Influence of Dietary Calcium Concentration on the Digestion of Nutrients along the Intestinal Tract of Broiler Chickens

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The effects of dietary calcium (Ca) concentration on the digestion of Ca, phosphorus (P), nitrogen (N), fat and starch along the intestinal tract of broilers were assessed. Three-week old broilers were fed maize-soy diets containing 6, 9 or 12 g/kg of Ca (Ca: total P ratios of 1:1, 1.4:1 and 2:1, respectively) for six days and digesta were collected from the duodenum, jejunum, upper ileum and lower ileum. Apparent digestibility coefficients of P, Ca, N, fat and starch in different intestinal segments were calculated based on indigestible marker ratios in the diet and digesta. Apparent digestibility coefficients of P and Ca were determined to be negative in the duodenum. Apparent P digestibility was reduced (P<0.05) by increasing dietary Ca concentrations, but there was a Ca x intestinal site interaction (P<0.05). Jejunum was the major site of P absorption in birds fed the low Ca and normal Ca diets, but both the jejunum and upper ileum were involved in birds fed high Ca diets. Dietary Ca concentration had no effect (P>0.05) on apparent Ca digestibility. Calcium was absorbed predominantly in the jejunum. Digestibility of N and fat was reduced (P<0.05) by increasing dietary Ca concentrations. A significant (P<0.05) dietary Ca x intestinal site interaction was observed for N. In birds fed low Ca and normal Ca diets, N was primarily digested by the end of jejunum, but in birds fed high Ca diet both jejunum and upper ileum were involved. At all dietary Ca concentrations, fat was digested mainly in the jejunum and upper ileum, but digestion continued in the lower ileum. Apparent starch digestibility and AME were unaffected (P>0.05) by dietary Ca concentrations. Most of the starch digestion was completed by the end of the jejunum. The present data suggest that the site of digestion of P and N shifts depending on dietary Ca concentrations. Increasing dietary Ca concentrations negatively influenced the digestion of P, N and fat, but had no effect on those of Ca and starch.

Key words: broilers, calcium, digestion, intestinal segments, phosphorus

Introduction

The digestion of calcium (Ca) and phosphorus (P) in poultry have been generally measured over the total digestive tract (Tyler and Willcox, 1942; Common et al., 1948). Such evaluations, however, do not provide information on the site(s) of intestinal digestion. Identification of the sites of Ca and P digestion is critical to understand the dynamics of digestion. Only limited studies have been conducted to investigate the absorption of Ca and P in broilers (Hurwitz and Bar, 1970, 1971, 1972). Results from these studies, using yttrium 91 (⁹¹Y) as a non-absorbable reference material to calculate the absorption of P, showed that most of the dietary P and Ca were absorbed in the proximal segments of the intestine. The upper jejunum was identified as the major site of P absorption, with most of the dietary Ca being absorbed between the duodenum and lower jejunum (Hurwitz and Bar, 1970).

The inter-relationship that exists between dietary Ca and P concentrations in poultry nutrition and metabolism has been recognised for many years (Suttle, 2010) and the negative effects of high dietary Ca on P absorption in different species are well documented (Young et al., 1966; Kaup et al., 1990; Liu et al., 2000). A Ca: non-phytate P ratio of 2.2:1 is recommended for the optimum performance of broilers (NRC, 1994). A wider Ca:P ratio negatively influences the utilisation of both Ca and P, whereas a positive impact on retention can be achieved through narrower ratios (Mohammed et al., 1991; Qian et al., 1997; Tamim et al., 2004; Santos et al., 2008). Because of this critical relationship, studies to identify the specific region(s) in the
intestinal tract where Ca may alter the absorption of P are of interest.

Some studies have examined the specific regions in the digestive tract where Ca alters the utilisation of P in ruminants (Care, 1994) and pigs (Liu et al., 2000). Studies have also been conducted to examine the effect of dietary Ca concentrations on the absorption of P and Ca in layers (Hurwitz and Bar, 1965) and turkeys (Hurwitz et al., 1979). A suppressive effect of high dietary Ca concentrations on P absorption was evident in layers with no influence on Ca absorption (Hurwitz and Bar, 1965). In turkeys, the efficiency of P absorption was found to be slightly affected by dietary P concentrations, whereas Ca absorption was negatively influenced by the dietary Ca concentration (Hurwitz et al., 1979). Corresponding studies with broilers, however, are scant.

Some reports suggest that high dietary Ca can adversely affect the utilisation of fat (Sibbald and Price, 1977), nitrogen (Shafey and McDonald, 1991a), and metabolisable energy (Shafey and McDonald, 1991a) in broilers. The absorption of protein, fatty acids and starch along the digestive tract of chickens (Renner, 1965; Bielorai et al., 1973; Sklan and Hurwitz, 1980; Weurding et al., 2001; Tanchaoenrat et al., 2014) has been investigated. However, none have examined the specific intestinal segments where Ca may alter the utilisation of these nutrients.

The aim of the current study was to examine the effects of dietary Ca concentration on the digestion of Ca, P, nitrogen (N), fat and starch along the intestinal tract of broiler chickens. The hypothesis that high dietary Ca may reduce the utilisation of nutrients and may alter the site of digestion was tested.

**Materials and Methods**

The experimental procedures were approved by the Massey University Ethics Committee and complied with the New Zealand Code of Practice for the Care and Use of Animals for Scientific Purposes.

**Birds**

Day-old male broilers (Ross 308) were obtained from a commercial hatchery, raised in floor pens and fed a commercial broiler starter diet. On day 14, birds were transferred to grower cages. On day 21 post-hatch, birds were individually weighed and 72 birds of uniform weight were selected and assigned to 12 grower cages of six birds each so that the cage average weight was similar. Room temperature was maintained at 32±1 °C during the first week and gradually reduced to 21±1 °C by the end of the third week. A lighting schedule of 20h light/day was provided. Feed was given *ad libitum* and water was freely available throughout the experiment.

**Dietary Treatments**

A maize-soy basal diet (normal Ca) was formulated to contain recommended Ca concentrations and Ca:P ratio for Ross 308 broiler growers (Ross, 2007; Table 1). Two additional experimental diets (low Ca and high Ca) were formulated to contain similar nutrient profiles, except for dietary Ca (Table 1). The Ca concentrations in low, normal and high Ca diets were 6, 9 or 12 g/kg, respectively (corresponding to Ca: total P ratios of 1:1, 1.4:1 and 2:1, respectively). Titanium dioxide was added to all diets as an indigestible marker at a concentration of 3 g/kg.

**Digesta and Excreta Collection**

Between days 25 and 27 post hatch, grab samples of fresh excreta were collected. Daily collections were pooled within a cage and, representative samples were taken and lyophilised (Model 0610, Cuddon Engineering, Blenheim, New Zealand). Diet and excreta samples were then ground to pass through 0.5-mm sieve and stored in air-tight plastic containers till analysis for dry matter (DM), gross energy (GE) and titanium.

On day 27, birds were euthanised by intra-venous injection of sodium pentobarbitone and the digesta from duodenum, jejunum, upper ileum and lower ileum were collected. The duodenum was defined as the portion of the small intestine extending from pyloric junction to the distal-most point of insertion of the duodenal mesentery, whereas the jejunum was identified as the portion that descending down to Meckel’s diverticulum (Amerah et al., 2009). The ileum was defined as the section of the small intestine starting from Meckel’s diverticulum to a point approximately 40 mm anterior to the ileo-caecal junction (Ravindran et al., 1999). The ileum was divided into two halves and identified as upper and lower ileum. Digesta from different segments were flushed out with reverse-osmosis water, pooled within a cage and lyophilised (Model 0610, Cuddon Engineering, Blenheim, New Zealand). Diet and digesta samples were ground to pass through a 0.5-mm sieve and stored in air-tight plastic containers till analysis for DM, Ca, P, N, fat, starch and titanium.

**Chemical Analysis**

Dry matter was determined by drying samples at 105°C for 16 h in a pre-weighed dried crucible in a convection oven (AOAC International, 2005; method no: 930.15). Samples were ashed and P was determined colorimetrically (UV mini 1240 Shimadzu Corp., Kyoto, Japan) at 680 nm (AOAC International, 2005; method no: 968.08D). Calcium was determined by colorimetric assay (Flexor E, Vital Scientific NV, Spankeren/Dieren, the Netherlands) following digestion with 6M HCl to release Ca (AOAC International, 2005; 968.08D). Titanium dioxide was determined by the colorimetric method (UV mini 1240 Shimadzu Corp., Kyoto, Japan) at 410 nm as described by Short et al. (1996). Gross energy was determined by adiabatic bomb calorimetry (Gallenkamp Autobomb, London, UK) standardised with benzoic acid. Nitrogen was determined by total combustion (AOAC International, 2005; method no: 968.06D) using a CNS-2000 auto analyser (LECO Corporation, St. Joseph, MI). Fat was determined by Soxhlet extraction (AOAC International, 2005; method no: 991.36). Starch was measured using alpha-amylase method (AOAC International, 2005; method no: 996.11).

**Calculations**

Apparent digestibility coefficients of P, Ca, N, fat and...
starch in different segments of the intestinal tract and energy utilisation coefficients at the excreta level were calculated by the following formula using the indigestible marker ratios.

Apparent digestibility coefficient of nutrient
\[
\left\{ \frac{(N_t/T_i)_d - (N_t/T_i)_i}{(N_t/T_i)_d} \right\}
\]

Where, \((N_t/T_i)_d\) = ratio of nutrient and titanium in diet, and \((N_t/T_i)_i\) = ratio of nutrient and titanium in digesta or excreta.

Apparent metabolisable energy was calculated by the following formula.

AME (MJ/kg DM) = Energy utilisation coefficient x GE of the diet

**Statistical Analysis**

Data were analysed using a repeated measure analysis using the General Linear Models procedures of SAS (2004) to assess the effects of dietary Ca concentration and Ca x intestinal site interactions. Data on duodenal values were not included in the statistical analysis, because of the negative digestibility coefficients determined in this segment. Cage served as the experimental unit. Differences were considered significant at \(P < 0.05\) and, when a significant F-test was detected, means were separated using the least significant difference test.

**Results**

Analysed DM, Ca and P contents of experimental diets are shown in Table 1. Analysed values were in good agreement with calculated values, except for Ca. The analysed contents of Ca in the diets were 0.3 to 1.9 g/kg higher than calculated, but the expected differences in Ca between the diets were broadly achieved. Therefore it was assumed that these differences will not affect the interpretation of the results of the study.

**Digestibility of P and Ca**

The influence of dietary Ca concentration on the apparent digestibility of P and Ca in different intestinal segments is...
presented in Table 2. A significant interaction \((P<0.01)\) between Ca concentration and intestinal site was observed for P digestibility. This interaction was due primarily to a lower P digestibility at the jejunum and a greater change in P digestibility between jejunum and upper ileum of birds fed the high Ca diet, compared to those fed low Ca and normal Ca diets.

Apparent digestibility of P was determined to be highly negative in the duodenum. In birds fed low Ca and normal Ca diets, P was rapidly digested and absorbed in the jejunum, but the digestion continued in the upper ileum. On the other hand, in birds fed the high Ca diet, digestibility was lower \((P<0.05)\) in the jejunum and the digestion shifted to the upper ileum. At all three dietary Ca concentrations, there were no differences \((P>0.05)\) between the digestibility of P determined at lower and upper ileal levels.

Dietary Ca concentration influenced \((P<0.05)\) apparent P digestibility. In all intestinal segments, increasing concentrations of dietary Ca reduced \((P<0.05)\) P digestion. The negative effect was particularly evident in the duodenum of birds fed the high Ca diet.

Apparent digestibility of Ca was negative in the duodenum (Table 2). Calcium digestibility values determined at jejunum, upper ileum and lower ileum were similar \((P>0.05)\), with digestion of Ca being completed in the jejunum. Calcium digestibility was not influenced \((P>0.05)\) by dietary Ca concentrations.

As shown in Fig. 1, the site of absorption of P shifted with increasing dietary Ca concentrations. Phosphorus was absorbed primarily in the jejunum in birds fed low Ca and normal Ca diets. In birds fed high Ca diets, both the jejunum and upper ileum were involved in P absorption. For Ca,

### Table 2. Influence of dietary Ca concentration on the apparent digestibility coefficients of phosphorus (P) and calcium (Ca) along the intestinal tract of broilers

<table>
<thead>
<tr>
<th>Diet (^2)</th>
<th>Site</th>
<th>Apparent digestibility coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>Ca</td>
</tr>
<tr>
<td>Low Ca</td>
<td>Duodenum</td>
<td>−2.15</td>
</tr>
<tr>
<td></td>
<td>Jejunum</td>
<td>0.325(^{bc})</td>
</tr>
<tr>
<td></td>
<td>Upper Ileum</td>
<td>0.387(^{ef})</td>
</tr>
<tr>
<td></td>
<td>Lower Ileum</td>
<td>0.417(^{c})</td>
</tr>
<tr>
<td>Normal Ca</td>
<td>Duodenum</td>
<td>−1.11</td>
</tr>
<tr>
<td></td>
<td>Jejunum</td>
<td>0.292(^{b})</td>
</tr>
<tr>
<td></td>
<td>Upper Ileum</td>
<td>0.349(^{ed})</td>
</tr>
<tr>
<td></td>
<td>Lower Ileum</td>
<td>0.379(^{le})</td>
</tr>
<tr>
<td>High Ca</td>
<td>Duodenum</td>
<td>−1.93</td>
</tr>
<tr>
<td></td>
<td>Jejunum</td>
<td>0.141(^{a})</td>
</tr>
<tr>
<td></td>
<td>Upper Ileum</td>
<td>0.292(^{b})</td>
</tr>
<tr>
<td></td>
<td>Lower Ileum</td>
<td>0.325(^{bc})</td>
</tr>
</tbody>
</table>

### SEM\(^3\)

<table>
<thead>
<tr>
<th>Diet (^2)</th>
<th>Site</th>
<th>SEM(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Ca</td>
</tr>
<tr>
<td>Low Ca</td>
<td>Duodenum</td>
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<tr>
<td>Normal Ca</td>
<td>Duodenum</td>
<td>0.0267</td>
</tr>
<tr>
<td>High Ca</td>
<td>Duodenum</td>
<td>0.0080</td>
</tr>
</tbody>
</table>

### Main Effects

**Dietary Ca concentration**

<table>
<thead>
<tr>
<th>Diet (^2)</th>
<th>Duodenum</th>
<th>Jejunum</th>
<th>Upper Ileum</th>
<th>Lower Ileum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Ca</td>
<td>0.376</td>
<td>0.370</td>
<td>0.342</td>
<td>0.374</td>
</tr>
<tr>
<td>Normal Ca</td>
<td>0.340</td>
<td>0.374</td>
<td>0.342</td>
<td>0.358</td>
</tr>
<tr>
<td>High Ca</td>
<td>0.374</td>
<td>0.340</td>
<td>0.374</td>
<td>0.389</td>
</tr>
</tbody>
</table>

### Probability \((P ≤)\)

<table>
<thead>
<tr>
<th>Dietary Ca concentration</th>
<th>Site</th>
<th><strong>NS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*</td>
<td>NS</td>
</tr>
</tbody>
</table>

**NS**, not significant; *\(P<0.05); **\(P<0.01); ***\(P<0.001).  
\(^1\) Each value represents the mean of four replicates.  
\(^2\) Low Ca, low Ca diet; Normal Ca, normal Ca diet; High Ca, high Ca diet.  
\(^3\) Pooled standard error of mean (excluding the duodenal values).  
\(^a-f\) Means in a column not sharing a common superscript are significantly different. \((P<0.05). Data were analysed excluding the duodenal values.
digestion and absorption was completed by the jejunum (Fig. 1).

**Digestibility of N, Fat and Starch**

The influence of dietary Ca concentration on the apparent digestibility of N, fat and starch in different intestinal segments is presented in Table 3. Duodenal contents were not analysed for N, fat and starch due to insufficient digesta samples and duodenal data are therefore not presented. A significant interaction ($P<0.05$) between Ca concentration and intestinal site was observed for N digestibility. This interaction was due primarily to a lower N digestibility in the jejunum and a greater change in N digestion between the jejunum and upper ileum of birds fed the high Ca diet, compared to those fed low Ca and normal Ca diets. In birds fed low Ca and normal Ca diets, N was primarily digested in the jejunum, and the digestion continued in the upper ileum (Fig. 2). On the other hand, in birds fed the high Ca diet, both jejunum and upper ileum were involved in N digestion. At all three Ca concentrations, N digestion continued in the lower ileum and the digestibility coefficients determined at lower ileum and upper ileum differed ($P<0.05$). However, the digestibility coefficients measured at the lower ileum was not different ($P>0.05$) between the three diets.

Dietary Ca concentration had a significant effect ($P<0.05$) on the apparent N digestibility, but there was also a significant Ca x intestinal site interaction. Nitrogen digestibility was reduced by increasing concentrations of dietary Ca in the jejunum and upper ileum, but was unaffected ($P<0.05$) in the lower ileum.

Dietary Ca concentration had a significant effect ($P<0.05$) on apparent fat digestibility. Fat digestibility was reduced by increasing Ca concentrations in all intestinal segments, as reflected by the lack of interaction ($P>0.05$) between Ca concentration and intestinal site. As shown in Fig. 2, in birds fed low Ca, normal Ca and high Ca diets, fractional fat digestion was highest by the end of jejunum and the upper ileum, but continued in the lower ileum. Digestibility coefficients of fat determined in low, normal and high Ca diets at the lower ileum were 0.898, 0.890 and 0.856, respectively.

Apparent starch digestibility was not influenced ($P>0.05$) by dietary Ca concentrations (Table 3) and there was no
interaction \((P > 0.05)\) between Ca concentration and intestinal site. Irrespective of dietary Ca concentrations, jejunum was the predominant site of starch digestion (Fig. 2). The digestibility coefficients of starch in low, normal and high Ca diets at the lower ileum were 0.979, 0.974 and 0.975, respectively.

Apparent metabolisable energy was not affected \((P > 0.05)\) by dietary Ca concentrations. The AME of low, normal and high Ca diets were calculated to be 14.5, 14.3 and 14.2 MJ/kg DM, respectively.

**Discussion**

The highly negative apparent digestibility of P and Ca in the duodenum is indicative of marked net secretion of these minerals into this segment. This finding is in agreement with that of Hurwitz and Bar (1970) who also observed a net flow of Ca into the duodenum in 3-week old broilers fed diets containing 10.8 g/kg Ca and 7.7 g/kg P. A heavy endogenous secretion of P in the duodenum has also been previously reported in layers (Hurwitz and Bar, 1965) and broilers (van der Klis, 1993). This net flow of P may be explained by the secretion of copious amounts of digestive juices from the pancreas and glands in the duodenal wall (Hurwitz et al., 1979). Phospholipids in the bile (van Berge Henegouwen et al., 1987) are other major contributors to the endogenous P flow. Bile is also the major source of endogenous Ca, in which the Ca exists as bile acid conjugates, free ionised Ca or insoluble Ca salts such as calcium bilirubinate, calcium carbonate, calcium orthophosphate and calcium palmitate (Moore, 1984; Gleeson et al., 1990). The existence of continuous duodenal-gizzard reflexes in chickens could also account, in part, for the observed negative digestibility estimates. Digesta, digestive enzymes and bile are known to be shuttled between the gizzard and duodenum to optimise nutrient digestion by prolonging the retention time (Duke, 1982) and this reverse peristalsis may be expected to increase the net concentration of P and Ca in the duodenum.

The current work showed that P absorption occurred predominantly in the jejunum in broilers fed low and normal Ca diets. According to Hurwitz and Bar (1972), the jejunum is the major site of vitamin D3 action on P absorption. The absorption of P, however, continued in the upper ileum. An interesting finding of the current work was that the site of P absorption shifted at high Ca concentration. Both the jeju-
num and upper ileum were involved in P digestion in birds fed diets with high Ca concentrations. Reasons for the observed shift in high Ca diets are not clear. Additional Ca as limestone has the potential to increase the precipitation of phytate-P and phosphates by increasing both gut pH and Ca: phytate molar ratios (Selle et al., 2009) and it is tempting to speculate that this effect may have slowed phytate-P hydrolysis and P absorption. However, at all Ca concentra-

tions, digestion of P was completed by the upper ileum, and the digestibility coefficients determined at the upper and lower ileal sites were similar.

The results of the current study show that, irrespective of dietary Ca concentrations, Ca digestion was completed in the jejunum. In contrast, Hurwitz and Bar (1970) reported that Ca absorption was highest between the duodenum and lower jejunum, and continued in the upper ileum of broilers fed

![Digestion (as a proportion of total digestion determined at lower ileum) of N (A), fat (B) and starch (C) along the small intestine of broilers fed diets containing different concentrations of Ca.](image-url)
diets containing 10.8 g/kg Ca. Swaminathan et al. (1978), on the other hand, found that the increase in Ca absorption was more pronounced in the ileum than in the duodenum and jejunum of birds as dietary Ca concentrations were reduced.

In all intestinal segments, apparent digestibility of P was progressively reduced with increasing concentrations of dietary Ca. These findings are in agreement with previous research (Hurwitz and Bar, 1965; Plumstead et al., 2008). Among the formally plausible reasons, three are worth considering. First, high dietary Ca concentrations may decrease the utilisation of phytate P by the formation of insoluble Ca-phytate complex (Qian et al., 1997; Liu et al., 1998; Plumstead et al., 2008) making the P less available (Angel et al., 2002). Second, the ability of Ca to react with dietary inorganic P to form insoluble calcium orthophosphate (Hurwitz and Bar, 1971; Plumstead et al., 2008; Selle et al., 2009) may also make inorganic P less available for absorption at high Ca intakes. Finally, Ca is thought to be a key factor influencing the activity of mucus phytase in the small intestine of poultry (Wise, 1983). Several studies have shown the negative effects of high dietary Ca concentrations on the intestinal activity of phytase (McCuaig et al., 1972; Angel et al., 2002; Applegate et al., 2003) and alkaline phosphatases (McCuaig et al., 1972) by competing for active sites of the enzyme.

Dietary Ca, at the concentrations used in the present study, had no effect on the apparent digestibility of Ca, which is in an agreement with the findings of Hurwitz and Bar (1965). In contrast, studies in several species including poultry have shown that the efficiency of Ca absorption is increased in low Ca diets (Swaminathan et al., 1978), which was attributed as a response of animals to Ca restriction via increased production of 1,25-dihydroxycholecalciferol in the intestine (Edelstein et al., 1975) which in turn stimulates the expression of Ca binding protein (Deluca and Schneois, 1976). At the dietary Ca concentration of 15 g/kg, maximum suppression of Ca binding protein has been observed (Hurwitz et al., 1995). On the other hand, some authors have reported a positive correlation between dietary Ca concentration and Ca absorption (Tamim and Angel, 2003; Tamim et al., 2004).

In the present study, most of the digestion of N was found to have taken place by the end of jejunum in broilers fed low Ca and normal Ca diets. Similar to P digestion, both jejunum and upper ileum were involved in the digestion of N in birds fed the high Ca diet. However, apparent digestibility coefficients of N in birds fed low, normal and high Ca diets were similar at the lower ileum and ranged between 0.812 and 0.833. The major site of N digestion reported in this study is in an agreement with the findings of Sklan and Hurwitz (1980). In this study, jejunum was found to be the major site of protein digestion with heavy N secretion into the duodenum.

In all intestinal segments, apparent digestibility of N was reduced at the highest concentration of dietary Ca. The negative effect of high dietary Ca on N digestion in poultry, while in agreement with the findings Shafey and McDonald (1991a,b) and Wilkinson et al. (2014), is not readily explainable. It may be speculated that the increased pH in the gastric phase created by the provision of high levels of Ca as limestone (Ca carbonate), a source with extremely high acid-binding capacity (Lawlor et al., 2005), may be partly responsible. This increase in gastric digesta pH, in turn, may reduce the action of pepsin (Walk et al., 2012) and lower protein digestion. Another possibility is that the carbonate ion (CO₃²⁻), one of the strongest known kosmotropes (Zhang et al., 2005), may play some role by lowering protein solubility. Shafey and McDonald (1991b) speculated that high Ca diets slow the digesta transit time as well as increase the intestinal microbial counts causing mucosal irritation and impairing absorption, but no supporting evidence was provided.

The results of the present study indicated that the fat digestion predominantly occurred in the jejunum and upper ileum, a finding that corresponds to that of Tancharoenrat et al. (2014). In general, apparent digestibility of fat was reduced with increasing concentrations of dietary Ca. This finding is in an agreement with that of Atteh and Leeson (1984) who found lower fat retention in broilers fed high Ca diets but the effect was dependant on the source of fat. During fat digestion, complete hydrolysis of triglycerides produces both glycerol and free fatty acids which are the absorbable units of fat (Mu and Hoy, 2004). These free fatty acids have a potential to form insoluble salts with minerals, especially with Ca and Mg, rendering both the fatty acids and minerals unavailable to the animal (Atteh and Leeson, 1984). These insoluble soaps once formed will be excreted and it has been shown that the formation and excretion of insoluble soaps are greater with fats containing high levels of saturated fatty acids as compared to those containing high levels of unsaturated fatty acids. Reduced fat retention was observed in both saturated and unsaturated fat, but the effect was more pronounced in the presence of saturated fat (Atteh and Leeson, 1983). Soybean oil, rich in unsaturated fatty acids, was included as the supplemental fat source in the present study. Observed negative effect of high dietary Ca concentration on fat digestion in the present study is suggestive of soap formation between Ca and unsaturated fatty acids. Similarly, Yacowitz et al. (1967) found a positive correlation between lipid excretion and dietary Ca concentration in rats fed maize oil, a source of high proportion of unsaturated fatty acids.

Dietary Ca, at the concentrations used in the present study, had no effect on the apparent digestibility of starch. In general, most of the starch digestion was completed by the end of jejunum, which accounted for 86–87% of total starch digestion. As stated by Weurding et al. (2001), nearly 90% of digested starch in cereal grains was completely digested prior to the ileum and 98% prior to the lower ileum.

Apparent metabolisable energy was unaffected by dietary Ca concentrations. Starch is the major energy source in cereal-based broiler diets and the observed absence of effect on the AME may be explained by the lack of effect of Ca on starch digestion. Suppressive effects of Ca on the AME have been reported to depend on dietary Ca concentration and the
AME was not affected when dietary Ca concentrations were maintained at or below 12 g/kg (Atteh and Leeson, 1983, 1984). Feeding diets with over 12 g/kg of dietary Ca resulted in significant decrease in the AME (Atteh and Leeson, 1984; Shafey and McDonald, 1991a). All diets in the current experiment contained Ca concentrations at or below 12 g/kg and this may explain the present findings.

In conclusion, the present study demonstrated that there was net secretion of P and Ca into the duodenum of broilers and that the digestion of P and Ca was essentially completed by upper ileum and jejunum, respectively. However, the site of digestion of P was found to shift depending on dietary Ca concentrations. Overall, the present data showed that increasing dietary Ca concentrations negatively influenced the digestion of P, N and fat, but had no effect on those of Ca and starch.

References


