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Effect of Dietary Supplementation of Curcumin on Growth Performance, Intestinal Morphology and Nutrients Utilization of Broiler Chicks

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The objective of this study was to determine the appropriate concentration of dietary supplementation of curcumin, and its effect on growth performance, intestinal morphology, fat metabolism and nutrients utilization of broiler chicks. Four hundred eighty, 1-day-old Arbor Acre broiler chicks were allocated into four groups with 6 replicates of 20 birds per cage. Birds were fed a corn-soybean basal diet supplemented with curcumin at 0 (control, CRM0), 100 (CRM100), 150 (CRM150) and 200 mg/kg (CRM200) levels for 42 days. All birds were kept in wire floor triple deck battery cages under semi-intensive housing management. The results revealed that dietary supplementation of curcumin at 200 mg/kg significantly improved live body weight and feed efficiency at marketing age (42 d); while, there was no significant difference on feed intake as compared to control. Curcumin significantly improved utilization of apparent metabolizable energy and decreased abdominal fat at 42 d in CRM150 and CRM200 broilers, respectively. Plasma T4 hormone level and fat utilization were significantly increased; while plasma cholesterol level was significantly reduced in dose dependent manner for CRM200 broilers. The results showed that dietary supplementation of curcumin influenced the histomorphological measurements of small intestinal villi. The villus height was significantly increased in duodenum, jejunum and ileum in curcumin supplemented broilers. Villus width was also significantly increased in duodenum and jejunum (42 d). While, there was no significant difference in ileum villus width. Furthermore, villus height to crypt depth ratio was significantly increased in all segments (except jejunum 42 d) of small intestine in CRM200 group; however, the intestinal crypt depth was lowered in curcumin supplemented broilers. In conclusion, supplementation of curcumin at 200 mg/kg feed enhanced the growth performance and fat metabolism, and increased villus absorptive area of small intestine, resulting in improved nutrients absorption in CRM200 group.

Key words: broiler performance, curcumin, intestinal morphology, nutrients utilization

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Introduction

Curcumin (diferuloylmethane), a natural polyphenol, is the principle active ingredient of turmeric (curcuma longa). It has been a popular spice in Asian and middle-eastern cuisines since centuries (Chattopadhyay *et al*., 2004). The curcumin has been reported to perform a number of biological activities, like anti-inflammatory, antioxidant (Gandhi *et al*., 2011), antimicrobial (Araujo and Leon, 2001), anticoagulant, antidiabetic and antiulcer (Lokova *et al*., 2001). It has also been reported to improve the nutrients digestibility, metabolism, and prevent biliary disorders and anorexia in humans and farm animals (Al-Sultan and Gameel, 2004; Chattopadhyay *et al*., 2004). Supplementation of curcumin stimulates the secretion of bile acids and activities of lipase, amylase and proteases, which are responsible for important roles in metabolism and accelerated digestion (Platel and Srinivasan, 1996, 2000). Curcumin also improves the liver functions and reduces the serum triglycerides, LDL cholesterol and blood glucose levels (Emadi and Kermanshahi, 2007; Seo *et al*., 2008; Gandhi *et al*., 2011).

Structure of small intestine plays a vital role in nutrient digestion and absorption (Lenhardt and Mozes, 2003); however, manipulation in the feed may alter villus height to crypt depth ratio, and absorptive area of intestine (Fasina *et al*., 2006). Moreover, the supplementation of phenolic compounds, like curcumin, may decrease gut inflammation, increase nutrients digestibility and metabolic activity (de Beer *et al*., 2008; Buchanan *et al*., 2008; Giannenas *et al*., 2010). These compounds may also have ability to alter the structure and function of gastrointestinal tract (Viveros *et al*., 2011). Dietary manipulation of feed and its effects on structure and nutrients absorption capability of gut is a major rationale for

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research, because these are indispensable for improving digestibility and productivity of animals, especially when growth-promoting antibiotics are not permitted in feed. It is an established fact that any agent, which affects the health and structure of the gut, will certainly influence the nutrient digestion and growth, and subsequently alter feed efficiency (Choct, 2009). The other issue this study addressed is the accumulation of fat in the abdominal area of chicken, which is considered as waste in the broiler processing industry due to its low return in the chicken market (Nouzarian *et al*., 2011). Thyroid hormones have a direct link with the process of fat digestion and these stimulate the basal metabolic rate of lipid (Monika *et al*., 2008).

Various studies on health promoting effects of turmeric and its active ingredient curcumin in human and animals have been reported (Gandhi *et al*., 2011); however, influence of curcumin on intestinal morphology and its relationship with metabolism and nutrients absorption in chickens is yet to be explored. Thus, the purpose of the present study was to determine the appropriate concentration of dietary supplementation of curcumin and its effect on the intestinal morphology, nutrient digestibility, fat metabolism and growth performance of broiler chickens under commercial poultry farming system.

Materials and Methods

Birds and Housing Management

Four hundred eighty, one-day-old Arbor acre broiler chicks were procured from a commercial hatchery. All the birds were initially weighed and randomly allocated into four groups (CRM0, CRM100, CRM150 and CRM200). Each group had six replicates (20 birds per cage) and kept in wire floor triple deck battery cages (200×120×32 cm) under semi-intensive housing system. The light regimen was a 12-h light-dark cycle. Temperature was maintained around 34 to 35℃ at first week and then gradually reduced by 2.3℃ per week until it reached around 21 to 23℃. Relative humidity was maintained around 55 to 65 percent. All the procedures were approved by the Institutional Animal Care and Use Committee of the Nanjing Agricultural University, China.

Feed and Treatment

The broiler chickens were fed a basal diet formulated according to the provisions of National Research Council (1994) to meet the nutrients requirements of broilers (Table 1). The curcumin (diferuloylmethane) procured from a commercial company (Guangzhou Leader Biotechnology Co Ltd, China), with the purity of 98%. Curcumin was first added in small amount of the basal diet and then small batch was mixed with a larger amount of feed until the total amount of the respective diets was well mixed. The birds were fed a starter diet from 1 to 21 d, followed by a finisher diet from 22 to 42 d. The birds in the CRM100, CRM150 and CRM200 treatment groups were fed a basal diet supplemented with curcumin at the dietary levels of 100, 150 and 200 mg/kg feed, respectively; while, the birds in CRM0 group were fed basal diet without curcumin supplementation. All birds were allowed to consume feed and water *ad libitum*.

Table 1. **Feed ingredients and nutrient composition of basal diets for experimental broiler chicks**

Item	Starter (1 to 21 d)	Finisher (22 to 42 d)
Ingredients (%)		
Corn	60.7	66.0
Soybean meal	30.0	24.0
Corn gluten meal	2.5	3.0
Soybean oil	2.8	3.05
Lime stone	1.2	1.2
Dicalcium phosphate	1.7	1.7
Mineral premix[1]	0.5	0.5
Sodium chloride	0.3	0.3
L- lysine	0.16	0.15
Dl- methionine	0.15	0.1
Analyzed chemical composition of experimental diet		
ME (kcal/kg)	3055	3120
Crud Protein (%)	21.92	19.65
Ether Extract (%)	5.48	6.13
Dry matter (%)	89.74	88.12
Methionine+cystine* (%)	0.82	0.73
Available P* (%)	0.43	0.40

Calculated*

[1] Mineral premix provided per kilogram of diet: transretinyl acetate, 25 mg; cholecalciferol, 6 mg; menadione, 1.2 mg; thiamine, 2.3 mg; riboflavin, 8 mg; nicotinamide, 42 mg; choline chloride, 400 mg; calcium pantothenate, 10 mg; pyridoxine HCl, 4 mg; biotin, 0.04 mg; folic acid, 1 mg; Cobalamin, 0.012 mg; Fe (from ferrous sulfate), 82 mg; Cu (from copper sulfate), 7.5 mg; Mn (from manganese sulfate), 110 mg; Zn (from zinc oxide), 64 mg; I (from calcium iodate), 1.1 mg; Se (from sodium selenite), 0.28 mg.

Sample Collection

Cumulative weight gain and feed intake were recorded at the end of 21 and 42 d of age to calculate feed conversion ratio. One bird per replicate was selected randomly and weighed after feed deprivation for 12 h. Individual blood samples were taken into heparinized plastic tubes and blood plasma was separated by centrifugation at 250×*g* for 10 min at 4℃ and stored at −20℃ for determination of hormones and cholesterol. After blood collection, the birds were killed by exsanguination, de-feathered and eviscerated. The abdominal fat pad was weighed and relative weight was calculated according to the formula (Abdominal fat weight / Total live body weight×100).

Plasma Analysis

The plasma samples were thawed at room temperature for laboratory analysis. Plasma cholesterol concentrations were measured by enzymatic method using an automatic biochemical analyzer (Olympus AU-800, Olympus, Tokyo, Japan) according to the procedure described by Sigma Chemical Co. (1995). Thyroid stimulating hormone (TSH), Triiodothyronine (T3) and Thyroxin (T4) concentrations were determined by radioimmunoassay (RIA) using commercial kits (Adlitteram Diagnostic Laboratories, USA) as described by Iqbal (2009). Briefly, 50 μL of 1:1 diluted samples and respective anti-goat captured antibodies were added to plate wells and incubated at 37℃ for one hour. The plates were

washed and then 80 μL of enzyme (streptavidin-peroxydase) was added to each well and incubated again at 37℃ for 30 min. After incubation, plates were washed three times with ELISA wash buffer, 50 μL of substrate solutions were pipetted into the plate wells and again incubated at 37℃ for 10 min to develop color. Then, 50 μL of H_2SO_4 was added to each well to stop the reaction and the plates were read for absorbance in a spectrophotometer at 450 nm. The levels of hormones were determined by using the standard curves. The lowest limit of sensitivity for T3, T4 and TSH were 0.1 nmol/L, 1.70 nmol/L and 0.03 IU/L respectively. All samples were run in one batch.

Intestinal Morphology

The entire small intestinal tract was removed for histomorphological examination. Two cm tissue samples of small intestine were taken from upper (start point of organ), middle (center point of organ) and lower (end point of organ) parts of duodenum (from the gizzard outlet to the end of the pancreatic loop), jejunum (from the pancreatic loop to Meckel's diverticulum) and ileum (from Meckel's diverticulum to the ileo-caeco-colic junction), according to the method of Giannenas *et al*. (2010). Briefly, the tissue samples were preserved in 10% neutral buffered formaldehyde (NBF) for 72 h, then processed for dehydration and clearing, and embedded in wax. Histological study was performed on 5 μm thick transverse sections (cut by a microtome), fixed on slides and stained with haemotoxylin and eosin. The tissue sections were examined on a Nikon phase contrast microscope coupled with a Micro computer integrated digital imaging analysis system (Nikon Eclipse 80i, Nikon Co., Tokyo, Japan).

Villus height was measured from tip (with a lamina propria) of the villus to the base (villus-crypt junction), and villus width was measured at its middle part; while, the crypt depth was measured from villus-crypt junction to the distal limit of the crypt. Three sections from each part (upper, middle and lower) of duodenum, jejunum and ileum (two villi/section/segment/bird) were measured. Eighteen villi were counted from nine different sections in each segment (duodenum, jejunum and ileum) per bird, and their average was expressed as the mean villus height and villus width for each bird. Finally, the villus height and villus width from six birds were expressed as mean villus height and villus width for one treatment group (Yamauchi *et al*., 2006).

Fecal Samples Collection

At the end of 15 and 36 d of age, one bird per replicate was transferred to metabolic cage fitted with fecal collection tray. After three days of adaptation period, feces were collected at morning, noon and evening for three consecutive days (18 to 20 d for starter period and 39 to 41 d for finisher period), pooled and stored at −20℃ for further analysis. Feed consumption was also recorded during this period.

Chemical Analysis of Feed and Feces

Fecal/feed samples were dried in forced air oven at 65℃ for 48 h (Zhang, 2003). The grinder (FW100-high speed universal disintegrator, Tian Jin Taisite Instruments Co., Ltd. China) was used in order to attain fine and uniform particle size of feed and feces for proximate chemical analysis. For determination of DM, 0.9 to 1 g sample was filled in a preweighed empty crucible, kept in oven at 105℃ for 3 h and weighed afterwards. The fat was extracted with methanol by soxhlet apparatus. Gross energy was measured by bomb calorimeter (TYHW-V China) and crude protein content was determined according to the Kjeldahl method by Kjeltec 2300 apparatus of Foss USA. Apparent nutrients retention was calculated (nutrient in feed - nutrient in feces / nutrient in feed ×100) and expressed as a percentage.

Table 2. **Effect of curcumin supplementation on feed intake, body weight, FCR and abdominal fat of broiler chicks**

Item	Dietary Treatment[1]			
	CRM0	CRM100	CRM150	CRM200
0−21 d				
Feed intake (kg)	1.121±0.014	1.090±0.019	1.135±0.017	1.143±0.008
Body weight (kg)	0.737±0.006	0.724±0.009	0.748±0.005	0.730±0.004
FCR*	1.51±0.013	1.49±0.027	1.51±0.025	1.56±0.005
22−42 d				
Feed intake (kg)	3.290±0.031	3.294±0.038	3.317±0.028	3.298±0.015
Body weight (kg)	1.752±0.011^{c}	1.794±0.007^{b}	1.787±0.009^{bc}	1.833±0.010^{a}
FCR*	1.87±0.023^{a}	1.83±0.022^{ab}	1.85±0.016^{ab}	1.79±0.004^{b}
0−42 d				
Feed intake (kg)	4.411±0.020	4.384±0.020	4.453±0.034	4.442±0.013
Body weight (kg)	2.489±0.012^{c}	2.518±0.07^{bc}	2.535±0.010^{ab}	2.563±0.008^{a}
FCR*	1.77±0.011^{a}	1.74±0.007^{ab}	1.75±0.009^{ab}	1.73±0.001^{b}
Abdominal fat	2.037±0.133^{a}	1.942±0.132^{a}	1.612±0.182^{ab}	1.430±0.120^{b}

[1] CRM0＝0 mg/kg of curcumin, CRM100＝100 mg/kg of curcumin, CRM150＝150 mg/kg of curcumin, CRM200＝200 mg/kg of curcumin. * FCR＝feed conversion ratio.
[abc] Values in the same row with no common superscript differ significantly ($P<0.05$).
All values are represented as means±SEM (n＝6).

Table 3. **Effect of curcumin supplementation on plasma cholesterol and thyroid hormones of broiler chicks**

Item[2]	Dietary Treatment[1]			
	CRM0	CRM100	CRM150	CRM200
21 d				
Cholesterol mmol/L	2.68±0.14[a]	2.35±0.18[ab]	2.22±0.10[ab]	2.05±0.15[b]
TSH IU/L	0.71±0.19	0.69±0.06	0.85±0.02	0.86±0.07
T3 nmol/L	0.72±0.24	0.88±0.08	0.73±0.11	0.70±0.07
T4 nmol/L	41.31±1.41[ab]	38.39±1.65[b]	45.83±2.13[a]	45.78±0.83[a]
42 d				
Cholesterol mmol/L	3.50±0.12[a]	3.06±0.10[ab]	2.83±0.13[b]	2.74±0.11[b]
TSH IU/L	0.87±0.05	0.85±0.02	1.08±0.14	0.93±0.03
T3 nmol/L	2.20±0.17	2.56±0.16	2.22±0.19	2.40±0.27
T4 nmol/L	36.35±1.82[b]	39.85±1.82[ab]	41.94±1.81[ab]	44.39±1.10[a]

[1] Curcumin CRM0=(0 mg/kg diet), CRM100=(100 mg/kg diet), CRM 150=(150 mg/kg diet), CRM 200=(200 mg/kg diet).
[2] TSH=Thyroid stimulating hormone; T3= triiodothyronine; T4=thyroxin.
[abc] Values in the same row with no common superscript differ significantly ($P<0.05$).
All values are represented as means±SEM ($n=6$).

Statistical Analysis

A complete randomized model was used to analyze data for various parameters. The data was analyzed by 1-way ANOVA (SAS 9.0, SAS Institute Inc., Cary, NC) and presented as mean±SEM. Significant differences among means were evaluated by Tukey's comparison test at $P<0.05$.

Results

Growth Performance

The results of growth performance are presented in Table 2. Dietary supplementation of curcumin had no significant effect ($P>0.1069$) on feed intake throughout the trial. It had no significant effect on live body weight and feed conversion ratio (FCR) at starter period (21 d); however, during finisher period (42 d), live body weight ($P<0.0003$) and FCR ($P<0.0172$) were significantly improved in CRM200, as compared to control and other groups. Furthermore, relative weight of abdominal fat (42 d) was decreased ($P<0.0108$) by curcumin supplementation in dose dependent manner (Table 2).

Plasma Cholesterol and Thyroid Hormone

The results of plasma concentrations of cholesterol and thyroid hormones are presented in Table 3. The concentrations of plasma cholesterol ($P<0.0243$) were significantly reduced in dose dependent manner throughout the trial. Plasma T4 level ($P<0.0257$) was significantly higher in CRM200 group, as compared to control; however, concentrations of T3 and TSH were not significantly affected by the supplementation of curcumin throughout the trial.

Gut Morphology

Results of gut morphology are presented in Figure 1 to 3.

Villus Height

The duodenal villus heights were significantly greater in CRM200 at 21 and 42 d ($P<0.0001$). The jejunum villus heights were significantly greater in CRM200 at 21 d ($P<0.0006$) and in CRM100 at 42 d ($P<0.0009$); while, ileum villus heights were significantly greater ($P<0.0078$) in CRM 150 and CRM200, in comparison with control and CRM100 groups at 21 and 42 d (Fig. 1).

Villus Width

The duodenal villus width was significantly greater ($P<0.0015$) in CRM200 at 21 d; while, at 42 d, control and CRM 150 groups exhibited more width. There were no significant differences in jejunum villus width (21 d) and ileum villus width (21 and 42 d) among the groups. Furthermore, jejunum villus width (42 d) was significantly more ($P<0.0010$) in CRM150, followed by CRM200, as compared to CRM0 and CRM100, respectively (Fig. 2).

Villus Height to Crypt Depth Ratio

The intestinal crypt depth in curcumin supplemented groups was significantly less for all segments (except jejunum 42 d) of small intestine, as compared to those of control group. Likewise, the duodenum (21 and 42 d), jejunum (21 d) and ileum (21 and 42 d), villus height to crypt depth ratios were higher ($P<0.0431$) in CRM200 and CRM150 groups as compared to CRM0 and CRM100, respectively (Fig. 3).

Apparent Nutrients Utilization

Results on apparent nutrients utilization are presented in Figure 4. Dietary supplementation of 200 mg/kg curcumin significantly improved ($P<0.0161$) apparent utilization of fat (ether extract) by 13.41% and 14.38% at 21 and 42 d, respectively, as compared to control. The apparent utilization of metabolizable energy (ME) was significantly higher ($P<0.0174$) in CRM150 group (by 4.71%), as compared to control at 42 d; however apparent utilization of crude protein (CP) and dry matter (DM) were comparatively better in curcumin supplemented broilers, but the differences were non-significant ($P>0.05$). Apparent utilization of all nutrients was higher for the finisher period than starter period (Fig. 4).

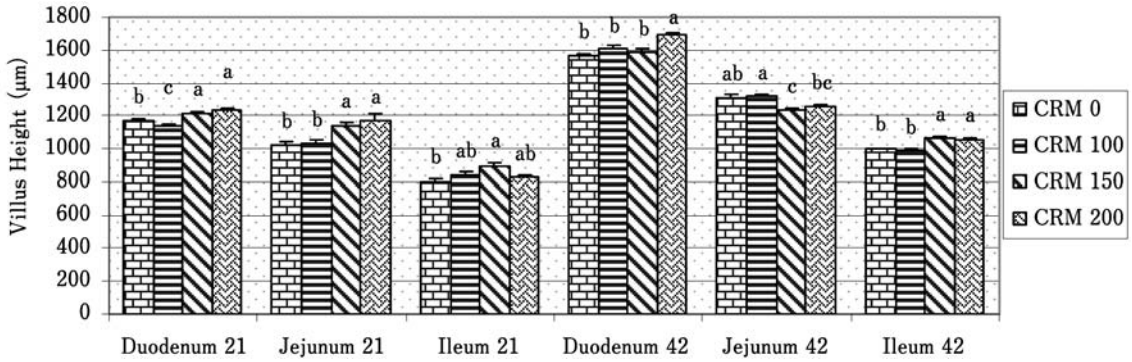

Fig. 1. **Comparison of villus height at 21 and 42 d of broiler chicks supplemented with curcumin.** CRM0＝(0 mg/kg diet), CRM100＝(100 mg/kg diet), CRM 150＝(150 mg/kg diet), CRM 200＝(200 mg/kg diet). Values are mean±SEM (n＝6), ^{abc} Different letters showing significant difference among mean values (P＜0.05).

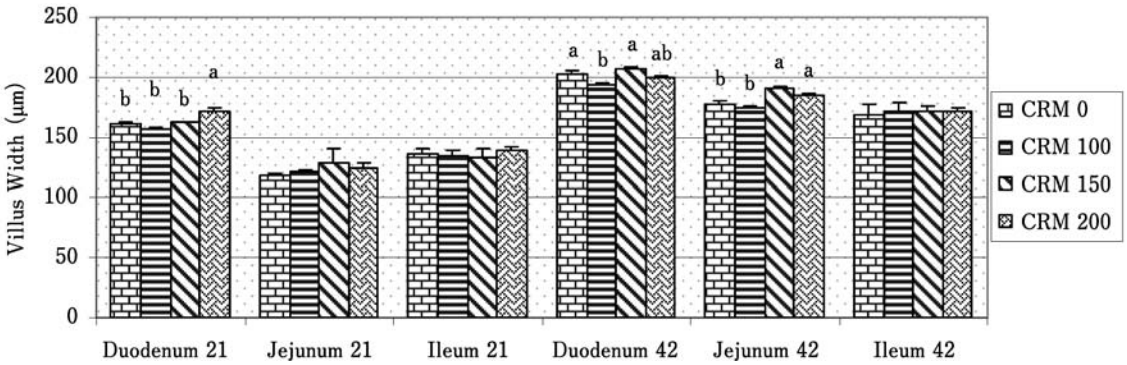

Fig. 2. **Comparison of villus width at 21 and 42 d of broiler chicks supplemented with curcumin.** CRM0 ＝(0 mg/kg diet), CRM100＝(100 mg/kg diet), CRM 150＝(150 mg/kg diet), CRM 200＝(200 mg/kg diet). Values are mean±SEM (n＝6), ^{abc} Different letters showing significant difference among mean values (P＜0.05).

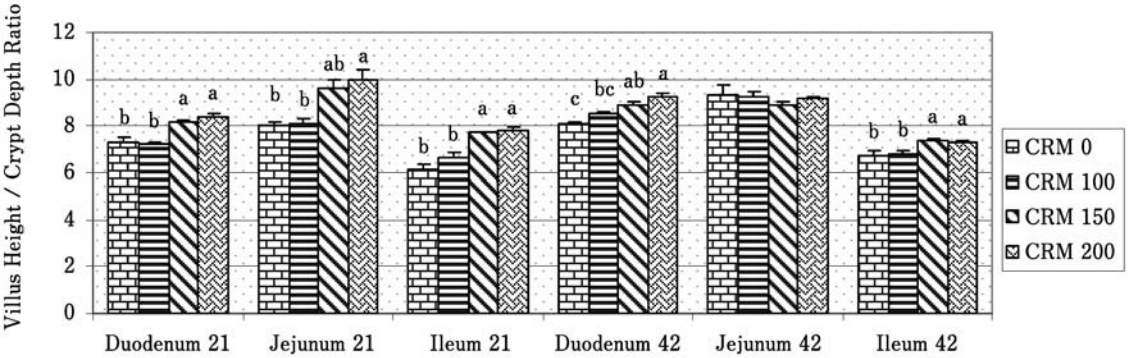

Fig. 3. **Comparison of villus height to crypt depth ratio at 21 and 42 d of broiler chicks supplemented with curcumin.** CRM0＝(0 mg/kg diet), CRM100＝(100 mg/kg diet), CRM 150＝(150 mg/kg diet), CRM 200＝(200 mg/kg diet). Values are mean±SEM (n＝6), ^{abc} Different letters showing significant difference among mean values (P＜0.05).

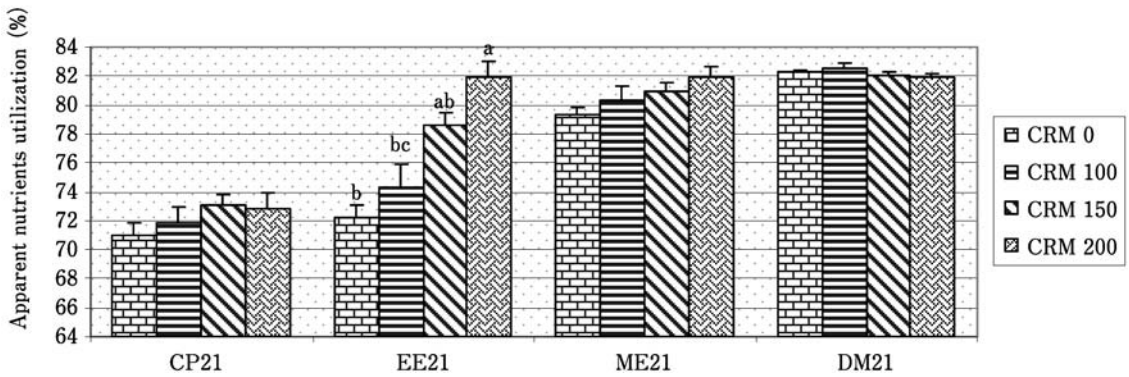

Fig. 4a. **Comparison of apparent nutrients utilization at 21 d of broiler chicks supplemented with curcumin CRM0＝(0 mg/kg diet), CRM100＝(100 mg/kg diet), CRM150＝(150 mg/kg diet), CRM200＝(200 mg/kg diet).** CP＝Crude Protein; EE＝Ether Extract; ME＝Metabolizable energy; DM＝Dry matter. Values are mean±SEM (n＝6). [abc] Different letters showing significant difference among mean values ($P<0.05$).

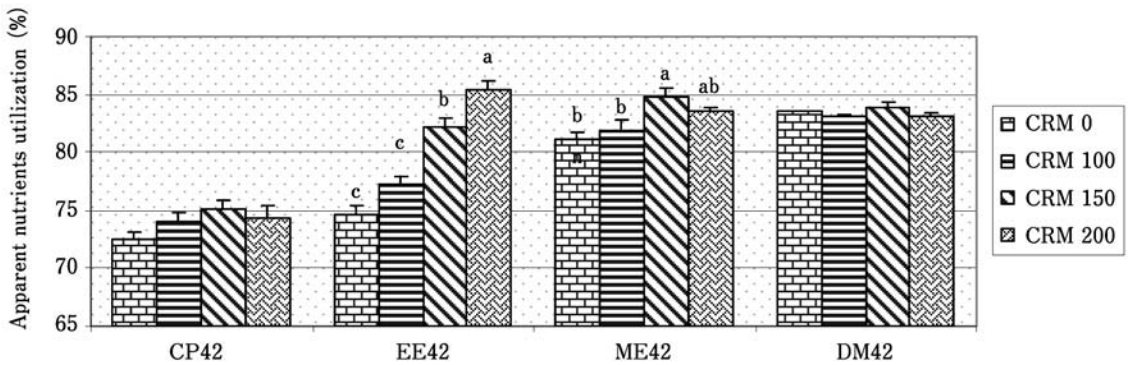

Fig. 4b. **Comparison of apparent nutrients utilization at 42 d of broiler chicks supplemented with curcumin CRM0＝(0 mg/kg diet), CRM100＝(100 mg/kg diet), CRM150＝(150 mg/kg diet), CRM200＝(200 mg/kg diet).** CP＝Crude Protein; EE＝Ether Extract; ME＝Metabolizable energy; DM＝Dry matter. Values are mean±SEM (n＝6). [abc] Different letters showing significant difference among mean values ($P<0.05$).

Discussion

Although various studies have been conducted on the use of turmeric and its active principle ingredient curcumin as an antioxidant and immunity enhancer in human, animals and broilers (HMPC, 2009; Kumari *et al*., 2007; Gandhi *et al*., 2011); the effect of curcumin on intestinal morphology is further needed to be explored.

Dietary supplementation of curcumin exhibited a significantly positive effect on weight gain and feed efficiency at marketing age (42 d), which is in accordance with several reports (Platel and Srinivasan, 2004; Durrani *et al*., 2006; Kumari *et al*., 2007), who validated positive effect of curcuma longa/ curcumin on broiler growth performance. In the same way, our second experiment identified similar results on body weight gain and FCR. Higher feed efficiency might be due to the larger villus area as recorded in present study. This positive effect might be due to the well reported anti-inflammatory, antioxidant and antibacterial activities (Chattopadhyay *et al*., 2004) or prebiotic like effects of curcumin, as reported by Niamsa and Sittiwet (2009). Present results also agreed with the findings of Emadi and Kermanshahi (2007), who reported that curcuma longa improved FCR in broilers and their beneficial effects might be due to enhanced secretions of amylase, trypsin, chymotrypsin and lipase enzymes (Platel and Srinivasan, 2000).

Dietary supplementation of curcumin had no effect on feed intake of broiler. Similar to our findings, Wuthi-udomler *et*

al. (2000) indicated that curcumin did not affect feed intake of broiler chickens. On the other hand, relative weight of abdominal fat decreased in a dose dependent manner. Lower abdominal fat might be due to the influence of curcumin on adipocyte apoptosis or glucose withdrawn from blood as reported by Sugiharto *et al*. (2011). In addition, de Beer *et al*. (2008) reported that higher fat mobilization might be due to stimulated T4 hormone. Dietary curcumin decreased cholesterol levels (Unnikrishnan and Rao, 1995) and stimulated fat digestion (Cunningham and Klein, 2007). Moreover, Gandhi *et al*. (2011) and Kumari *et al*. (2007) reported that curcumin significantly decreased total cholesterol, which might be due to inhibition of active enzyme hepatic 3-hydroxyl-3-methyglutaryl CoA- reductase (HMGCR), which is responsible for cholesterol synthesis in the liver (Crowell, 1999; Galib *et al*., 2011).

Thyroid hormones play an important role in regulating the fat metabolism, and plasma concentrations of these hormones could be potential indicators of metabolic activity and physiological responses of birds at commercial poultry farming (Melesse *et al*., 2011). In this study, the concentration of T4 hormone increased, while that of T3 remained unaffected by supplementation of curcumin. Monika *et al*. (2008) also reported the stimulatory effect of curcumin on biosynthetic activity of thyroid gland in rats, where concentration of thyroid hormones significantly increased after curcumin administration. Furthermore, the efficiency of curcumin for digestion and utilization of lipids might be related to high level of T4 as found in our study.

The present results revealed that the supplementation of curcumin to broiler feed increased the villus height and width, which might be due to increased epithelial cell turnover in all segments (duodenum, jejunum and ileum) of small intestine. Longer villi are associated with activated cell mitosis (Samanya and Yamauchi, 2002). Longer villi provided more nutrients absorption area in small intestine, which might enhance nutrient absorption (Pluske *et al*., 1996); while, short or damaged intestinal villi impair the absorption capability of animals due to decreased absorption area of intestine, which might lead to poor feed efficiency and weight gain (Ilsley *et al*., 2005). A shortening of villi with deeper crypts may lead to poor nutrient absorption and lower performance (Xu *et al*., 2003). The intestinal epithelial cells originate in the crypt and migrate along the villus surface upward to the villus tip (Potten, 1998). Deeper crypts indicate fast tissue turnover to permit renewal of the villus as needed in response to tissue sloughing, inflammation or toxins produced by any pathogen and high demands for tissue (Yason *et al*., 1987). In current study, crypt depth was lower in curcumin supplemented broilers as compared with control, which indicated that there was no need for renewal of villi as a result of tissue sloughing, inflammation or toxins produced by any pathogen. In addition, the present experimental birds were kept under commercial semi-intensive housing system and there was always a chance of exposure to pathogenic microorganism. Furthermore, previous in vitro studies showed that curcumin reduced the population of harmful gut bacteria and had inhibitory effect against various pathogenic bacteria (Niamsa and Sittiwet, 2009). Our (unpublished) data also showed that curcumin had antibacterial and immuno-modulatory effects on broiler chicken. This study indicated the digestion enhancing potential of curcumin that might be due to digestive enzymes and bile production (Rahimi *et al*., 2011; Al-Sultan and Gameel, 2004; Platel and Srinivasan, 2000). Less fat in the excreta of curcumin supplemented broilers, probably, indicated the stimulatory action of curcumin for bile production or might be related to high levels of T4 that ultimately promote fat digestion (Ammon and Wahl, 1991). In addition, Brenes *et al*. (2008) reported that dietary inclusion of natural antioxidant, vitamin E increased utilization of fat in birds; while curcumin has been reported to be better antioxidant than vitamin E (Reddy and Lokesh, 1992). The presence of antioxidant improved digestibility of nutrients (Tatli *et al*., 2008). Similarly, Brenes *et al*. (2008) concluded that the dietary supplementation of grape pomace concentrate, a phenolic compound like curcumin, had no significant influence on protein utilization in chicken, as found in our study.

In conclusion, dietary supplementation of curcumin at 200 mg/kg enhanced overall growth performance, metabolism and nutrients absorptive area of villi in small intestine, while decreased fat deposition in abdominal area. These observations provided the first account on curcumin potential to modulate gut structure, enhanced nutrients absorption and performance of broiler chicken.

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