifetime productivity. Adv Pork Prod. 2002;13:47-59.
29. Altmann BA, Gertheiss J, Tomasevic I, Engelkes C, Glaesener T, Meyer J, et al. Human perception of color differences using computer vision system measurements of raw pork loin. Meat Sci. 2022;188:108766. https://doi.org/10.1016/j.meatsci.2022.108766
30. Sampath V, Han K, Kim IH. Influence of yeast hydrolysate supplement on growth performance, nutrient digestibility, microflora, gas emission, blood profile, and meat quality in broilers. J Anim Sci Technol. 2021;63:563-74. https://doi.org/10.5187/jast.2021.e61
31. Apple JK, Wallis-Phelps WA, Maxwell CV, Rakes LK, Sawyer JT, Hutchison S, et al. Effect of supplemental iron on finishing swine performance, carcass characteristics, and pork quality during retail display. J Anim Sci. 2007;85:737-45. https://doi.org/10.2527/jas.2006-231
32. Yan H, Wei W, Hu L, Zhang Y, Zhang H, Liu J. Reduced feeding frequency improves feed efficiency associated with altered fecal microbiota and bile acid composition in pigs. Front Microbiol. 2021;12:761210. https://doi.org/10.3389/fmicb.2021.761210