

DIETARY LAURIC ACID SUPPLEMENTATION IN LARGE WHITE YORKSHIRE CROSS PIGLETS AND ITS EFFECT ON PRODUCTION AND HEALTH

G.G. Marsha¹, M. Venkateswarlu², G. Alexander³, M. Hanumanth Rao⁴,
B. Ekambaram⁵ and S. Parashuramulu*⁶

Department of Animal Nutrition

College of Veterinary Science

*PV Narsimha Rao, Telangana Veterinary University
Rajendranagar, Hyderabad- 500 030, Telangana, India*

ABSTRACT

*An experiment (97 days) was conducted to investigate the dietary lauric acid (LA) supplementation on performance, digestibility and faecal microflora counts in Large White Yorkshire cross piglets. A basal diet was (BD) prepared as a negative control without supplementation and a positive control with an antibiotic (chlortetracycline at 0.05%) supplementation (BDA). Another two diets were prepared by supplementing LA at 0.2 and 0.4% levels to the basal diet. Dietary inclusion of LA or antibiotic significantly ($P < 0.01$) improved the body weight and feed efficiency and recorded highest ($P < 0.01$) body weights with 0.4% LA, while lowest ($P < 0.01$) weight gain with control group. Significantly higher FCR ($P < 0.01$) was observed in LA fed animals and the lowest ($P < 0.01$) was recorded in the BD and BDA groups. The improved ($P < 0.05$) digestibility of organic matter, crude fiber, ether extract and nitrogen free extract was observed with 0.4% LA. The faecal total bacterial count and *E.coli* count were lowered ($P < 0.01$) with LA supplementation, while highest count was observed in control group. Hence, it was concluded that, supplementation of LA at 0.2 to 0.4 % in the diets of LWY piglets showed increased weight gain, feed efficiency and nutrient digestibility by reducing faecal microflora count in LWY piglets.*

Key words: Antibiotic, Digestibility, Faecal microflora, Growth, Lauric acid, Piglets

Received : 20.10.2023

Revised : 01.12.2023

Accepted : 01.12.2023

¹M.V.Sc Student

²Professor and University Head, Department of Animal Nutrition, CVSc, PVNRTVU, Korutla, Jagtial dist,

³Associate Professor and Head, Department of Animal Nutrition, CVSc, PVNRTVU, Mamnoor, Warangal dist,

⁴Associate Professor and Head, Department of Poultry Science, CVSc, PVNRTVU, Mamnoor, Warangal dist

⁵Director of Research, PVNRTVU, Rajendranagar, Hyderabad

⁶Assistant Professor, Department of Animal Nutrition, College of Veterinary Science, PVNRTVU, Korutla, Jagtial dist, corresponding author Email id: spramnutri@gmail.com

INTRODUCTION

Among all livestock enterprises, pig production can be highly advantageous due to the fact that pigs have high fecundity and extremely high feed conversion efficiency. But there are certain constraints in the rearing of pigs and one of the biggest ones is mortality at weaning. Weaning is the most critical time in a piglet's life. During this period, the intestinal tract and immune system of piglets

are not fully developed (Bailey *et al.*, 2005), which makes them vulnerable targets for micro-organisms and induces gastrointestinal pathologies (Castillo *et al.*, 2006) leading to both disease and deaths in piglets.

However, all of these issues were lessened when feed-grade antibiotics were introduced to piglets' weaning diets as a preventative strategy, but because of their unethical use and drug residue in pork, the use of antibiotics in feeds have been banned in India and other countries. This ban initiated the need for exploring alternatives to antibiotics. Several alternatives to antibiotics have been investigated since, of which short-chain fatty acids, showed promise as antimicrobial acidifiers (Partanen and Mroz, 1999). Further, certain organic acids like benzoic acid (Zhang *et al.*, 2016) fluvic acid (Kunavue and Lien, 2012) have resulted in improved piglet performance, as an antimicrobial agent. Another type of organic acid, medium-chain fatty acids (MCFAs), are also substances which can be considered as replacements to antibiotics. They have strong antibacterial activity against gram-positive cocci (Bergsson *et al.*, 2001) and *Escherichia coli* (Skřivanová *et al.*, 2009). Moreover, they can improve post-weaning gut development (Tang *et al.*, 1999).

Among MCFAs is lauric acid (C12), it is the primary fatty acid present in coconut oil and palm oil. The health benefits of these oils are attributed to its high lauric acid (LA) content. Numerous studies have been conducted in laboratory animals for assessing

the antimicrobial properties of lauric acid both *in vitro* (Schuster *et al.*, 1980; Skřivanová *et al.*, 2005) and *in vivo* (Galbraith and Miller, 1973; Yuhás *et al.*, 2006). LA has shown to be very effective against gram positive bacteria as well as certain viruses and fungi (Dayrit, 2015). However, earlier studies on LA are mainly limited to rats and other laboratory animals. The research on LA supplementation in the diets of piglets in India is scanty. Hence, present study was undertaken with an aim to assess the effect of LA supplementation on growth performance, nutrient digestibility and faecal microflora counts in Large White Yorkshire (LWY) cross piglets.

MATERIALS AND METHODS

The experiment was conducted in Livestock Farm Complex (LFC), College of Veterinary Science, Rajendranagar, Hyderabad. Synthetic Lauric acid (LA) was procured from M/s AI Nutritions Private Limited, Malaysia. The antibiotic chlortetracycline (Zoetis Indian Limited) having a trade name AUROFAC-150A was sourced from the local market.

Experimental animals

A total of 28 LWY cross piglets (70-75 days old) were selected and were tagged individually using standard ear tags. The piglets were randomly distributed to 4 treatments, of 7 animals each by following completely randomized design. Each treatment had an initial average body weight of 10±0.2 kgs. All the piglets were housed according to their treatment groups and maintained under good, hygienic management practices throughout

the trial period (97 days). Feed and water were offered *ad libitum* during the entire course of the experiment.

Experimental diets

A basal diet (BD) was prepared by using locally available ingredients (Table 1) following the recommendations of ICAR (2013). The BD has no supplements, served as a negative control. An antibiotic (chlortetracycline at 0.05%) supplemented diet (BDA) was prepared as a positive control. The remaining two diets were prepared by supplementing LA at two levels i.e., 0.2% (BDL-0.2) and 0.4% (BDL-0.4) to the basal diet.

Performance parameters

The performance of animals was measured by recording daily feed intake and body weights at fortnightly intervals. The overall performance of the piglets was analyzed by calculating fortnightly body weight gain, average daily gain and finally total weight gain of all piglets fed experimental diets. Feed efficiency was calculated for overall experiment.

Digestibility trial

A digestibility trial was conducted on the last 15 days of the experimental period i.e., the 83rd to the 97th day, consisting of a 5-day preliminary period and a 10-day collection period. A double indicator method was adopted to determine the dry matter (DM), crude protein (CP), crude fiber (CF) and ether extract (EE) digestibility, as well as DM intake in individual

piglets, of 4 experimental groups. Each piglet was fed 3g of chromic oxide (Cr_2O_3) at the beginning of the day, before offering feed. To ensure that the entire amount of Cr_2O_3 was consumed by each piglet, the Cr_2O_3 was pre-filled into vegetable capsules of 1g capacity made of Hydroxypropylmethylcellulose (HPMC) and therefore each piglet was fed 3 capsules per day. Faecal grab samples were collected 3 times a day by massaging of the rectum and pooled together. Out of the total sample collected in a day, 1/10th was weighed for estimation of nitrogen and stored in a deep freezer. The remaining feces was dried at $100 \pm 0.5^\circ\text{C}$ for 8-10 hours for the estimation of dry matter. The dried feces from all 10 days was pooled together, homogenized and stored for the estimation of CF, EE, NFE as well as Cr_2O_3 and acid insoluble ash following the standard procedures (AOAC, 2012).

Total bacterial and *Escherichia coli* count

Faecal microflora count was obtained by diluting 1g of freshly collected faecal sample in 10ml of normal saline in order to obtain a decimal dilution. Using a separate sterile pipette 10^{-10} dilutions were prepared by transferring 1ml of previous dilution to 9ml of diluents (Miller and Wolin, 1974). Dilution of 10^{-5} and 10^{-6} were used for enumeration of total bacterial and *Escherichia coli*, as obtained colonies from these dilutions contained a reasonable number of bacteria to count. For this, 0.1ml diluted digesta of each dilution was pipetted out into separate marked sterile disposable petri dishes (Hi Media Laboratories Ltd., Mumbai, India) and to this 12-15ml of

plate count agar (Hi Media Laboratories Ltd.) was poured for enumeration of total bacteria. While 12-15ml Eosin Methylene Blue agar (Hi Media Laboratories Ltd.) was poured in another 2 separate petri plates for enumeration of *Escherichia coli* (AOAC, 2012). After solidification of agar inverted solidified petri plates were incubated for 48±2 hours at 35°C. The colonies were enumerated using a colony counter (Optics Technology, New Delhi, India) and the results were expressed as log₁₀ Colony Forming Units (CFU)/gram feces.

Statistical analysis

The results obtained were subjected to analysis through SPSS software (version 16.0; SPSS, 2007) by applying one-way analysis of variance and the treatment means were ranked using Duncan's multiple range test (Duncan, 1955) with a test of significance at 5 and 1%. All the statistical procedures were done as per the procedures of Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

The nutrient composition of the basal diet formulated in the present study (Table 1) was in accordance with the recommendations of ICAR, (2013). The formulated diet was in line with diets used in the earlier studies conducted on medium chain fatty acid supplementation (Hong *et al.*, 2012 and Zentek *et al.*, 2012) and on organic acid supplementation (Wang *et al.*, 2008; Kunavue and Lien, 2012; Zeng *et al.*, 2015; Zhang *et al.*, 2016) in the diets of growing piglets.

Growth performance

The fortnight bodyweights of piglets of different groups were comparable to each other (Table 2). Although there was a numerical increase in the body weights with LA supplementation the values obtained were not significant statistically. The average daily gain (ADG) of LWY piglets did not differ significantly ($P > 0.05$) during the 1st, 3rd, 4th and 6th fortnight. However, during the 2nd and 5th fortnight significantly ($P < 0.05$) higher ADG was observed in LA supplemented groups (Table 3). The overall average daily gains were also significantly ($P < 0.01$) higher in LA supplemented groups. There were 52.19% higher ADG was found in LWY piglets fed BDL-0.4 diet than BD diet, 25.9% higher than BDL-0.2 diet and 8.67% higher than BDA diet. Similarly, the total weight gained by piglets was significantly ($P < 0.01$) higher in BDL-0.2 and BDL-0.4 compared to BDA and BD groups (Table 4). An improvement in the growth of weaned pigs may be due to the unique physiological and biological properties of LA, being MCFA it will be digested and absorbed and cross the double mitochondrial membrane very rapidly and undergo oxidation; unlike long chain fatty acids, they do not require the presence of carnitine (Sidossis *et al.*, 1996). In agreement with the present study, improved weight gain was observed in weaned pigs fed MCFAs (Dierick *et al.*, 2003 and Chwen *et al.*, 2013) and MCFAs combined with organic acids (Hanczakowska *et al.*, 2011; Kuang *et al.*, 2015).

The improvement in the ADG with the increase in LA supplementation in the diets of piglets can be attributed to reasons such as an increase in nutrient digestibility (Table 5) and a decrease in the microflora count (Table 6) observed in this study. Antimicrobial activity of LA lowers the load of pathogenic bacteria leading to the reduced metabolic needs of nutrients, thereby increasing the availability of nutrients for growth. Reduction in the bacterial load in the gut ultimately leads to a decrease in the concentrations of toxic metabolites formed by bacteria. The MCFAs could reduce the number of gut bacteria that need nutrients for their use and therefore compete with the host for the limited nutrients in the gastrointestinal tract (Li *et al.*, 2015).

The dry matter and feed intake were comparable in all four dietary treatments (Table 4). However, the feed conversion ratio (FCR) was significantly ($P<0.01$) improved with 0.2 and 0.4% LA supplementation (Table 4). There was a significant increase in the FCR despite no increase in the feed intake, which indicates higher productivity in piglets supplemented with LA. The increase in the FCR in the present experiment could be due to other findings in the study such as improved weight gain (Table 4), and improved digestibility of OM, CF, EE NFE (Table 5). Improved FCR could also be attributed to the reduced pathogenic bacteria load (Table 6). Reduction in the *E. coli* count might have minimized wastage of nutrients and also diverted them for body weight gain, which eventually resulted in improved feed efficiency in piglets supplemented with LA. Corroborating with the present study,

significantly improved FCR was observed in piglets fed diets supplemented with a blend of organic acids and MCFAs (Kuang *et al.*, 2015 and Upadhaya *et al.*, 2016) or mixture of short and MCFAs (Hansczakowska *et al.*, 2010) or medium-chain triglycerides (MCT) oil (Lai *et al.*, 2014; Li *et al.*, 2015) or blend of MCFAs and probiotics (Dutta *et al.*, 2015).

Nutrient digestibility

The DM and CP digestibility in pigs were not affected ($P>0.05$) with LA supplementation (Table 5). The digestibility of OM, EE and NFE was significantly improved ($P<0.05$) with 0.4% of LA supplementation (Table 5). The CF digestibility was significantly ($P<0.01$) improved with both LA and antibiotic supplementation. The highest CF digestibility was observed in 0.4% of LA supplemented group, while the lowest value was recorded in control group (Table 5). Earlier studies reported that MCT changes the structure of small intestinal mucosa, i.e. increased villus height, and may increase the nutrient digestibility of young pigs (Dierick *et al.*, 2003; Awad *et al.*, 2009; Hanczakowska *et al.*, 2011). Thus, it was hypothesized that LA supplementation could have increased the intestinal villi height and crypt depth in turn could have provided a more surface area for nutrient absorption and consequently, improved digestibility of OM, EE, CF and NFE. Similarly, Price *et al.* (2013) observed that total fat digestibility was significantly greater ($P<0.001$) when piglets were fed with MCFA compared to piglets supplied with long chain fatty acids. Hong *et al.* (2012) found an

Table 1. Ingredient and calculated nutrient composition of the basal diet.

Ingredients	Parts
Maize	40
Ground nut cake	33
Red gram chunni	10
De-oiled rice bran	12
Calcite powder	2
Salt	0.5
Mineral mixture	1.97
L-Lysine HCl	0.2
DL-Methionine	0.33
Nutrient composition (%)	
Digestible energy (kcal/kg)	3168.3
Crude protein	18.34
Calcium	0.77
Phosphorus	0.56
Lysine	0.76
Methionine	0.57

Each kg of mineral mixture contained: Vitamin A – 750000 IU; Vitamin D₃ – 75000 IU; Vitamin E – 300mg; Niacinamide – 1.200g; Vitamin B₆ – 20mg; Copper – 4.200g; Cobalt – 150mg; Magnesium – 6500g; Iron – 1.750g; Zinc – 9.600g; Iodine – 350mg; Manganese – 1.500g; Sulphur – 9.200g, Potassium – 150mg; Sodium – 20mg; Calcium – 250mg; Phosphorus – 127.5g; DL-Methionine – 1.929g; L-Lysine – 4.40g; *Lactobacillus sporogenes* – 75 billion CFU; *Saccharomyces cerevisiae* – 15 billion CFU.

Table 2. Effect of supplementation of lauric acid on fortnightly body weight gain of Large White Yorkshire cross piglets

Treatments	Initial weight	Fortnight Body weight (kg)					
		First	Second	Third	Fourth	Fifth	Sixth
BD	10.26±1.4	10.67±1.4	12.72±1.9	14.60±2.1	17.94±2.1	21.17±2.2	24.08±2.5
BDA	10.16±1.0	10.94±1.1	13.77±1.2	16.32±1.2	20.07±1.3	24.27±1.9	27.74±2.1
BDL-0.2	10.20±0.6	10.6±0.6	13.41±0.6	15.88±0.8	20.42±0.9	25.62±1.5	30.21±1.8
BDL-0.4	10.23±0.4	11.18±0.5	14.81±0.7	17.68±1.0	21.86±1.2	27.87±1.7	31.44±2.0
P	1	0.975	0.715	0.491	0.338	0.121	0.107

BD: Basal Diet (BD); BDA: BD + 0.05% antibiotic; BDL-0.2: BD + 0.2% lauric acid; BDL-0.4: BD + 0.4% lauric acid

Table 3. Effect of supplementation of lauric acid on average daily gain of Large White Yorkshire cross piglets

Treatment	Fortnight average daily gain (g)						Overall average daily gain (g)**
	First	Second*	Third	Fourth	Fifth*	Sixth	
BD	44.76 ±	128.57	124.76	222.86	215.24	194.28	153.29
	17.00	±39.24 ^a	±23.57	±20.41	±23.12 ^a	±19.91	±14.70 ^a
BDA	52.38 ±	188.57	170.48	249.52	278.09	235.24	193.57
	12.88	±16.04 ^{ab}	±17.14	±13.40	±50.80 ^{ab}	±67.32	±16.70 ^{ab}
BDL-0.2	26.66	187.62	164.76	302.86	346.67	305.71	220.00
	±5.44	±10.83 ^{ab}	±20.03	±27.17	±44.62 ^{ab}	±31.28	±14.54 ^b
BDL-0.4	63.80	241.90	191.43	278.09	400.9	238.10	233.29
	±16.19	±16.75 ^b	±19.22	±35.20	±57.09 ^b	±31.49	±21.36 ^b
P	0.297	0.021	0.154	0.162	0.045	0.319	0.01

^{ab}Means with different superscripts in a column differ significantly: (*P < 0.05, **P < 0.01)

BD: Basal Diet (BD); BDA: BD + 0.05% antibiotic; BDL-0.2: BD + 0.2% lauric acid; BDL-0.4: BD + 0.4% lauric acid

Table 4. Effect of supplementation of lauric acid on feed intake and feed conversion ratio of Large White Yorkshire cross piglets.

Treatment	Dry Matter Intake (kg)	Feed Intake (kg)	Total Weight Gain (kg) *	Average Daily Gain (kg)*	Feed Conversion Ratio (kg feed/kg gain) **
BD	0.63±0.05	0.68±0.6	13.95±1.3 ^a	0.15±0.014 ^a	4.48±0.09 ^a
BDA	0.68±0.07	0.73±0.8	17.61±1.5 ^{ab}	0.19±0.016 ^{ab}	4.37±0.1 ^a
BDL-0.2	0.76±0.02	0.83±0.3	20.01±1.3 ^b	0.22±0.014 ^b	3.77±0.1 ^b
BDL-0.4	0.74±0.06	0.83±0.7	21.21±1.9 ^b	0.23±0.021 ^b	3.53±0.1 ^b
P	0.42	0.32	0.01	0.031	0.001

^{ab}Means with different superscript in a column differ significantly: (*P < 0.05, **P < 0.01)

BD: Basal Diet (BD); BDA: BD + 0.05% antibiotic; BDL-0.2: BD + 0.2% lauric acid; BDL-0.4: BD + 0.4% lauric acid

Table 5. Effect of supplementation of lauric acid on nutrient digestibility of Large White Yorkshire cross piglets.

Treatment	Dry Matter	Organic Matter*	Crude Protein	Crude Fibre**	Ether Extract*	Nitrogen Free Extract*
BD	82.26±0.9	64.46±1.3 ^a	78.94±1.5	43.41±2.3 ^a	69.31±1.1 ^a	63.97±1.8 ^a
BDA	85.80±0.9	68.46±1.8 ^{ab}	82.12±1.2	52.60±4.7 ^b	71.58±1.3 ^{ab}	65.04±1.8 ^a
BDL-0.2	82.31±0.8	66.46±1.2 ^{ab}	79.38±1.3	56.17±1.7 ^b	71.32±1.0 ^{ab}	63.46±2.6 ^a
BDL-0.4	83.50±1.2	70.65±1.4 ^b	80.14±1.06	60.95±2.3 ^b	74.56±1.3 ^b	71.04±1.5 ^b
P	0.07	0.04	0.3	0.002	0.03	0.02

^{ab}Means with different superscripts in a column differ significantly: (*P<0.05, **P<0.01)

BD: Basal Diet (BD); BDA: BD + 0.05% antibiotic; BDL-0.2: BD + 0.2% lauric acid; BDL-0.4: BD + 0.4% lauric acid

Table 6. Effect of lauric acid supplementation on faecal microflora count of Large white Yorkshire cross piglets.

Treatment	Total bacterial count (log ₁₀ CFU/g)**	<i>Escherichia coli</i> count (log ₁₀ CFU/g)**
BD	9.32±0.2 ^c	8.81±0.5 ^c
BDA	9.58±0.1 ^c	8.51±0.8 ^{bc}
BDL-0.2	8.46±0.2 ^b	7.01±0.4 ^{ab}
BDL-0.4	7.07±0.3 ^a	6.56±0.2 ^a
P	0.001	0.001

^{abc}Means with different superscripts in a column differ significantly: (P < 0.01)

BD: Basal Diet (BD); BDA: BD + 0.05% antibiotic; BDL-0.2: BD + 0.2% lauric acid; BDL-0.4: BD + 0.4% lauric acid

increased (P < 0.05) DM digestibility in piglets supplemented with MCT oil at 0.33 and 0.55% of the diet. Li *et al.* (2015) found linearly increased EE digestibility with the increase in the concentration of MCT in the diet. Hanczakowska *et al.* (2013) found increased fibre and fat digestibility by supplementing propionic, formic, capric, caprylic acid.

Total bacterial and *Escherichia coli* count

The faecal total bacterial count and *Escherichia coli* counts were significantly (P < 0.01) reduced in LA supplemented groups

and the lowest (P < 0.01) counts were recorded in 0.4% LA supplemented group (Table 6). In accordance with the present study, a reduction in faecal *E. coli* count was observed in piglets supplemented with a dietary blend of acidifiers and citric acid (Ahmed *et al.*, 2014), fumaric acid (Hanczakowska *et al.*, 2011) and blend of organic acids and 1.2% MCFA (Upadhaya *et al.*, 2014; Devi *et al.*, 2016). Organic acids not only possess antimicrobial activity but also can reduce dietary buffering capacity and pH (Dibner and Buttin, 2002). Weaning pigs are usually not ready to produce enough

hydrochloric acid in the stomach, resulting in a high pH in the upper GIT. The high pH can be favorable for certain microbial proliferation, particularly coliform bacteria (Sissons, 1989). It is accepted that organic acids can lower gastric pH to inhibit the growth of bacteria (Giesting and Easter, 1985; Bosi *et al.*, 1999). Among the organic acids, LA and monolaurin have been shown to be very effective against gram positive bacteria and a number of viruses and fungi by destruction of the cell membranes of pathogens, interference with cellular processes and stabilization of host cell membranes (Dayrit, 2015). Thus, based on the findings of the present study and earlier studies it is imperative that LA supplementation in diets of piglets could reduce the faecal total bacterial count and *Escherichia coli* counts.

CONCLUSION

Based on the results obtained in this study, it can be concluded that lauric acid supplementation at 0.4% in the diets of Large White Yorkshire cross piglets improved the growth performance and feed efficiency by improving the nutrient digestibility and lowering the harmful microbial load in the gut of piglets. Thus, it is imperative that lauric acid could be an alternative to antibiotics usage in piggery farming.

REFERENCES

Ahmed, S.T., Hwang, J.A., Hoon, J., Mun, H.S. and Yang, C.J. (2014). Comparison of single and blend acidifiers as alternative to antibiotics on growth performance, faecal microflora, and

humoral immunity in weaned piglets. *Asian-Australasian Journal of Animal Sciences*, **27**(1): 93 - 100.

AOAC. (2012). Official Methods of Analysis of AOAC International, 19th edition. Association of Official Analytical Chemist, Gaithersburg, Maryland, USA.

Awad, W., Ghareeb, K. and Böhm, J. (2009). Intestinal structure and function of broiler chickens on diets supplemented with a synbiotic containing *Enterococcus faecium* and oligosaccharides. *International Journal of Molecular Sciences*, **9**(11): 2205 - 2216

Bailey, M., Haverson, K., Inman, C., Harris, C., Jones, P., Corfield, G. and Stokes, C. (2005). The development of the mucosal immune system pre- and post-weaning: Balancing regulatory and effector function. *Proceedings of the Nutrition Society*, **64**(4): 451- 457.

Bergsson, G., Arnfinnsson, J., Steingrímsson, Ó. and Thormar, H. (2001). Killing of Gram-positive cocci by fatty acids and monoglycerides Note. *Apms*, **109**(10): 670 - 678.

Bosi, P., Jung, H.J., Han, I.K., Perini, S., Cacciavillani, J.A., Casini, L. and Mattuzzi, S. (1999). Effects of dietary buffering characteristics and protected or unprotected acid on piglet growth, digestibility and characteristics of gut

- content. *Asian-Australasian Journal of Animal Sciences*, **12**(7): 1104 - 1110.
- Castillo, M., Martín-Orúe, S.M., Roca, M., Manzanilla, E.G., Badiola, I., Perez, J.F. and Gasa, J. (2006). The response of gastrointestinal microbiota to avilamycin, butyrate, and plant extracts in early-weaned pigs. *Journal of Animal Science*, **84**(10): 2725 - 2734.
- Chwen, L.T., Foo, H.L., Thanh, N.T. and Choe, D.W. (2013). Growth performance, plasma fatty acids, villous height and crypt depth of preweaning piglets fed with medium chain triacylglycerol. *Asian-Australasian Journal of Animal Sciences*, **26**(5): 700 - 704.
- Devi, S.M., Lee, K.Y. and Kim, I.H. (2016). Analysis of the effect of dietary protected organic acid blend on lactating sows and their piglets. *Revista Brasileira de Zootecnia*, **45**(2): 39 -47.
- Dibner, J.J. and Buttin, P. (2002). Use of organic acids as a model to study the impact of gut microflora on nutrition and metabolism. *Journal of Applied Poultry Research*, **11**(4): 453 - 463
- Dayrit, F.M. (2015). The properties of lauric acid and their significance in coconut oil. *Journal of the American Oil Chemists Society*, **92**(1): 1 - 15.
- Dierick, N.A., Decuyper, J.A. and Degeyter, I. (2003). The combined use of whole Cuphea seeds containing medium chain fatty acids and an exogenous lipase in piglet nutrition. *Archives of Animal Nutrition*, **57**(1): 49 - 63.
- Duncan, D.B. (1955). Multiple range and multiple F tests. *Biometrics*, **11**(1): 1-42.
- Dutta, S., Pan, S. and Samanta, G. (2015). Organic Acid as an alternative growth promoter in Ghungroo pigs. *International Journal of Bio-resource, Environment and Agricultural Science*, **1**(4): 163 - 166.
- Galbraith, H. and Miller, T.B. (1973). Effect of metal cations and pH on antibacterial activity and uptake of long chain fatty acids. *Journal of Applied Bacteriology*, **36**(4): 635 - 646.
- Giesting, D.W. and Easter, R.A. (1985). Response of starter pigs to supplementation of corn-soyabean meal diets with organic acids. *Journal of Animal Science*, **60**(5): 1288 - 1294.
- Hanczakowska, E., Wiatkiewicz, M. and Hanc-Zakowski, P. (2010). Medium-chain fatty acids as feed supplements for weaned piglets. *Medycyna Weterynaryjna*, **66**(5): 331 - 334.
- Hanczakowska, E., Szewczyk, A. and Okoń, K. (2011). Caprylic, capric and/or fumaric acids as antibiotic replacements in piglet feed. *Annals of Animal Science*, **11**: 115 - 124.

- Hanczakowska, E., Szewczyk, A., Świątkiewicz, M. and Okoń, K. (2013). Short-and medium-chain fatty acids as a feed supplement for weaning and nursery pigs. *Polish Journal of Veterinary Sciences*, **16**(4): 647 - 654.
- Hong, S.M., Hwang, J.H. and Kim, I.H. (2012). Effect of medium-chain triglyceride (MCT) on growth performance, nutrient digestibility, blood characteristics in weanling pigs. *Asian-Australasian Journal of Animal Sciences*, **25**(7): 1003 - 1008.
- ICAR. (2013). Nutrient Requirements of Pig, Indian Council of Agriculture Research, New Delhi, India.
- Kuang, Y., Wang, Y., Zhang, Y., Song, Y., Zhang, X., Lin, Y. and Fang, Z. (2015). Effects of dietary combinations of organic acids and medium chain fatty acids as a replacement of zinc oxide on growth, digestibility and immunity of weaned pigs. *Animal Feed Science and Technology*, **208**: 145 - 157.
- Kunavue, N. and Lien, T.F. (2012). Effects of fulvic acid and probiotic on growth performance, nutrient digestibility, blood parameters and immunity of pigs. *Journal of Animal Science Advances*, **2**(8): 711 - 721.
- Lai, W.K., Yen, H.C., Lin, C.S. and Chiang, S.H. (2014). The effects of dietary medium-chain triacylglycerols on growth performance and intestinal microflora in young pigs. *Journal of Animal and Feed Sciences*, **23**(4): 331 - 336.
- Li, Y., Zhang, H., Yang, L., Zhang, L. and Wang, T. (2015). Effect of medium-chain triglycerides on growth performance, nutrient digestibility, plasma metabolites and antioxidant capacity in weanling pigs. *Animal Nutrition Journal*, **1**(1): 12 - 18.
- Miller, T.L. and Wolin, M.J. (1974). A serum bottle modification of the Hungate technique for cultivating obligate anaerobes. *Applied Microbiology*, **27**(5): 985 - 987.
- Partanen, K.H. and Mroz, Z. (1999). Organic acids for performance enhancement in pig diets. *Nutrition Research Reviews*, **12**(1): 117 - 145.
- Price, K.L., Lin, X., Van Heugten, E., Odle, R., Willis, G. and Odle, J. (2013). Diet physical form, fatty acid chain length, and emulsification alter fat utilization and growth of newly weaned pigs. *Journal of Animal Science*, **91**(2): 783 - 792.
- Skřivanová, E., Marounek, M., Dlouha, G. and Kaňka, J. (2005). Susceptibility of *Clostridium perfringens* to C2-C18 fatty acids. *Letters in Applied Microbiology*, **41**(1): 77- 81
- Skřivanová, E., Molatová, Z., Skřivanová, V. and Marounek, M. (2009).

- Inhibitory activity of rabbit milk and medium-chain fatty acids against enteropathogenic *Escherichia coli* O128. *Veterinary Microbiology*, **135**(3-4): 358 - 362.
- Schuster, G.S., Dirksen, T.R., Ciarlone, A.E., Burnett, G.W., Reynolds, M.T. and Lankford, M.T. (1980). Anticaries and anti-plaque potential of free-fatty acids *in vitro* and *in vivo*. *Pharmacology and Therapeutics in Dentistry*, **5**(1-2): 25 - 33.
- Sidossis, L.S., Stuart, C.A., Shulman, G.I., Lopaschuk, G.D. and Wolfe, R.R. (1996). Glucose plus insulin regulate fat oxidation by controlling the rate of fatty acid entry into the mitochondria. *The Journal of Clinical Investigation*, **98**(10): 2244 - 2250.
- Sissons, J.W. (1989). Potential of probiotic organisms to prevent diarrhoea and promote digestion in farm animals- a review. *Journal of the Science of Food and Agriculture*, **49**(1): 1 - 13.
- Snedecor, G.W. and Cochran, W.G. (1980). *Statistical Methods*. Oxford and IBH Publishing Company, New Delhi.
- Tang, M., Laarveld, B., Van Kessel, A.G., Hamilton, D.L., Estrada, A. and Patience, J.F. (1999). Effect of segregated early weaning on post weaning small intestinal development in pigs. *Journal of Animal Science*, **77**(12): 3191 - 3200.
- Upadhaya, S.D., Lee, K.Y. and Kim, I. H. (2014). Influence of protected organic acid blends and diets with different nutrient densities on growth performance, nutrient digestibility and faecal noxious gas emission in growing pigs. *Veterinari Medicina*, **59**(10): 491 - 497.
- Upadhaya, S.D., Lee, K.Y. and Kim, I.H. (2016). Effect of protected organic acid blends on growth performance, nutrient digestibility and faecal micro flora in growing pigs. *Journal of Applied Animal Research*, **44**(1): 238 - 242.
- Wang, Q., Chen, Y.J., Yoo, J.S., Kim, H.J., Cho, J.H. and Kim, I.H. (2008). Effects of supplemental humic substances on growth performance, blood characteristics and meat quality in finishing pigs. *Livestock Science*, **117**(2-3): 270 - 274.
- Yuhas, R., Pramuk, K. and Lien, E.L. (2006). Human milk fatty acid composition from nine countries varies most in DHA. *Lipids*, **41**(9): 851 - 858.
- Zhang, Z.F., Rolando, A.V. and Kim, I.H. (2016). Effects of benzoic acid, essential oils and *Enterococcus faecium* SF68 on growth performance, nutrient digestibility, blood profiles, faecal microbiota and faecal noxious gas emission in weanling pigs. *Journal of Applied Animal Research*, **44**(1): 173 - 179.

- Zeng, Z., Xu, X., Zhang, Q., Li, P., Zhao, P., Li, Q. and Piao, X. (2015). Effects of essential oil supplementation of a low-energy diet on performance, intestinal morphology and microflora, immune properties and antioxidant activities in weaned pigs. *Animal Science Journal*, **86**(3): 279 - 285.
- Zentek, J., Buchheit-Renko, S., Männer, K., Pieper, R. and Vahjen, W. (2012). Intestinal concentrations of free and encapsulated dietary medium-chain fatty acids and effects on gastric microbial ecology and bacterial metabolic products in the digestive tract of piglets. *Archives of Animal Nutrition*, **66**(1): 14 - 26.