

Effects of caprylic acid and *Yucca schidigera* extract on growth performance, relative organ weight, breast meat quality, haematological characteristics and caecal microbial shedding in mixed sex Ross 308 broiler chickens

M. BEGUM, M.M. HOSSAIN, I.H. KIM

Department of Animal Resource and Science, Dankook University, Cheonan, Republic of Korea

ABSTRACT: Caprylic acid (CA) and *Yucca schidigera* (YS) extract have many functional and nutritional properties that may have applications in animal nutrition. These beneficial effects include improvement of growth performance, immunity and anti-microbial activity. This study was conducted to assess the effects of dietary supplementation with CA and YS extract on growth performance, relative organ weight, meat quality, blood characteristics and caecal microbial shedding in broilers. In total, 672 one-day-old Ross 308 (BW of 34.05 ± 0.21 g) mixed-sex broiler chicks were allotted randomly into three dietary treatment groups with 14 replicate pens per treatment and 16 birds per pen. The experiment lasted for five weeks and dietary treatments were as follows: (1) PC, basal diet; (2) PC, basal diet + 44 mg/kg of avilamycin; and (3) CAY100 (basal diet + 100 mg/kg CA + 100 mg/kg YS extract). Chicks fed the CAY100 diet exhibited improved overall body weight gain (BWG) and feed intake (FI), and reduced feed conversion ratio (FCR) compared with those fed the NC diet ($P < 0.05$). Compared with the NC and PC treatments, mortality was decreased in chicks fed the CAY100 diet during the finisher phase and also overall. Broilers fed the CAY100 diet exhibited increased ($P < 0.05$) relative organ weight of bursa of Fabricius, compared with the PC diet and demonstrated decreased relative organ weight of the gizzard compared with those fed the NC diet. The relative organ weight of the liver, spleen, breast, and abdominal fat was unaffected by any of the dietary supplements tested. The breast meat redness (a^*) was reduced ($P < 0.05$) in the CAY100 diet compared with the NC and PC diets. White blood cell (WBC) counts were increased in the CAY100 treatment compared with the NC treatment ($P < 0.05$). Moreover, the CAY100 diet resulted in improved lymphocyte counts compared with the PC and NC diets ($P < 0.05$). Broilers fed the CAY100 diet exhibited reduced caecal *E. coli* counts compared with those fed the NC diet ($P < 0.05$). In conclusion, the CAY extract-supplemented diet improved growth performance, relative weight of bursa of Fabricius and reduced mortality rate, breast muscle a^* and caecal *E. coli* counts in broiler chickens.

Keywords: broilers; caprylic acid; *E. coli*; lymphocyte; breast meat redness; *Yucca schidigera*

List of abbreviations

a^* = breast meat redness; **BW** = body weight; **BWG** = body weight gain; **CA** = caprylic acid; **FCR** = feed conversion ratio; **FI** = feed intake; **WBC** = white blood cell; **YS** = *Yucca schidigera*

In response to decreases in the therapeutic effectiveness of antibiotics for the treatment of bacterial infections in humans, several European countries have banned the use of dietary antibiotics for livestock and poultry (Simon et al. 2003). Thus, much attention has been paid to developing alternatives to antibiotic growth promoters (AGPs) in livestock feed (Yan et al.

2012; Zhang et al. 2012; Wang et al. 2013; Zhang and Kim 2013; Zhao et al. 2013; Cho and Kim 2014; Park and Kim 2014; Zhang and Kim 2014). In particular, now that feeding antibiotics is banned, other substances have become increasingly important.

Caprylic acid (CA) is a medium-chain fatty acid (MCFA) with eight carbons, found naturally in hu-

man breast milk, bovine milk (Jensen 2002) and in coconut oil (Jensen et al. 1990; Sprong et al. 2001). Both *in vitro* and fattening experiments have demonstrated that CA favourably influences the digestive tract (Bach and Babayan 1982). The addition of CA (5 g/kg) to a diet for piglets increased ($P < 0.05$) weight gain versus the basal diet (Marounek et al. 2004). Recently, caprylic acid was reported to have anti-microbial activity against a wide range of microorganisms such as *Salmonella enteritidis* and *Campylobacter jejuni* in chicken caecal contents (Vasudevan et al. 2005; Skrivanova et al. 2006; Solis de los Santos et al. 2008; Wang and Kim 2011) and *Escherichia coli* 0157:H7 in bovine rumen fluid (Annamalai et al. 2004). The use of *Yucca schidigera* (YS) extract in poultry feed is a good alternative to improve feed efficiency and increased production (Ayasan et al. 2005). Saponins, the main chemical component of YS extract, exist in steroidal form, whereas they are found in a triterpenoid form in other plants, such as *Quillaja saponaria* (Wang and Kim 2011). *Yucca saponins* have antibacterial properties which may work together with other antibacterial agents, such as CA (Katsunuma et al. 2000; Wang et al. 2000c, Wang and Kim 2011). Moreover, to the best of our knowledge, effects of CA and YS extract in broiler chickens have not been investigated yet. Therefore, this study was carried out to evaluate the effects of caprylic acid and *Yucca schidigera* on growth performance, relative organ weight, meat quality, blood characteristics and caecal microbial shedding in broilers.

MATERIAL AND METHODS

The experiment received prior approval from the Animal Protocol Review Committee of Dankook University. All birds used in this trial were handled in accordance with the guidelines set forth by the Animal Care and Use Committee of Dankook University.

Experimental design, animal and diets. A total of 672 one-day-old Ross 308 (BW of 34.05 ± 0.21 g) mixed-sex broiler chicks were obtained from a commercial hatchery (Yang Ji Company, Cheonan, Choongnam, South Korea). The broilers were randomly allotted to one of three treatments with 14 replicate pens per treatment and 16 chicks per pen. The dietary treatments were: (1) NC, basal diet; (2) PC, basal diet + 44 mg/kg of

Table 1. Ingredients and nutrient composition of basal diets (% , as-fed basis)¹

Items	Starter	Finisher
Ingredient (%)		
Corn	55.42	62.98
Soybean meal (48% CP)	28.25	24.61
Corn gluten meal (60% CP)	6.50	3.50
Soybean oil	5.50	4.89
Dicalcium phosphate	2.46	2.29
Limestone	0.89	0.75
Salt	0.20	0.20
DL-Met (98%)	0.17	0.17
L-Lys HCl (78%)	0.21	0.21
Vitamin premix ²	0.20	0.20
Trace mineral premix ³	0.20	0.20
Calculated composition		
ME (Kcal/kg) ⁴	3140	3200
CP	22.00	20.09
Lys	1.10	1.05
Met	0.54	0.41
Met + Cys	0.93	0.93
Ca	1.00	0.87
Total P	0.80	0.75
Crude fat	4.32	5.87
Crude fiber	4.71	6.21

¹Starter, provided from Day 1 to 21; finisher, provided during from Day 22 to 35

²Provided per kilogram of complete diet: 15 000 IU of vitamin A, 3750 IU of vitamin D3, 377.5 mg of vitamin E, 2.55 mg of vitamin K3, 3 mg of thiamin, 7.5 mg of riboflavin, 4.5 mg of vitamin B6, 24 µg of vitamin B12, 51 mg of niacin, 1.5 mg of folic acid, 0.2 mg of biotin, and 13.5 mg of Ca-pantothenate

³Provided per kilogram of complete diet: 37.5 mg of Zn (as ZnSO₄), 37.5 mg of Mn (as MnO₂), 37.5 mg of Fe (as FeSO₄·7H₂O), 3.75 mg of Cu (as CuSO₄·5H₂O), 0.83 mg of I (as KI), and 0.23 mg of Se (as Na₂SeO₃·5H₂O)

⁴ME of the diet was calculated according to NRC (1994)

avilamycin; and (3) CAY100 (basal diet + 100 mg/kg CA + 100 mg/kg YS extract). Broilers were fed with starter (one to 21 days) and finisher (22 to 35 days) diets in mash form. The YS extract contained 12.5% saponins. All diets were formulated to meet or exceed the recommended nutrient contents (NRC 1994) for broilers (Table 1). Broilers were raised in a temperature-controlled room with three floors of stainless steel pens of identical size (1.75 × 1.55 m). Room temperature began at 33 °C from Day 1 to Day 3

doi: 10.17221/8532-VETMED

and was reduced gradually to 24 °C by the end of the experiment. The relative humidity was around 60%. Birds had free access to feed and water throughout the study.

Sampling and measurements. The broilers were weighed by pen and feed intake (FI) was recorded on Days 0, 7, 21, and 35. This was then used to calculate body weight gain (BWG) and feed conversion ratio (FCR). At the end of the experiment, 14 broilers were selected randomly from each treatment (one per pen) and blood samples were collected from the wing vein using a sterile syringe into both non-heparinised tubes and vacuum tubes containing K₃EDTA (Becton, Dickinson and Co., Franklin Lakes, NJ) to obtain plasma and whole blood, respectively. The blood samples were centrifuged (1500 × g, 15 min, 4 °C) within 1 h of collection and after centrifugation blood plasma was obtained. Individual samples of plasma were stored in a freezer at –80 °C. Concentrations of total protein were determined in plasma using an automatic biochemistry analyser (Hitachi 747, Japan). The WBC, red blood cell, and lymphocyte counts in whole blood were determined using an automatic blood analyser (Advia 120, Bayer, Tarrytown, NY).

After blood collection, the same broilers were weighed individually and slaughtered by cervical dislocation. The breast meat, gizzard, bursa of Fabricius, liver, spleen, and abdominal fat were then removed by trained personnel and weighed. Organ weight was expressed as a percentage of BW. The breast meat Hunter lightness (L^*), redness (a^*) and yellowness (b^*) values were measured using a Minolta CR410 Chroma Meter (Konica Minolta Sensing Inc., Osaka, Japan). Duplicate pH values for each sample were measured using a pH meter (Fisher Scientific, Pittsburgh, PA, USA).

The same slaughtered broiler chickens were then used for microbial counts. Caecal contents were collected into Qorpak glass containers (118 ml) under CO₂, sealed and placed on ice until transported to the laboratory for enumeration of microbial populations. Caecal samples were assessed for populations of *Lactobacillus*, *E. coli*, *C. perfringens* and *Bifidobacteria*. One gram of the composite excreta sample from each cage was diluted with 9 ml of 1% peptone broth (Becton, Dickinson and Co., Franklin Lakes, NJ) and then homogenised. Viable counts of bacteria in the caecal samples were then estimated by plating serial 10-fold di-

lutions (in 1% peptone solution) onto lactobacilli medium III agar plates (Medium 638; DSMZ, Braunschweig, Germany), MacConkey agar plates (Difco Laboratories, Detroit, MI), Perfringens agar base (Perfringens TSC Agar; Oxoid, Basingstoke, UK) and Wilkins-Chalgren agar (Oxoid, Nepean, Ontario, Canada) supplemented with glacial acetic acid (1 ml/l) and mupirocin (100 mg/l) extracted from antimicrobial discs (Oxoid; Rada et al. 1999) to isolate the *Lactobacillus*, *E. coli*, *C. perfringens* and *Bifidobacteria*, respectively. The lactobacilli medium III agar plates were then incubated for 48 h at 37 °C under anaerobic conditions. The MacConkey and Perfringens agar plates were incubated for 24 h at 37 °C and the Wilkins-Chalgren agar plates were incubated for 72 h at 37 °C. The microflora colonies were counted immediately after removal from the incubator. Concentration of microflora was finally expressed as log₁₀ colony-forming units per gram of intestinal content.

Statistical analysis. Data were analysed using the GLM procedure of SAS/STAT®9.2 (SAS Institute 2008), with the pen as the experimental unit. Before conducting statistical analysis of the *Lactobacillus*, *E. coli*, *Clostridium perfringens* and *Bifidobacteria* counts, the value was transformed logarithmically. Differences among treatments were assessed using Tukey's range test. Variability in the data was expressed as the pooled SE and probability values of less than 0.05 were considered significant.

RESULTS

Growth performance and mortality

Table 2 presents the effects of CAY extract on growth performance and broiler mortality throughout the experiment. Broilers fed the different treatments exhibited no significant differences in growth performance during the starter phase. Broilers fed the CAY100 diet had higher BWG and FI compared with those fed the NC and PC diets ($P < 0.05$) during the finisher phase and also overall. During the overall period, FCR was lower ($P < 0.05$) in the CAY100 diet than in the NC and PC diets. Broilers fed the CAY100 diet exhibited a reduced mortality rate compared with those fed the NC diet during the starter phase. Moreover, in the finisher stage and overall, the CAY100 diet reduced the mortality rate compared with the NC and PC diets ($P < 0.05$).

Table 2. Effects of CA and *Yucca schindigera* extract on growth performance and mortality in broilers¹

Items	NC	PC	CAY100	SE ²
Starter				
BWG (g/chick)	675	710	712	23.52
FI (g/chick)	1043	1070	1083	22.54
FCR	1.544	1.508	1.521	0.06
Mortality rate (%)	1.14 ^a	0.57 ^{ab}	0.00 ^b	0.59
Finisher				
BWG (g/chick)	854 ^b	878 ^{ab}	980 ^a	34.64
FI (g/chick)	1708 ^b	1728 ^{ab}	1794 ^a	24.15
FCR	2.008 ^a	1.968 ^{ab}	1.832 ^b	0.02
Mortality rate (%)	9.77 ^a	6.29 ^b	1.14 ^c	0.57
Overall				
BWG (g/chick)	1529 ^b	1589 ^{ab}	1692 ^a	44.37
FI (g/chick)	2751 ^b	2799 ^{ab}	2877 ^a	30.65
FCR	1.800 ^a	1.762 ^b	1.701 ^c	0.02
Mortality rate (%)	10.98 ^a	6.82 ^b	1.14 ^c	0.62

¹NC, basal diet; PC, basal diet + 44 mg/kg of avilamycin; CAY100 (basal diet + 100 mg/kg CA + 100 mg/kg YS extract).

²standard error

^{a,b}means in the same row with difference superscripts differ ($P < 0.05$)

Relative organ weight and breast meat quality

The relative organ weights of the liver, spleen, breast and abdominal fat did not differ among treatments (Table 3). The weight of the bursa of Fabricius increased ($P < 0.05$) with the CAY100

treatment compared with the PC treatment. However, the weight of the gizzard decreased ($P < 0.05$) with the CAY100 treatment versus the NC treatment. Broilers fed the CAY100 group had lower ($P < 0.05$) meat redness compared with the NC and PC treatments (12.39 vs. 13.38 and 13.85).

Table 3. Effects of CA and *Yucca schindigera* extract on relative organ weight and breast meat quality in broilers¹

Items	NC	PC	CAY100	SE ²
Relative organ weight (% of live BW)				
Liver	2.73	2.62	2.69	0.13
Spleen	0.089	0.090	0.078	0.01
Bursa of Fabricius	0.147 ^{ab}	0.123 ^b	0.166 ^a	0.01
Breast	8.44	8.01	8.72	0.23
Gizzard	1.78 ^a	1.75 ^{ab}	1.63 ^b	0.05
Abdominal fat	1.54	1.62	1.63	0.05
Meat colour				
<i>L</i> *	50.38	52.69	53.82	2.75
<i>a</i> *	13.38 ^a	13.85 ^a	12.39 ^b	0.25
<i>b</i> *	10.78	10.76	11.20	0.32
pH	6.51	6.47	6.39	0.15

¹NC = basal diet; PC = basal diet + 44 mg/kg of avilamycin; CAY100 = (basal diet + 100 mg/kg CA + 100 mg/kg YS extract)

²standard error

*L** = indicates lightness; *a** = indicates redness; *b** = indicates yellowness

^{a,b}means in the same row with difference superscripts differ ($P < 0.05$)

doi: 10.17221/8532-VETMED

Table 4. Effects of CA and *Yucca schindigera* extract on blood characteristics in broilers¹

Items	NC	PC	CAY100	SE ²
Total protein (g/dl)	3.18	3.23	3.08	0.10
RBC (No/mm ⁶)	1.99	2.06	2.02	0.10
WBC (mm ³)	286 ^b	330 ^{ab}	449 ^a	36.20
Lymphocyte ³ (%)	73.00 ^b	72.25 ^b	80.25 ^a	1.53

¹NC = basal diet; PC = basal diet + 44 mg/kg of avilamycin; CAY100 = (basal diet + 100 mg/kg CA + 100 mg/kg YS extract)²standard error³values are presented as the percentage of the total white blood cell count^{a,b}means in the same row with difference superscripts differ ($P < 0.05$)

Blood characteristics and caecal microbiota

No significant differences were observed in total protein or RBC counts among treatments (Table 4). Broilers fed the CAY100 diet had higher WBC counts compared with the NC diet ($P < 0.05$). Moreover, broilers fed the CAY100 diet exhibited increased lymphocyte counts compared with the NC and PC diets ($P < 0.05$). No significant differences in *Lactobacillus*, *Clostridium perfringens* and *Bifidobacteria* counts were observed in broilers fed the different diets, but *E. coli* counts were reduced ($P < 0.05$) in the CAY100 diet (6.62 log₁₀ cfu/g) when compared with the NC diet (7.03 log₁₀ cfu/g; Table 5).

DISCUSSION

From the results of our study, it can be seen that inclusion of CAY extract in the broiler diet improved BWG and FI, while reducing FCR and mortality rate. In contrast to our results, Yeo and Kim (1997) reported that *Yucca schidigera* inclusion in broiler diets had no effect on feed intake or feed efficiency. As demonstrated elsewhere, broilers receiving *Yucca saponins* at a level of 63 ppm/kg

diet were significantly heavier than controls at 28 and 51 days of age (Johnston et al. 1981). Al-Bar et al. (1992) reported that dietary *Yucca schidigera* extract at a level of 125 mg/kg in rabbit diet increased the growth rate. The improvement in feed conversion and significant increase in body weight gain may be due to a synergistic effect of chemical constituents present in *Yucca schidigera* powder, such as steroidal saponins and phenolic compounds. These chemical constituents have antimicrobial (Wallace et al. 1994; Killen et al. 1998; Sen et al. 1998; Wang et al. 1999; Wang et al. 2000a; Wang et al. 2000b; Czczot et al. 2003), antioxidant, anti-inflammatory, anti-carcinogenic, anti-fungal (Siemann and Creasy 1992; Olas et al. 2002; Olas et al. 2003), antiviral (Docherty et al. 1999), and phytoestrogen properties (Calabrese 1999). The combined effects of these chemical constituents may have increased vitality. *Yucca schidigera* is a major source of natural saponins that inhibit the development of protozoa by interacting with the cholesterol present in the parasite cell membrane, resulting in parasite death. Several studies with saponins have demonstrated that they improve nutrient absorption by increasing intestinal permeability via membrane depolarisation (Killen et al. 1998; Wang et al. 1999). Based on their emulsifying

Table 5. Effects of CA and *Yucca schindigera* extract on caecal microbiota (log₁₀ cfu/g of wet digesta) in broilers¹

Items	NC	PC	CAY100	SE ²
<i>Lactobacillus</i>	6.80	6.85	6.87	0.10
<i>E. coli</i>	7.03 ^a	6.81 ^{ab}	6.62 ^b	0.19
<i>Clostridium perfringens</i>	7.75	7.70	7.72	0.14
<i>Bifidobacteria</i>	8.51	8.50	8.54	0.09

¹NC = basal diet; PC = basal diet + 44 mg/kg of avilamycin; CAY100 = (basal diet + 100 mg/kg CA + 100 mg/kg YS extract)²standard error^{a,b}means in the same row with difference superscripts differ ($P < 0.05$)

properties (stabilising water or oil emulsions) and their role in making monoglycerides more soluble, dietary supplementation with saponins will result in the emulsification of oil fats, promoting their digestion. Moreover, medium chain fatty acids (MCFAs), including caproic (C6), caprylic (C8), capric (C10), and lauric (C12) acids, exert strong antimicrobial effects and are of nutritional interest because they are absorbed more quickly in the intestine and are utilised better by animals than long-chain fatty acids. It has been demonstrated that the mixture of capric and caprylic acids (20–100 g/kg) can enhance average daily gain (ADG) with no effect on average daily feed intake (ADFI) for weaning pigs during the first two weeks after supplementation (Cera et al. 1989; Rodas and Maxwell 1992). In a test in Mexico with *Yucca schidigera* extract fed to heavy broilers, general mortality was reduced from 27% to 21% and ascites-related mortality was reduced from 19% to 14%. Thus, we hypothesised that addition of CAY extract may improve growth performance and reduce mortality.

Measurement of immune organ weight is a common method to evaluate the immune status of chickens (Heckert et al. 2002). Development of these organs is also considered to be crucial for optimal lymphocyte synthesis (Glick 1977). In this study, the inclusion of dietary CAY extract increased the relative weight of the bursa of Fabricius in broilers compared with the PC treatment, consistent with Dong et al. (2007) who reported that polysavone (mainly saponins and polysaccharides) supplementation increased the relative bursa weight. Moreover, our results revealed that the immune-related blood profile, WBCs and lymphocyte concentrations were enhanced by the effects of CAY extract. However, the mechanism by which CAY affects immune responses is completely unknown, although it has been stated that the gastrointestinal system and its associated lymphoid tissues play a crucial role in animal immune function (Insoft et al. 2005). Willis et al. (2007) suggested that the bursa was the main lymphoid organ in broiler chickens; therefore, an increased relative weight of this organ may be associated with the increased blood lymphocyte counts in the current study. Moreover, in our study CAY extract reduced caecal *E. coli* counts, which are necessary for the development of the gut immune system. In our experiment, all CAY diet-fed chicks, compared with the control diet, had more WBC and higher populations of lymphocytes.

The same trend in lymphocyte populations may be indicative of higher humoral immune response activity in chicks fed CAY-supplemented diets. The CAY diet can stimulate the immune system of the chick, and therefore it will affect WBCs. In the current study, we found that CAY extract decreased the relative weight of the gizzard. The size of the gizzard is determined by the amount of work required by the muscular walls of the organs to grind feed particles and particulars of ingesta (Abdelsamic et al. 1983; Johnson and McNab 1983). Thus, we can assume that CAY supplementation can reduce the muscular work of the gizzard and improve immunity in broiler chickens.

Meat colour is considered as a index that can determine consumer acceptance of the product. In the current study, CAY extract supplementation reduced Hunter redness (a^*) compared with NC and PC treatments. Allen et al. (1993) found that there was a correlation between pH and meat colour. Lightness (L^*) and yellowness (b^*) were found to correlate negatively with pH, whereas redness (a^*) had a positive correlation. Thus, as the pH decreased, the lightness and yellowness values increased, but the redness values were reduced. However, in the current study, no significant differences were observed in breast meat pH among the treatments, although CAY supplementation reduced the value numerically, which may have had an effect on the present findings. Nevertheless, we assume there are other possible mechanisms involved in the reduction of breast meat redness in our study. One of the reasons may be modulation of myoglobin which is the predominant meat pigment, accounting for 80% of the total, and plays a crucial role in meat colour (Mancini and Hunt 2005). Myoglobin consists of the globin protein and the non-protein haem ring portion. The haem portion is important because the colour of meat depends predominantly on the chemical state of the Fe present in the haem ring (Cole et al. 1968; Mroz et al. 2000). We hypothesise that the CAY extract could possibly affect the Fe status and microorganisms in breast meat. Moreover, many other factors are also related to meat colour, including bird sex, age, strain, stress, moisture, rigor development and method of processing, exposure to chemicals, cooking method, irradiation and freezing time (Mugler and Cunningham 1972; Owens et al. 2000; Woelfel et al. 2002). Consumers prefer the fresh raw breast meat to have a pale pink colour (Qiao et al. 2002);

doi: 10.17221/8532-VETMED

therefore, we can conclude that CAY supplementation can improve the breast meat quality by reducing the redness in broilers.

Previously, de Vrese and Marteau (2007) reported that the gastrointestinal and lymphoid system is the largest immunologically competent organ in the body and suggested that the development and composition of the indigenous microflora (i.e. *Lactobacillus*, *E. coli*, *Clostridium perfringens* and *Bifidobacteria*) are the principal factors influencing maturation and optimal development of the gastrointestinal and lymphoid system (Zhang et al. 2012; Zhang and Kim 2013). Therefore, caecal microbial shedding was investigated in this study. Broilers fed the CAY100 diet exhibited reduced *E. coli* counts compared with the NC diet, which is in agreement with Wang and Kim (2011), who suggested that supplementation of the laying hen diet with 120 mg/kg caprylic acid and 120 mg/kg yucca extract significantly decreased excreta *E. coli* both at the three and five week stages. Moreover, several researchers have claimed that caprylic acid has anti-microbial activity against a wide range of microorganisms such as *E. coli*, *Campylobacter jejuni* and *Salmonella enteritidis* in poultry and bovines (Annamalai et al. 2004; Solis de los Santos et al. 2008; Solis de los Santos et al. 2009). The *Yucca saponins* also have antibacterial properties against *E. coli* (Wang et al. 2000a; Cheeke et al. 2006; Wang and Kim 2011). Thus, CAY supplementation may improve gut health and subsequently improve immunity and growth performance. However, more studies are needed to evaluate the effects of CAY on caecal microbiota in broiler chickens.

In conclusion, the addition of 100 mg/kg caprylic acid and 100 mg/kg *Yucca schidigera* extract to broiler diets can improve performance, immunity, gut health and meat quality. To the best of our knowledge, studies on CAY are very limited. Therefore, further research is still necessary to investigate the effects of CAY in broiler chickens.

REFERENCES

- Abdelsamic AE, Ranaweera KN, Nano WE (1983): The influence of fibre content and physical texture on performance of broilers in the Tropics. *British Poultry Science* 24, 383–390.
- Al-Bar A, Cheeke PR, Nakaue HS (1992): Effect of yucca extract (deodorase) on environmental ammonia levels and growth performance of rabbits. *Journal of Applied Rabbit Research* 15, 1105–1112.
- Allen CD, Russell SM, Fletcher DL (1993): The relationship of broiler breast meat color and shelf-life and odor development. *Poultry Science* 76, 1042–1046.
- Annamalai T, Mohan Nair MK, Marek P, Vasudvan P, Schreiber D, Knight R, Hoagland R, Hoagland TK, Venkitanarayanan K (2004): In vitro inactivation of *Escherichia coli* O157:H7 in bovine rumen fluid by caprylic acid. *Journal of Food Protection* 67, 884–888.
- Ayasan T, Yurtseven S, Baylan M, Canogullari S (2005): Effects of dietary *Yucca schidigera* on egg yield parameters and egg shell quality of laying Japanese quails (*Coturnix coturnix japonica*). *International Journal of Poultry Science* 4, 159–162.
- Bach AC, Babayan VK (1982): Medium-chain triglycerides: an update. *American Journal of Clinical Nutrition* 36, 950–962.
- Calabrese G (1999): Nonalcoholic compounds of wine: the phytoestrogen resveratrol and moderate red wine consumption during menopause. *Drugs Experimental Clinical Research* 25, 111–114.
- Cera KR, Mahan DC, Reinhart GA (1989): Apparent fat digestibilities and performance responses of post weaning swine fed diets supplemented with coconut oil, corn oil or tallow. *Journal of Animal Science* 67, 2040–2047.
- Cheeke PR, Piacente S, Oleszek W (2006): Antiinflammatory and anti-arthritic effects of *Yucca schidigera*: a review. *Journal of Inflammation* 3, 6–12.
- Cho JH, Kim IH (2014): Effects of lactulose supplementation on performance, blood profiles, excreta microbial shedding of *Lactobacillus* and *Escherichia coli*, relative organ weight, and excreta noxious gas contents in broilers. *Journal of Animal Physiology and Animal Nutrition* 98, 424–430.
- Cole BJA, Beal RM, Luscombe JR (1968): The effect on performance and bacterial flora of lactic acid, propionic acid, calcium propionate and calcium acrylate in the drinking water of weaned pigs. *Veterinary Record* 119, 108–112.
- Czczot H, Podsiad M, Skrzyzcki M, Stochmal A, Oleszek W (2003): Evaluation of the mutagenic activity of phenolics from the bark of *yucca schidigera* Roezl. *Acta Poloniae Pharmaceutica – Drug Research* 60, 357–362.
- de Vrese M, Marteau PR (2007): Probiotics and prebiotics: effects on diarrhea. *Journal of Nutrition* 137, 803–811.
- Docherty JJ, Fu MM, Stiffler BS, Limperos RJ, Pokabla M, Delucia AL (1999): Resveratrol inhibition of herpes simplex virus replication. *Antiviral Research* 43, 145–155.
- Dong XF, Gao WW, Tong JM, Jia HQ, Sa RN, Zhang Q (2007): Effect of polysavone (alfalfa extract) on abdominal fat deposition and immunity in broiler chickens. *Poultry Science* 86, 1955–1959.

- Glick B (1977): The bursa of Fabricius and immunoglobulin synthesis. *International Review of Cytology* 48, 345–402.
- Heckert RA, Estevez I, Russek-Cohen E, Pettit-Riley R (2002): Effects of density and perch availability on the immune status of broilers. *Poultry Science* 81, 451–457.
- Insoft RM, Sanderson IR, Walker WA (2005): Development of immune function in the intestine and its role in neonatal diseases. *Pediatric Clinics of North America* 43, 551–571.
- Jensen RG (2002): The composition of bovine milk lipids: January 1995 to December 2000. *Journal of Dairy Science* 85, 295–350.
- Jensen RG, Ferris AM, Lammi-Keefe CJ, Henderson RA (1990): Lipids of bovine and human milks: A comparison. *Journal of Dairy Science* 73, 223–340.
- Johnson C, McNab JM (1983): Grain meal as an ingredient in diets of broiler chicks. *British Poultry Science* 24, 361–369.
- Johnston NL, Quarles CL, Fagerberg DJ, Caveny DD (1981): Evaluation of yucca saponin on broiler performance and ammonia suppression. *Poultry Science* 60, 2289–2292.
- Katsunuma Y, Nakamura Y, Toyoda A, Minato H: (2000): Effect of *Yucca schidigera* extract and saponins on growth of bacteria isolated from animal intestinal tract. *Animal Science* 71, 164–170.
- Killen GF, Madigan CA, Connolly CR, Walsh GA, Clark C, Hybes MJ, Timmins BF, James P, Headon DR, Power RF (1998): Anti-microbial saponins of *Yucca schidigera* and the implication of their in vitro properties for their in vivo impact. *Journal of Agricultural and Food Chemistry* 46, 3178–3186.
- Mancini RA, Hunt MC (2005): Current research in meat color. *Meat Science* 71, 100–121.
- Marounek M, Skrivanova E, Skrivanova V (2004): A note on the effect of caprylic acid and triacylglycerols of caprylic and capric acid on growth rate and shedding of coccidia oocysts in weaned piglets. *Journal of Animal and Feed Science* 13, 269–275.
- Mroz Z, Jongbloed AW, Partanen KH, Vreman K, Kemme PA, Kogut J (2000): The effects of calcium benzoate in diets with or without organic acids on dietary buffering capacity, apparent digestibility, retention of nutrients, and manure characteristics in swine. *Journal of Animal Science* 78, 2622–2632.
- Mugler DJ, Cunningham FE (1972): Factors affecting poultry meat color: A review. *World's Poultry Science* 28, 400–406.
- NRC (1994): *Nutrient Requirements of Poultry*. 9th rev. ed. National Academy Press, Washington, DC, USA.
- Olas B, Wachowicz B, Stochmal A, Oleszek W (2002): Anti-platelet effects of different phenolic compounds from *Yucca schidigera* Roehl. bark. *Platelets* 13, 167–173.
- Olas B, Wachowicz B, Stochmal A, Oleszek W (2003): Inhibition of oxidative stress in blood platelets by different phenolics from *Yucca schidigera* Roehl. bark. *Nutrition* 19, 633–640.
- Owens CM, Hirschler EM, McKee SR, Martinez Dawson R, Sams AR (2000): The characterization and incidence of pale, soft, exudative turkey meat in commercial plant. *Poultry Science* 79, 553–558.
- Park JH, Kim IH (2014): Supplemental effect of probiotic *Bacillus subtilis* B2A on productivity, organ weight, intestinal *Salmonella* microflora, and breast meat quality of growing broiler chicks. *Poultry Science* 93, 2054–2059.
- Qiao M, Fletcher DL, Smith DP, Northcutt JK (2002): Effects of raw broiler breast meat color variation on marination and cooked meat quality. *Poultry Science* 81, 276–280.
- Rada V, Sirotek K, Petr J (1999): Evaluation of selective media for bifidobacteria in poultry and rabbit caecal samples. *Journal of Veterinary Medicine Series B* 46, 369–373.
- Rodas BD, Maxwell CV (1992): The effect of fat source and medium-chain triglyceride level on performance of the early-weaned pig. *Pig News Information* 13, 273.
- SAS (2008): *SAS User's Guide*. SAS Institute Inc., Cary, USA.
- Sen S, Makkar HP, Muetzel S, Becker k (1998): Effect of *Quillaja saponaria* saponins and *Yucca schidigera* plant extract on growth of *Escherichia coli*. *Letters in Applied Microbiology* 27(1), 35–38.
- Siemann EH, Creasy LL (1992): Concentration of phytoalexin resveratrol in wine. *American Journal of Enology and Viticulture* 43, 49–52.
- Simon O, Vahjen W, Scharek L (2003): Microorganisms as feed additives probiotics. In: Ball R.O. (ed.): *Proceeding of the 9th International Symposium on Digestive Physiology in Pigs*. University of Alberta, Edmonton, Alberta, Canada, 1, 295–318.
- Skrivanova E, Marounek M, Benda V, Brezinia P (2006): Susceptibility of *Escherichia coli*, *Salmonella* sp. and *Clostridium perfringens* to organic acids and monolaurin. *Veterinarni Medicina* 51, 81–88.
- Solis de los Santos F, Donoghue AM, Venkitanarayanan K, Dirain ML, Reyes-Herrera I, Blore PJ, Donoghue DJ (2008): Caprylic acid supplemented in feed reduces enteric *Campylobacter jejuni* colonization in ten-day-old broiler chickens. *Poultry Science*, 87, 800–804.
- Solis de los Santos F, Donoghue AM, Venkitanarayanan K, Metcalf JH, Reyes-Herrera I, Dirain ML, Aguiar VE, Blore PJ, Donoghue DJ (2009): The natural feed additive caprylic acid decreases *Campylobacter jejuni* colonization in market-aged broiler chickens. *Poultry Science* 88, 61–64.
- Sprong RC, Hulstein MFE, Van der Meer R (2001): Bactericidal activities of milk lipids. *Antimicrobial Agents and Chemotherapy* 45, 1298–1301.
- Vasudevan P, Patrick M, Nair M, Annamalai T, Darre M, Khan M, Venkitanarayanan K (2005): In vitro inactivation

doi: 10.17221/8532-VETMED

- of *Salmonella enteritidis* in chicken cecal contents by caprylic acid. *Journal of Applied Poultry Research* 14, 122–125.
- Wallace RJ, Arthauo L, Newbold CJ (1994): Influence of *Yucca schidigera* (Sic) extract on ruminal ammonia concentrations and ruminal microorganisms. *Applied and Environmental Microbiology* 60, 1762–1767.
- Wang JP, Kim IH (2011): Effect of caprylic acid and *Yucca schidigera* extract on production performance, egg quality, blood characteristics, and excreta microflora in laying hens. *British Poultry Science* 52, 711–717.
- Wang Y, McAllister TA, Cheeke PR, Cheng KJ (1999): Assessment of the inhibitory effects of ruminal fluid on biological activity of steroidal saponins using a hemolytic assay. *Canadian Journal of Animal Science* 79, 561–564.
- Wang Y, McAllister TA, Yanke LJ, Cheeke PR (2000a): Effect of steroidal saponin from *Yucca schidigera* extract on ruminal microbes. *Journal of Applied Microbiology* 88, 887–896.
- Wang Y, McAllister TA, Yanke LJ, XU ZJ, Cheeke PR, Cheng KJ (2000b): In vitro effects of steroidal saponins from *Yucca Schidigra* extract on rumen microbial protein synthesis and ruminal fermentation. *Journal of Science of Food and Agriculture* 80, 2114–2122.
- Wang Y, McAllister TA, Vanke LJ, Cheeke PR (2000c): Effect of steroidal saponin from *Yucca schidigera* extract on ruminal microbes. *Journal of Applied Microbiology* 88, 887–896.
- Wang JP, Yan L, Lee JH, Kim IH (2013): Evaluation of bacteriophage supplementation on growth performance, blood characteristics, relative organ weight, breast muscle characteristics and excreta microbial shedding in broilers. *Asian Australian Journal of Animal Science* 26, 573–578.
- Willis WL, Isikhuemhen OS, Ibrahim SA (2007): Performance assessment of broiler chickens given mushroom extract alone or in combination with probiotic. *Poultry Science* 86, 1856–1860.
- Woelfel RL, Owens CM, Hirschler EM, Martinez-Dawson R, Sams AR (2002): The characterization and incidence of pale, soft, exudative broiler meat in a commercial processing plant. *Poultry Science* 81, 579–584.
- Yan L, Zhang ZF, Park JC, Kim IH (2012): Evaluation of *Houttuynia cordata* and *Taraxacum officinale* on growth performance, nutrient digestibility, blood characteristics, and fecal microbial shedding in diet for weaning pigs. *Asian Australian Journal of Animal Science* 25, 1439–1444.
- Yeo J, Kim KI (1997): Effect of feeding diets containing an antibiotic, a probiotic, or yucca extract on growth and intestinal urease activity in broiler chicks. *Poultry Science*, 76, 381–385.
- Zhang ZF, Kim IH (2013): Effects of probiotic supplementation in different energy and nutrient density diets on performance, egg quality, excreta micro flora, excreta noxious gas emission, and serum cholesterol levels in laying hens. *Journal of Animal Science* 91, 4781–4787.
- Zhang ZF, Kim IH (2014): Effects of levan supplementation on growth performance, nutrient digestibility and dry matter content of feces in comparison to apramycin (antibacterial growth promoter) in weanling pigs. *Livestock Science* 159, 71–74.
- Zhang S, Jung JH, Kim HS, Kim BY, Kim IH (2012): Influences of phytoncine supplementation on growth performance, nutrient digestibility, blood profiles, diarrhea scores and fecal microflora shedding in weaning pigs. *Asian Australian Journal of Animal Science* 25, 1309–1315.
- Zhao PY, Wang JP, Kim IH (2013): Evaluation of dietary fructan supplementation on growth performance, nutrient digestibility, meat quality, fecal microbial flora, and fecal noxious gas emission in finishing pigs. *Journal of Animal Science* 91, 5280–5286.

Received: 2015–01–12

Accepted after corrections: 2015–09–18

Corresponding Author:

In Ho Kim, Dankook University, Department of Animal Resource and Science, No. 29 Anseodong, Cheonan, Choongnam, 330-714, Republic of Korea
E-mail: inhokim@dankook.ac.kr