Influence of Caecectomy on Digestibility of Amino Acids for Soybean, Canola and Sunflower Meals in Adult Cockerels

Ali Nouri-Emamzadeh¹ and Akbar Yaghobfar²

¹ Department of Animal Science, Faculty of Agriculture, Islamic Azad University, Garmsar Branch, Garmsar, Iran

² Animal Science Research Institute, Karaj-I.R. Iran

The experiment was conducted to determine influence of caecectomy on digestibility quantities of amino acids for soybean (SBM), canola (CM), sunflower (SFM) meals in adult Rhode Island Red (RIR) cockerels with using conventional addition method (CAM) for 7 d: a 4-d adaptation and a 3-d experiment period on the basis of a completely randomized design with 4 replicates. In assayed meals, caecectomy decreased ($P < 0.05$) apparent digestibility quantities of amino acids, except for tyrosine, methionine and leucine for CM and arginine and valine for SFM in adult cockerels. The most decrement of apparent digestibility quantity was for phenylalanine (8.9% decrement) in SBM and for cysteine (14.5% and 22.7% decrement, respectively) in CM and SFM. Differences between intact and caecetomised cockerels were ($P < 0.05$) significant for true digestibility quantities of amino acids, except for threonine in SBM, serine and valine in CM and histidine, arginine, threonine and valine in SFM. The most difference in true digestibility quantity was for phenylalanine (11.8%) in SBM and for cysteine (12.8 and 18%, respectively) in CM and SFM. However, caecectomy decreased mean apparent and true digestibility of total amino acid in SBM (3.8 and 3.1%, respectively), CM (3.1 and 3.0%, respectively) and SFM (5.3 and 5.1%, respectively) which this effect was greater for SFM. Therefore, the caecectomy is an effective method for increasing precision in measurements of the digestibility of amino acids for these meals in bioassays based on excreta collection in adult cockerels.

Key words: amino acid digestibility, caecectomy, canola meal, soybean meal, sunflower meal

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Introduction

Soybean (SBM), canola (CM) and sunflower (SFM) meals are suitable protein sources in the diets of mono-gastric animals, especially poultry. However, the protein and amino acids quality of these protein sources could be depended to varieties, amounts of antinutrient factors, and type of oil extraction process (Lee *et al.*, 1995; Vilamide and sanjuan, 1998). Therefore, more knowledge about nutritive value especially digestibility of amino acids in these vegetable protein sources produced in different countries aids to precision evaluation of the amounts used in poultry diets. Several methods to estimate the digestibility of amino acids have been developed by numerous authors (Payne *et al.*, 1971; Sibbald, 1987; Ravindran and Bryden, 1999; Adeola, 2005). The majority of published digestibility quantities of amino acids for feedstuffs are based on the collection of excreta in intact adult birds or

ileal digesta in chicks (Ravindran and Bryden, 1999; Parsons, 2002). But, bacteria present in the large intestine have an influence on digestibility measurements because they alter the composition and quantities of amino acids in the excreta, but have an insignificant effect on utilization of amino acids by the bird (Payne *et al.*, 1971; Johns *et al.*, 1986; Parsons, 1984). Surgical removal of the caeca, the major proportion of the large intestine, has been suggested to minimize bacterial effects on digestibility quantities of amino acids (Parsons, 1984; Johns *et al.*, 1986) while small and non-significant effects have been reported (Longstaff *et al.*, 1991; Ragland *et al.*, 1999). However, information concerning the effect of caecectomy on digestibility of amino acids for SBM and especially CM and SFM is limited and discrepancy (Green *et al.*, 1987; Angkanaporn *et al.*, 1997; Ragland *et al.*, 1999). Therefore, the objective of this experiment was to determine the influence of caecectomy on digestibility of amino acids for SBM, CM and SFM in adult cockerels.

Materials and Methods

Feedstuffs, Birds, Design and Management

The SBM, CM and SFM were obtained from a local oil seed crushing factory. Thirty two (16 intact and 16

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Correspondence: Dr. A. Nouri-Emamzadeh, Department of Animal Science, Faculty of Agriculture, Islamic Azad University, Garmsar Branch, Postal Code 3581631167, Garmsar, Iran.

(E-mail: ali.nouriem@gmail.com)

caecectomised) adult RIR cockerels (average age, 40 weeks; average weight, 2.9 kg) placed in individual metabolic cages with fixed aluminum trays for separately excreta collection.

Caecectomy was performed when cockerels were 38 weeks of age. Prior to surgery, the cockerels selected to undergo the caecectomy were deprived of feed for 24 h and water for 12 h. Caecectomy procedure was according with it described by Angkanaporn *et al.*, 1997. The caeca were removed from most proximal to the ileal junction. The wound was sutured by a simple interrupted pattern using silk. After the surgery, the birds were kept in a warm ($28 \pm 2^\circ\text{C}$) house with *ad libitum* supply of the water and also, solid food was withheld for 24 h. All birds were examined daily during the entire period of recovery. Their feed intake was comparable to it of intact birds within 10 days. Two weeks after the operation, the cockerels were used for experiment.

The experiment was carried out on the basis of a completely randomized design with 4 replicates; with using conventional addition method (CAM) included a 4-d adaptation period and a 3-d experiment period. In adaptation period, intact and caecectomised cockerels *ad libitum* consumed each of test meals gradually mixed with a commercial basal diet, then after 24 h starvation, each of the test meals were *ad libitum* fed as single ingredient by those cockerels during 2-d of experiment period, and 24 h starvation in end of experiment period. Also during experiment, a group of eight (four intact and four caecectomised) adult cockerels were given no feed as negative controls to measure of the endogenous amino acid losses (EAAL). Feed intake was recorded and total excreta were collected from each bird during experiment period. The average temperature in the experiment house was $24 \pm 2^\circ\text{C}$ with a lighting cycle of 16: 8 h (light: dark). Because of using adult cockerels and short period of the experiment, the cockerels' body weight average was changeless (2.9 kg) in end of experiment. The experiment and caecectomy procedure were according to the guidelines of Veterinary Faculty, Tehran University for the care and use of animals for scientific purposes.

Analytical Methods

The collected excreta were dried, weighed, and ground to pass a 1-mm screen. The samples of the meals and excreta were analyzed for dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) according to AOAC (1990). For amino acid analysis, the samples were hydrolyzed with 6N HCl and then quantities of amino acids determined by high-performance liquid chromatography (HPLC) according to the procedure described by Siriwan (1993). Before acid hydrolysis, cysteine and methionine were oxidized with performic acid.

Calculations

Apparent and true digestibility quantities of amino acids (ADAA and TDAA) were calculated using the following formula:

$$\text{AAAD}(\%) = \frac{\text{AA}_c - \text{AA}_e}{\text{AA}_c} \times 100$$

$$\text{TAAAD}(\%) = \frac{\text{AA}_c - \text{AA}_e + \text{EAAL}}{\text{AA}_c} \times 100$$

AA_c (Amino Acid Consumed) = feedstuff intake $\times$ feedstuff amino acid quantity (%)

AA_e (Amino Acid Excreted) = dry excreta weight $\times$ excreta amino acid quantity (%)

EAAL = Endogenous Amino Acid Losses

Statistical Analysis

Statistical analysis of the data for determining influence caecectomy on apparent and true digestibility of amino acids each of the meals was accomplished using the GLM procedure of SAS software (SAS Institute, 1990) based on completely randomized design with 4 replications. The Duncan's test was used to elucidate differences between treatments means, with 0.05 level considered as significant. Results are reported as means and pooled standard error of mean (SEM).

Results

Chemical and Amino Acid Compositions of the Meals

Chemical and amino acid compositions of SBM, CM and SFM are shown in Table 1.

Caecectomy Influence on the Meals

Table 2 represents influence of caecectomy on apparent and true digestibility quantities of amino acids for SBM in

Table 1. Chemical and amino acid compositions of SBM, CM and SFM

Analysis	SBM	CM	SFM
DM ^a (%)	92	93	95
Crud Protein (%) ^b	44	39	31
NDF (%) ^b	12.6	39.0	47.6
Amino acid (%) ^b			
Aspartic acid	3.15	1.87	1.19
Glutamic acid	9.6	9.93	8.05
Serine	3.47	2.73	1.96
Glycine	2.25	2.6	2.21
Histidine	1.37	1.14	0.93
Arginine	2.17	1.53	1.32
Threonine	3.63	2.8	2.08
Alanine	1.25	1.22	0.64
Tyrosine	1.84	1.25	0.93
Valine	2.27	2.02	1.52
Methionine	0.94	0.97	0.86
Cysteine	0.39	0.31	0.26
Isoleucine	2.02	2.13	0.91
Leucine	4.04	3.54	2.65
Phenylalanine	1.32	1.78	1.93
Lysine	3.4	2.17	1.73
TAA ^c	43.11	37.99	29.17

^a DM = dry matter.

^b Based on 100% dry matter.

^c TAA = total amino acids.

Table 2. Influence of caecectomy on apparent and true digestibility quantities of amino acids for SBM in adult cockerels (based on 100% DM)

Amino acid	Apparent Digestibility			True Digestibility		
	Intact	Caecetomised	SEM ¹	Intact	Caecetomised	SEM ¹
Aspartic acid	89.9 ^a	85.3 ^b	0.11	91.4 ^a	87.2 ^b	0.11
Glutamic acid	88.3 ^a	85.9 ^b	0.30	90.1 ^a	88.2 ^b	0.31
Serine	86.8 ^a	80.5 ^b	0.15	90.4 ^a	86.8 ^b	0.23
Glycine	80.7 ^a	77.5 ^b	0.18	84.3 ^a	81.9 ^b	0.22
Histidine	90.5 ^a	89.6 ^b	0.12	91.7 ^a	90.3 ^b	0.12
Arginine	91.6 ^a	89.7 ^b	0.10	93.7 ^a	92.6 ^b	0.16
Threonine	84.0 ^a	82.1 ^b	0.17	89.1	88.9	0.27
Alanine	85.6 ^a	82.2 ^b	0.15	88.2 ^a	84.8 ^b	0.18
Tyrosine	86.5 ^a	81.0 ^b	0.17	88.8 ^a	83.6 ^b	0.19
Valine	85.2 ^a	79.4 ^b	0.17	88.2 ^a	82.9 ^b	0.20
Methionine	79.8 ^a	75.0 ^b	0.24	82.3 ^a	77.3 ^b	0.31
Cysteine	85.8 ^a	80.2 ^b	0.20	88.9 ^a	86.4 ^b	0.25
Isoleucine	84.7 ^a	81.7 ^b	0.21	85.0 ^a	84.3 ^b	0.21
Leucine	91.3 ^a	90.0 ^b	0.09	93.3 ^a	91.6 ^b	0.12
Phenylalanine	69.6 ^a	60.7 ^b	0.31	85.2 ^a	73.4 ^b	0.63
Lysine	92.0 ^a	90.7 ^b	0.08	93.9 ^a	92.7 ^b	0.12
MTAA ²	85.8 ^a	82.0 ^b	0.14	89.0 ^a	85.9 ^b	0.13

^{a-b} Means within a row with no common (a, b) superscript differ significantly ($P < 0.05$).

¹ SEM = pooled standard error of mean.

² MTAA = mean of total amino acids.

adult cockerels. Results indicated that apparent digestibility quantities of amino acids were less ($P < 0.05$) in caecetomised compare to intact cockerels. The caecectomy decreased apparent digestibility quantity of phenylalanine greater than other amino acids; this effect was 8.9% for phenylalanine. Mean apparent digestibility quantity of total amino acids for SBM in caecetomised (82%) was 3.8% less ($P < 0.05$) than intact (85.8%) cockerels. Differences between intact and caecetomised cockerels were ($P < 0.05$) significant for true digestibility quantities of amino acids, except for threonine. The most difference was ($P < 0.05$) for true digestibility quantity of phenylalanine (11.8%). Mean true digestibility quantity of total amino acids for soybean meal in caecetomised and intact cockerels was 85.9 and 89%, respectively which this significant ($P < 0.05$) difference was 3.1%.

Influence of caecectomy on apparent and true digestibility quantities of amino acids for CM in adult cockerels are summarized in Table 3. The caecectomy decreased ($P < 0.05$) apparent digestibility quantities of amino acids, except for tyrosine, methionine and leucine. The most significant effect was on apparent digestibility quantity of cysteine (14.5% decrement). The caecectomy decreased ($P < 0.05$) mean apparent digestibility quantity of total amino acids of 86.8 to 83.7% (3.1% decrement) for CM. True digestibility quantities of amino acids, except for serine and valine were differ ($P < 0.05$) between intact and caecetomised cockerels. The true digestibility quantity of cysteine had most difference (12.8%) between intact and caecetomised cockerels. Mean true digestibility of total amino acids for CM in caecetomised cockerels (85.6%)

was 3.0% less ($P < 0.05$) than intact cockerels (88.6%).

Table 4 represents influence of caecectomy on apparent and true digestibility quantities of amino acids for SFM in adult cockerels. Results indicated that differences between intact and caecetomised cockerels were ($P < 0.05$) significant for apparent digestibility quantities of amino acids, except for arginine and valine in SFM. The most difference (22.7%) was ($P < 0.05$) for apparent digestibility quantity of cysteine. Mean apparent digestibility quantity of total amino acids for SFM in intact and caecetomised cockerels was 79.8 and 74.5% respectively which this difference (5.3%) was significant ($P < 0.05$). True digestibility quantities of amino acids except for histidine, arginine, threonine and valine in SFM were less ($P < 0.05$) in caecetomised than intact cockerels. The caecectomy decreased true digestibility quantity of cysteine greater than other amino acids; this decrement was 18% for true digestibility of cysteine. Difference (5.1%) between intact and caecetomised cockerels was ($P < 0.05$) significant for mean true digestibility quantity of total amino acids in SFM (87.2 and 82.1%, respectively).

Influence of caecectomy on intakes of SBM, CM and SFM in adult cockerels was represented in Table 5. Caecectomy hadn't ($P > 0.05$) significantly effect on intake of the meals in adult cockerels.

Discussion

Chemical and Amino Acid Compositions of the Meals

The Dry matter, crude protein and NDF contents of SBM, CM and SFM used in this study approximately were according to those listed by NRC (1994). Amino acids

Table 3. Influence of caecectomy on apparent and true digestibility quantities of amino acids for CM in adult cockerels (based on 100% DM) Amino acid

Amino acid	Apparent Digestibility			True Digestibility		
	Intact	Caecectomised	SEM ¹	Intact	Caecectomised	SEM ¹
Aspartic acid	88.3 ^a	84.4 ^b	0.11	90.0 ^a	86.5 ^b	0.11
Glutamic acid	91.7 ^a	89.4 ^b	0.08	92.8 ^a	90.9 ^b	0.08
Serine	84.3 ^a	81.6 ^b	0.14	87.0	87.0	0.18
Glycine	84.4 ^a	83.0 ^b	0.13	86.0 ^a	85.0 ^b	0.13
Histidine	95.7 ^a	90.1 ^b	0.06	95.7 ^a	90.2 ^b	0.06
Arginine	87.0 ^a	85.3 ^b	0.10	89.1 ^a	87.1 ^b	0.11
Threonine	89.2 ^a	87.0 ^b	0.01	89.2 ^a	87.0 ^b	0.10
Alanine	85.2 ^a	80.9 ^b	0.14	86.7 ^a	82.4 ^b	0.14
Tyrosine	86.2	86.0	0.11	88.4 ^a	87.9 ^b	0.12
Valine	84.0 ^a	83.0 ^b	0.13	85.4	85.1	0.13
Methionine	90.5	90.4	0.08	92.2 ^a	91.7 ^b	0.08
Cysteine	84.6 ^a	70.1 ^b	0.23	85.5 ^a	72.7 ^b	0.22
Isoleucine	86.6 ^a	84.8 ^b	0.12	88.3 ^a	85.0 ^b	0.11
Leucine	93.1	93.2	0.05	94.5 ^a	94.2 ^b	0.06
Phenylalanine	72.2 ^a	64.7 ^b	0.31	78.6 ^a	68.8 ^b	0.33
Lysine	86.9 ^a	85.3 ^b	0.10	88.7 ^a	87.2 ^b	0.11
MTAA ²	86.8 ^a	83.7 ^b	0.15	88.6 ^a	85.6 ^b	0.14

^{a-b} Means within a row with no common (a, b) superscript differ significantly ($P < 0.05$).

¹ SEM = pooled standard error of mean.

² MTAA = mean of total amino acids.

Table 4. Influence of caecectomy on apparent and true digestibility quantities of amino acids for SFM in adult cockerels (based on percentage DM)

Amino acid	Apparent Digestibility			True Digestibility		
	Intact	Caecectomised	SEM ¹	Intact	Caecectomised	SEM ¹
Aspartic acid	83.1 ^a	79.7 ^b	0.29	88.8 ^a	84.3 ^b	0.47
Glutamic acid	86.9 ^a	84.5 ^b	0.24	90.6 ^a	88.0 ^b	0.34
Serine	71.6 ^a	65.3 ^b	0.54	84.1 ^a	80.0 ^b	0.66
Glycine	66.3 ^a	57.1 ^b	0.68	73.8 ^a	63.7 ^b	0.84
Histidine	84.9 ^a	83.7 ^b	0.30	86.8	86.3	0.32
Arginine	75.3	75.0	0.43	80.8	80.7	0.58
Threonine	84.3 ^a	79.6 ^b	0.31	93.1	91.1	0.75
Alanine	76.6 ^a	70.7 ^b	0.48	85.7 ^a	77.6 ^b	0.80
Tyrosine	86.6 ^a	80.4 ^b	0.24	93.7 ^a	87.9 ^b	0.53
Valine	76.4	76.0	0.39	84.4	83.6	0.73
Methionine	87.3 ^a	84.7 ^b	0.22	92.5 ^a	88.4 ^b	0.45
Cysteine	86.9 ^a	64.2 ^b	0.47	94.5 ^a	76.5 ^b	0.89
Isoleucine	69.3 ^a	66.2 ^b	0.52	74.6 ^a	70.4 ^b	0.63
Leucine	83.1 ^a	80.9 ^b	0.31	89.7 ^a	85.2 ^b	0.58
Phenylalanine	75.2 ^a	72.7 ^b	0.41	92.2 ^a	88.9 ^b	1.20
Lysine	82.9 ^a	72.2 ^b	0.59	90.9 ^a	82.1 ^b	0.92
MTAA ²	79.8 ^a	74.5 ^b	0.22	87.2 ^a	82.1 ^b	0.23

^{a-b} Means within a row with no common (a, b) superscript differ significantly ($P < 0.05$).

¹ SEM = pooled standard error of mean.

² MTAA = mean of total amino acids.

quantities of the meals approximately were greater compare to those reported in NRC (1994), but quantities of some amino acids in SBM, CM and SFM were consistent with those reported by Adeola O. (2005), Lee *et al.* (1995) and Villamide and Sanjuan (1998), respectively. However, factors such as variety type and conditions of culture

and processing of oil seeds could affect compositions of the meals used in different studies.

Caecectomy Influence on the Meals

The results of present study which the caecectomy decreased digestibility quantities of amino acids for SBM, CM and SBM in adult cockerels support the opinion of

Table 5. Influence of caecectomy on intake of SBM, CM and SFM in adult cockerels (g/2-d of experiment period)

Oil Seed Meal	Feed Intake				
	Intact	Caecetomised	SEM ¹	Mean	SEM
SBM	181.47	175.26	6.68	178.37	4.68
CM	169.8	160.54	6.91	165.17	4.87
SFM	152.25	144.1	7.96	148.17	5.53

^{a-b} Means within a row with no common (a, b) superscript differ significantly ($P < 0.05$).

¹ SEM: pooled standard error of mean.

significant microbial metabolism of undigested amino acids in the hindgut of intact birds (Parsons, 1984; Johns *et al.*, 1986). Microbial activity in the caeca comprises both degradation of nitrogenous substrates and synthesis of microbial proteins; therefore the removal of the caeca results in increasing excretion of unabsorbed amino acids of dietary (Parsons, 1984) and endogenous origin (Green *et al.*, 1987). Also, the results that the caecectomy caused intensive decrement in apparent and true digestibility of some amino acids especially phenylalanine for SBM and cysteine for CM and SFM could be related to less digestibility of the amino acids previous to caeca (Angkanaporn *et al.*, 1997). Therefore, when excess amounts of amino acids are left undigested from small gut, it appears to be utilized by the caecal microorganisms. Also, more decrease of mean apparent and true digestibility of total amino acids in SFM (5.3 and 5.1%, respectively) than those in SBM (3.8 and 3.1%, respectively) and CM (3.1 and 3%) could be due to greater NDF content and less protein quality in SFM than those in SBM and CM. High NDF quantity in SFM presents a high degree of lignification of cell wall which could decrease bioavailability of amino acids for enzymatic digestion prior to caeca (Villamide and Sanjuan, 1998) and increase microbial degradation of these undigested amino acids in caeca.

The correction for endogenous amino acid losses resulted in true digestibility quantities which were higher than the corresponding apparent digestibility quantities and didn't decrease significantly the differences of digestibility quantities of most amino acids between intact and caecetomised cockerels. In cockerels fed on SBM, adjustment of apparent to true digestibility eliminated only the effect of caecectomy on (true) digestibility quantity of threonine that could be due to greater excretion of endogenous threonine in caecetomised than intact cockerels. Also, insignificant difference between caecetomised and intact cockerels for true digestibility quantities of serine and valine in CM and for those of histidine and threonine in SFM could reflect greater endogenous excretion of these amino acids in caecetomised than intact cockerels. Also, in cockerels fed on CM, adjustment of apparent to true digestibility caused the significant effect of caecectomy on (true) digestibility quantity of tyrosine, methionine and leucine which was due to greater excretion of endogenous those in intact cockerels. However, the great-

er effects of endogenous amino acid losses on apparent digestibility quantities of amino acids for SFM and CM could be attributed to approximately fewer intakes of the meals (Table 5) due to their higher hull and NDF content.

The results of present study are according to those presented by Johns *et al.* (1986) and Parsons (1986) that digestibility quantities of amino acids for protein sources could be decreased by caecectomy in adult cockerels. Parsons (1986) showed that this decrement was approximately 10% for true digestibility quantities of amino acids for meat meal. Ankanaporn *et al.* (1997) reported that caecectomy had no effect on the apparent digestibility of amino acids for SBM, except for histidine, lysine and arginine. A study on SBM and SFM indicated significant differences for apparent digestibility of some amino acids between intact and caecetomised cockerels (Green *et al.*, 1987).

In present study, mean true digestibility quantity of total amino acids for SBM in caecetomised cockerels (85.9%) was approximately less than it (92.0%) represented by Angkanaporn *et al.* (1997). However, true lysine digestibility quantity (92.7%) of SBM in caecetomised cockerels was consistent with it (92.8%, respectively) determined by Angkanaporn *et al.* (1997). There is a lack of published data about the digestibility of amino acids for CM and SFM measured by caecetomised birds. Green *et al.* (1987) indicated that true digestibility quantity of lysine for SFM was 83.4% in caecetomised cockerels. However, factors such as used bird type and age, experimental procedure, processing conditions of meals and feeding method probably could be responsible for the reported variations within the caecectomy effect on digestibility quantities of amino acids for a feedstuff.

In conclusion, the caecectomy decrease the microbial activities on digestibility of amino acids for SBM, CM and especially SFM in hindgut. Therefore, the caecectomy is an effective method for increasing precision in measurements of the digestibility of amino acids for these meals in bioassays based on excreta collection in adult cockerels.

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References

- Adeola O. Metabolisable energy and amino acid digestibility of high-oil maize, low-phytate maize and low-phytate soybean meal for white Pekin ducks. *British Poultry Science*, 46: 607–614. 2005.
- Angkanaporn K, Ravindran V and Bryden WL. Influence of caecectomy and dietary protein concentration on apparent excreta amino acid digestibility in adult cockerels. *British Poultry Science*, 38: 270–276. 1997.
- Association of Official Analytical Chemists. *Official Methods of Analysis*, 15th Edition. Arlington, VA, AOAC. 1990.
- Green S, Bertrand L, Duron JC and Maillard R. Digestibilities of amino acids in soybean, sunflower and groundnut meals, determined with caecectomised cockerels. *British Poultry Science*, 28: 643–652. 1987.
- Johns DC, Low CK, Sedcole JR and James KAC. Determination of amino acid digestibility using caecectomised and intact adult cockerels. *British Poultry Science*, 27: 451–461. 1986.
- Lee KH, Guang-Hai QI and Sim JS. Metabolizable energy and amino acid availability of full-fat seeds, meals, and oils of flax and canola. *Poultry Science*, 74: 1341–1348. 1995.
- Longstaff M, McBain B and McNab JM. The antinutritive effect of proanthocyanidin-rich and proanthocya-free hulls from field beans on digestion of nutrients and metabolisable energy in intact and caecectomised cockerels. *Animal Feed Science Technology*, 34: 147–161. 1991.
- National Research Council. *Nutrient Requirements of Domestic Animals. Nutrient Requirements of Poultry*, 9th revised edition. National Academy of press, Washington, D.C. 1994.
- Parsons CM. Determination of digestible and available amino acids in meat meal using conventional and caecectomized cockerels or chick growth assays. *British Journal of Nutrition*, 56: 227–240. 1986.
- Parsons CM. Digestibility and bioavailability of protein and amino acids. In *Poultry Feedstuffs: Supply, Composition and Nutritive Value*. (McNab. J. ed). CABI Publishing. Wallingford. Oxon. UK. 2002.
- Parsons CM. Influence of caecectomy and source of dietary fiber or starch on excretion of endogenous amino acids by laying hens. *British Journal of Nutrition*, 51: 541–548. 1984.
- Payne WL, Kifer RR, Snider DG and Combs GF. Studies of protein digestion in chicken. 1. Investigation of apparent digestibility fish meal protein using caecectomised adult male chicken. *Poultry Science*, 50: 143–150. 1971.
- Ragland D, Thomas CR, Elkin RG, Shafer DJ and Adeola O. The influence of cecectomy on metabolizable energy and amino acid digestibility of feedstuffs for white Pekin ducks. *British Poultry Science*, 78: 707–713. 1999.
- Ravindran V and Bryden WL. Amino acid availability in poultry: *In vitro* and *in vivo* measurements. *Australian Journal of Agricultural Research*, 50: 889–908. 1999.
- SAS Institute. *SAS Stat User's Guide Release 6.08*. SAS Institute Inc., Cary. NC. 1990.
- Sibbald IR. Estimation of bioavailable amino acids in feedstuffs for poultry and pigs: A review with emphasis on balance experiments. *Canadian Journal of Animal Science*, 67: 221–300. 1987.
- Siriwan P, Bryden WL, Mollah Y and Annison EF. Measurement of endogenous amino acid losses in poultry. *British Poultry Science*, 34: 939–949. 1993.
- Vilamide MJ and Sanjuan LD. Effect of chemical composition of sunflower seed meal on its true metabolizable energy and amino acid digestibility. *Poultry Science*, 77: 1884–1892. 1998.