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# Digestibility of Amino Acids of Maize, Low Tannin Sorghum, Pearl Millet and Finger Millet in Caecectomized Roosters

**P. Vasan*, A. B. Mandal[1], Narayan Dutta, S. K. Maiti and K. Sharma**
Division of Animal Nutrition, Indian Veterinary Research Institute, Izatnagar, U.P, India

**ABSTRACT :** The aim of the present study was to determine the apparent and true digestibilities of amino acids of maize, low tannin sorghum, pearl millet and finger millet in adult caecectomized cockerels. Adult cockerels (n = 60), 25-weeks old, were used in this study of which 30 birds were caecectomized as per a standard method. The apparent digestibilities of amino acids of sorghum were not affected by caecectomy, but were higher for maize, finger millet and pearl millet in caecectomized cockerels. Caecectomy had no influence on the true digestibilities of amino acids of maize, but higher digestibilities were observed for most of the amino acids of sorghum and finger millet in caecectomized cockerels. Caecectomy lowered the true digestibility of cystine, threonine and serine of pearl millet. The apparent digestibilities of amino acids of maize, finger millet and pearl millet were underestimated in intact cockerels. The true digestibilities of most of the amino acids of sorghum and finger millet were underestimated, while those of cystine, threonine and serine of pearl millet were overestimated in intact cockerels. The findings suggest that the amino acid digestibility values of cereal grains determined using caecectomized cockerels might be appropriate and reliable for poultry diet formulations. Moreover, the digestibilities of amino acids of finger millet were inferior to other cereal grains, while those of pearl millet were comparable to maize and sorghum. (**Key Words :** Amino Acid, Digestibility, Caecectomized Cockerels, Cereal Grains)

## INTRODUCTION

The dietary protein comprises a major element of the cost of poultry feed. It is universally accepted that the contribution of dietary protein to the animal depends not only on its amino acid composition but also on how effectively the amino acids are utilized (McNab, 1973). Corn is the most common cereal grain used in many parts of the world. It has a high amino acid digestibility coefficient. However, economic reasons have compelled the poultry industry to switch over to an array of alternative cereal grains such as sorghum, pearl millet and finger millet in many countries. Knowledge on the digestibilities of nitrogen and amino acids in cereal proteins aids in improving the utilization of dietary protein and to minimize nitrogen output through excreta (Lemme et al., 2004), thereby enhancing the performance of birds, reducing stress to birds and environmental pollution.

It is well understood that the microbial fauna inhabiting the large intestine interfere with amino acid digestibility determinations. Austic (1983) suggested that surgical removal of the caecum, the major site of gut microflora activity, might minimize the influence of microbial effects. A large volume of published data on the amino acid digestibility of corn and sorghum for poultry is available (Green et al., 1987; Ravindran et al., 1996a and 1996b), but there are no reports for millet grains. Hence, the present study was designed to determine the digestibility of amino acids of pearl millet and finger millet, in addition to the native variety of maize and low tannin sorghum, using caecectomized cockerels.

## MATERIALS AND METHODS

### Experimental procedure

Adult single comb white leghorn cockerels (n = 60), 25 weeks of age and weighing between 1.60 and 1.75 kg, were selected from a flock of same hatch for use in the present study. About 30 cockerels were caecectomized using the methodology described by Green et al. (1987) with slight modifications.

The caecectomized cockerels (30 in total) and the intact birds (total 30) were divided into five replicates of six birds

* Corresponding Author: P. Vasan. Institute of Animal Nutrition, Livestock Research Station, TANUVAS, India. Tel: +91-44-27451525, Fax: +91-44-27453909,E-mail: drpvasan@yahoo.com
[1] Central Avian Research Institute, Izatnagar, U.P, India.
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**Table 1.** Amino acid composition of cereal grains (g/100 g)

| Attributes | Maize | Finger millet | Pearl millet | Sorghum |
|---|---|---|---|---|
| Crude protein | 9.46 | 8.80 | 10.95 | 11.02 |
| Methionine | 0.24 | 0.28 | 0.24 | 0.16 |
| Cystine | 0.23 | 0.19 | 0.22 | 0.15 |
| Lysine | 0.31 | 0.24 | 0.28 | 0.24 |
| Threonine | 0.41 | 0.39 | 0.38 | 0.30 |
| Arginine | 0.50 | 0.38 | 0.43 | 0.36 |
| Isoleucine | 0.40 | 0.39 | 0.41 | 0.34 |
| Leucine | 1.50 | 0.93 | 0.98 | 1.05 |
| Valine | 0.52 | 0.57 | 0.55 | 0.44 |
| Histidine | 0.31 | 0.23 | 0.25 | 0.19 |
| Phenylalanine | 0.61 | 0.49 | 0.48 | 0.42 |
| Glycine | 0.40 | 0.33 | 0.35 | 0.32 |
| Serine | 0.57 | 0.48 | 0.44 | 0.38 |
| Proline | 0.91 | 0.66 | 0.67 | 0.67 |
| Alanine | 0.89 | 0.58 | 0.75 | 0.72 |
| Aspartic acid | 0.74 | 0.57 | 0.76 | 0.63 |

each. All the birds were starved for 48 h. Each replicate of operated birds and intact birds was fed with one test cereal grain. Maize, sorghum and pearl millet were fed according to Farrell's (1978) rapid ME method. Finger millet (50 g) was force fed by Sibbald's (1976) crop intubation method. Drinking water was provided *ad libitum*. The last group of birds of both treatments were force fed with 50 g of nitrogen-free diet, which was previously cold pelleted. The composition (g/kg) of the protein-free diet was starch 400.00, cellulose 76.00, glucose 487.15, and vitamin and mineral mixture 36.85. The vitamin and mineral mixture contained calcium phosphate, 7 g; calcium carbonate 8 g; dicalcium phosphate 15 g; iodized salt 4 g; trace mineral mixture 0.5 g; vitamin premix 0.2 g; B complex 0.15 g; and choline chloride (50%) 2.0 g. The vitamin premix contained (per g) vitamin A 82,500 IU; B2 50 mg; D3 62,000 IU and K 10 mg. The trace mineral premix contained (per 100 g) $FeSO_4$ 8 g; $ZnSO_4$ 10 g; $MnSO_4$ 10 g; $CuSO_4$ 1 g; KI 30 mg and starch 70.97 g.

The total excreta were collected for the following 48 h at 8 h intervals (three times daily). The excreta of each bird were oven dried individually at 80°C for 24 h, finely ground and stored separately in a sealed airtight polythene bag at -24°C (deep freezer) until further analysis. The dry matter and nitrogen were estimated by the AOAC (1995) methods.

**Amino acid analysis**

The amino acid concentrations of test ingredients and excreta samples were analyzed by ion-exchange chromatography (Llames and Fontaine, 1994) following hydrolysis of samples in 6N HCl under N for 24 h at 110°C. Methionine and cystine were analyzed after performic acid oxidation (Moore, 1963). Apparent amino acid digestibility values were calculated using the following equation:

Apparent amino acid digestibility (%)

$$= \frac{(AAI_f - AAE_f)}{AAI_f} \times 100$$

Where, $AAI_f$ is the amount of each amino acid consumed by the fed cockerel and $AAE_f$ is the amount of each amino acid excreted by the fed cockerel during the 48 h period post-feeding.

True amino acid digestibility (%)

$$= \frac{AAI_f - (AAE_f - EAAE_{pf})}{AAI_f} \times 100$$

Where, $AAI_f$ is the amount of each amino acid consumed by the fed rooster, $AAE_f$ is the amount of each amino acid excreted by the fed rooster and $EAAE_{pf}$ is the endogenous amino acid excreted by the rooster fed the protein-free diet.

All the experiments were approved by the Animal Ethics Committee of the University and Indian Council of Agricultural Research. The data obtained from the above experiments were subjected to statistical analysis (independent 't' test, and ANOVA) by standard procedures (Snedecor and Cochran, 1980).

## RESULTS

The amino acid concentrations of cereal grains are presented in Table 1. The amino acid contents of the different cereal grains studied were similar.

The apparent amino acid digestibilities of maize and low tannin sorghum (white variety) estimated in caecectomized and intact cockerels are presented in Table 2. The apparent digestibilities of methionine, lysine, isoleucine, leucine, valine, phenylalanine, proline, alanine, aspartic and glutamic acids in maize were significantly higher ($p<0.05$ to 0.001) in caecectomized cockerels than in the intact birds. The apparent digestibility of methionine in white sorghum was markedly higher ($p<0.05$) in caecectomized cockerels as compared to intact birds (85.22 vs. 75.46%). The apparent digestibilities of amino acids in finger millet are summarized in Table 3. Almost all the amino acids of finger millet (except threonine) were more ($p<0.001$) digestible in caecectomized birds than in intact ones. In comparison to maize, the apparent digestibilities of most of the essential amino acids of finger millet determined with caecectomized cockerels (except methionine, valine and phenylalanine) were markedly lower by about 7-15 per cent. On the contrary, the digestibilities were similar to sorghum. Significant differences ($p<0.05$ to 0.01) in the apparent amino acid digestibilities of methionine, lysine, arginine, isoleucine, leucine, valine, histidine, alanine and glutamic acid were evident for pearl

**Table 2.** Apparent amino acid digestibility (%) of maize and sorghum in caecectomized and intact cockerels

| Attributes | Maize | | | Sorghum | | |
|---|---|---|---|---|---|---|
| | Caecectomized | Intact | Pooled SEM | Caecectomized | Intact | Pooled SEM |
| Methionine | 91.92[a] | 88.20[b] | 0.69*** | 85.22[a] | 75.46[b] | 1.44* |
| Cystine | 83.68 | 81.83 | 0.76 | 64.19 | 62.44 | 1.42 |
| Lysine | 81.14[a] | 70.63[b] | 1.85*** | 67.16 | 62.63 | 1.75 |
| Threonine | 78.24 | 76.14 | 0.99 | 67.96 | 60.35 | 1.62 |
| Arginine | 88.72 | 86.48 | 0.61 | 79.52 | 71.18 | 1.90 |
| Isoleucine | 88.44[a] | 83.95[b] | 0.87** | 81.61 | 74.68 | 1.56 |
| Leucine | 94.66[a] | 93.12[b] | 0.34* | 89.88 | 86.44 | 0.38 |
| Valine | 87.23[a] | 83.84[b] | 0.78* | 79.66 | 74.50 | 1.67 |
| Histidine | 87.91 | 86.54 | 0.56 | 74.64 | 68.09 | 1.34 |
| Phenylalanine | 92.02[a] | 90.21[b] | 0.45* | 84.62 | 79.96 | 1.07 |
| Serine | 86.16 | 85.46 | 0.60 | 70.74 | 68.76 | 0.62 |
| Proline | 90.53[a] | 88.23[b] | 0.55* | 81.59 | 79.46 | 0.31 |
| Alanine | 90.79[a] | 88.14[b] | 0.58* | 84.95 | 81.05 | 0.99 |
| Aspartic acid | 84.33[a] | 80.68[b] | 0.90* | 74.92 | 68.76 | 1.28 |
| Glutamic acid | 93.30[a] | 91.53[b] | 0.41* | 87.22 | 83.48 | 0.71 |

The values are means of six cockerels.
[a, b] Means in a row bearing different superscripts are significantly different (p<0.05).
* p<0.05; ** p<0.01; *** p<0.001.

**Table 3.** Apparent amino acid digestibility (%) of finger millet and pearl millet in caecectomized and intact cockerels

| Attributes | Finger millet | | | Pearl millet | | |
|---|---|---|---|---|---|---|
| | Caecectomized | Intact | Pooled SEM | Caecectomized | Intact | Pooled SEM |
| Methionine | 88.18[a] | 78.87[b] | 1.56* | 92.57[a] | 88.76[b] | 0.73** |
| Cystine | 71.37[a] | 60.45[b] | 2.06** | 82.08 | 79.94 | 0.94 |
| Lysine | 65.23[a] | 41.69[b] | 4.01*** | 80.70[a] | 71.69[b] | 1.79** |
| Threonine | 68.81 | 63.99 | 1.37 | 76.78 | 76.90 | 1.05 |
| Arginine | 75.77[a] | 59.98[b] | 2.70*** | 87.30[a] | 81.85[b] | 1.11** |
| Isoleucine | 81.59[a] | 68.93[b] | 2.11*** | 89.36[a] | 85.38[b] | 0.85* |
| Leucine | 86.64[a] | 78.33[b] | 1.43*** | 91.92[a] | 89.24[b] | 0.60* |
| Valine | 81.92[a] | 72.15[b] | 1.72*** | 88.18[a] | 84.88[b] | 0.81* |
| Histidine | 74.79[a] | 60.38[b] | 2.51*** | 86.46[a] | 81.03[b] | 1.13** |
| Phenylalanine | 85.04[a] | 75.43[b] | 1.65*** | 89.86 | 87.47 | 0.64 |
| Serine | 77.24[a] | 69.70[b] | 1.48** | 82.90 | 81.39 | 0.85 |
| Proline | 80.52[a] | 71.44[b] | 1.64*** | 86.77 | 85.54 | 0.66 |
| Alanine | 76.14[a] | 68.93[b] | 1.46** | 89.68[a] | 86.53[b] | 0.74* |
| Aspartic acid | 69.75[a] | 56.30[b] | 2.45*** | 85.18 | 82.12 | 0.89 |
| Glutamic acid | 87.11[a] | 79.72[b] | 1.29*** | 92.16[a] | 90.08[b] | 0.52* |

The values are means of six cockerels.
[a, b] Means in a row bearing different superscripts are significantly different (p<0.05).
* p<0.05; ** p<0.01; *** p<0.001.

millet in caecectomized cockerels. The apparent digestibilities of almost all the essential amino acids of pearl millet determined using caecectomized cockerels were similar to maize, but higher than sorghum and finger millet.

The amino acids of metabolic origin excreted by cockerels fed the protein-free diet are presented in Table 4. The endogenous output of almost all the amino acids, with the exception of basic amino acids (His, Arg and Lys), was significantly higher (p<0.01) in caecectomized cockerels.

The true digestibilities of amino acids in maize and sorghum (low tannin) determined using caecectomized and intact cockerels are listed in Table 5. Lysine and histidine of maize showed a significant difference (p<0.05) in true digestibility. The true digestibility of lysine was significantly higher in caecectomized cockerels (88.90 vs. 83.30%), while that of histidine showed a higher digestibility in intact cockerels (96.26 vs. 93.08%). The true digestibilities of most of the amino acids in sorghum were higher (p<0.05 to 0.001) in caecectomized cockerels. Similarly, the true digestibilities of methionine, lysine, arginine, isoleucine, leucine, valine, phenylalanine, proline and glutamic acid in finger millet (Table 6) were higher (p<0.05 to 0.01) in caecectomized cockerels as compared to intact birds. The true digestibilities of basic amino acids (His, Arg and Lys) and non-essential amino acids viz., alanine and aspartate of finger millet determined using caecectomized cockerels were markedly lower when compared to that of maize, low tannin sorghum and pearl

**Table 4.** Endogenous amino acid excretion (mg/bird/d) in caecectomized and intact cockerels fed protein free diet

| Attributes | Caecectomized | Intact | Pooled SEM |
|---|---|---|---|
| Methionine | 5.62[a] | 5.08[b] | 0.13** |
| Cystine | 13.39[a] | 10.90[b] | 0.32*** |
| Lysine | 16.14 | 15.01 | 0.40 |
| Threonine | 29.94[a] | 18.22[b] | 1.16*** |
| Arginine | 17.86 | 17.59 | 0.35 |
| Isoleucine | 14.52[a] | 12.30[b] | 0.34*** |
| Leucine | 25.42[a] | 20.89[b] | 0.61*** |
| Valine | 22.23[a] | 17.37[b] | 0.59*** |
| Histidine | 11.53 | 12.04 | 0.43 |
| Phenylalanine | 16.76[a] | 12.93[b] | 0.46*** |
| Serine | 27.62[a] | 19.92[b] | 0.83*** |
| Proline | 28.29[a] | 21.03[b] | 0.76*** |
| Alanine | 23.68[a] | 19.12[b] | 0.62*** |
| Aspartic acid | 36.84[a] | 28.53[b] | 1.04*** |
| Glutamic acid | 47.51[a] | 39.89[b] | 1.17*** |

The values are means of six cockerels.

[a, b] Means in a row bearing different superscripts are significantly different ($p<0.01$).

** $p<0.01$; *** $p<0.001$.

millet. The true digestibility of cystine, threonine and serine were significantly ($p<0.05$ to 0.01) higher for pearl millet in intact cockerels than in their caecectomized counterparts. The true digestibilities of all the 15 amino acids of pearl millet determined with caecectomized cockerels were comparable to those of maize and sorghum.

## DISCUSSION

The amino acid levels in maize were higher than reported values (Fernandez et al., 1995; Huang et al., 2006). These differences were due to the lower crude protein contents of corn analyzed by earlier workers. The amino acid composition of sorghum observed in this study was comparable to the values reported by NRC (1994) and Mandal et al. (2004). However, the levels of indispensable amino acids (except methionine) in pearl millet were lower than the values reported by NRC (1994) and Mandal et al. (2004).

The apparent digestibilities of most of the amino acids of maize were significantly higher in caecectomized cockerels and the digestibility was remarkably higher than the apparent digestibility values reported by Green et al. (1987) in maize. The lower values obtained in their study might be attributed to the relatively lower intake of amino acids (50 g maize) as compared to the higher intake in the present study (>80 g maize). Similar relationships between intake and digestibility of amino acids were reported earlier (Payne et al., 1971; Sibbald, 1979). In contrast, caecectomy had no influence on the apparent digestibilities of most of the amino acids (except methionine) in sorghum. These observations suggested that the caecal microorganisms of intact birds had only a marginal influence on the amino acid excretion. It may be attributed to the higher solubility of dietary protein that results in minimum quantity of dietary (undigested) amino acids reaching the hindgut.

The apparent digestibilities of most of the amino acids of finger millet and pearl millet were higher in caecectomized cockerels. Moreover, the amino acids of finger millet were less digestible than those in the other three cereal grains. This difference in digestibility might be due to higher fibre content (5.90%) as compared to other cereals (2 to 3%). The higher fibre might lead to higher amounts of undigested dietary protein reaching the hindgut for further degradation by caecal microflora. The profound influence of hind gut microorganisms on the apparent digestibilities of amino acids in millet grains revealed that caecectomized birds were to be preferred for such studies

**Table 5.** True amino acid digestibility (%) of maize and sorghum in caecectomized and intact cockerels

| Attributes | Maize | | | Sorghum | | |
|---|---|---|---|---|---|---|
| | Caecectomized | Intact | Pooled SEM | Caecectomized | Intact | Pooled SEM |
| Methionine | 95.24 | 94.17 | 0.46 | 97.67[a] | 92.83[b] | 0.81*** |
| Cystine | 91.97 | 94.37 | 0.87 | 96.04 | 96.87 | 0.60 |
| Lysine | 88.90[a] | 83.30[b] | 1.33* | 92.06[a] | 84.23[b] | 1.38*** |
| Threonine | 89.40 | 89.13 | 1.04 | 96.78 | 95.23 | 0.67 |
| Arginine | 94.08 | 94.52 | 0.56 | 97.91[a] | 92.60[b] | 0.95*** |
| Isoleucine | 93.92 | 92.10 | 0.66 | 97.59[a] | 93.11[b] | 0.79*** |
| Leucine | 97.24 | 96.75 | 0.28 | 97.12[a] | 96.53[b] | 0.41*** |
| Valine | 93.68 | 92.77 | 0.66 | 93.66[a] | 94.91[b] | 0.69* |
| Histidine | 93.08[b] | 96.26[a] | 0.75* | 95.15 | 96.01 | 0.46 |
| Phenylalanine | 96.23 | 95.91 | 0.40 | 96.94 | 96.10 | 0.46 |
| Serine | 93.32 | 95.04 | 0.71 | 95.82 | 96.91 | 0.50 |
| Proline | 95.12 | 93.65 | 0.52 | 97.10[a] | 93.71[b] | 0.61*** |
| Alanine | 94.60 | 93.84 | 0.47 | 96.71[a] | 94.75[b] | 0.44* |
| Aspartic acid | 91.99 | 91.74 | 0.78 | 94.51[a] | 94.10[b] | 0.80** |
| Glutamic acid | 96.61 | 96.55 | 0.34 | 96.67[a] | 97.00[b] | 0.41* |

The values are means of six cockerels.

[a, b] Means in a row bearing different superscripts are significantly different ($p<0.05$).

* $p<0.05$; ** $p<0.01$; *** $p<0.001$.

**Table 6.** True amino acid digestibility (%) of finger millet and pearl millet in caecectomized and intact cockerels

| Attributes | Finger millet | | | Pearl millet | | |
|---|---|---|---|---|---|---|
| | Caecectomized | Intact | Pooled SEM | Caecectomized | Intact | Pooled SEM |
| Methionine | 92.59[a] | 87.96[b] | 0.91** | 95.37 | 95.31 | 0.37 |
| Cystine | 86.76 | 87.20 | 1.14 | 89.44[b] | 94.41[a] | 1.04** |
| Lysine | 80.98[a] | 71.21[b] | 2.18* | 87.77 | 86.68 | 0.96 |
| Threonine | 87.45 | 88.90 | 1.17 | 87.05[b] | 92.42[a] | 1.19* |
| Arginine | 87.04[a] | 79.40[b] | 1.61* | 92.54 | 92.04 | 0.61 |
| Isoleucine | 90.51[a] | 84.12[b] | 1.30** | 93.86 | 94.06 | 0.49 |
| Leucine | 93.20[a] | 88.92[b] | 0.89* | 95.26 | 95.34 | 0.37 |
| Valine | 91.29[a] | 87.03[b] | 1.02* | 93.39 | 94.25 | 0.53 |
| Histidine | 85.81 | 84.15 | 1.11 | 91.81 | 94.09 | 0.72 |
| Phenylalanine | 93.37[a] | 88.41[b] | 1.02** | 94.42 | 95.50 | 0.46 |
| Serine | 90.68 | 90.37 | 0.89 | 90.64[b] | 94.84[a] | 0.93* |
| Proline | 90.49[a] | 84.98[b] | 1.18* | 92.02 | 93.59 | 0.58 |
| Alanine | 85.32 | 84.73 | 0.93 | 93.47 | 93.91 | 0.47 |
| Aspartic acid | 85.46 | 82.34 | 1.33 | 91.44 | 93.87 | 0.72 |
| Glutamic acid | 92.89[a] | 89.81[b] | 0.73* | 95.50 | 96.68 | 0.38 |

The values are means of six cockerels.

[a, b] Means in a row bearing different superscripts are significantly different (p<0.05).

* p<0.05; ** p<0.01.

involving poorly digestible protein sources. The apparent digestibilities of amino acids of pearl millet were similar to those of maize and better than for sorghum and finger millet.

In the present study caecectomy had a marked effect on the endogenous output of amino acids. The higher amounts of endogenous losses by caecectomized cockerels reflected that the greater bacterial activity in intact birds might have contributed markedly to lessen the endogenous amino acid output. Similar observations were also reported by Kessler et al. (1981) and Parsons (1984) in caecectomized birds after fasting. In contrast, only threonine output was significantly higher in caecectomized birds (Green et al., 1987), while the excretion of other amino acids differed numerically rather than statistically between caecectomized and intact birds.

The true digestibilities of most of the amino acids of maize, sorghum and finger millet were higher in caecectomized cockerels. As a consequence the intact birds tended to underestimate the true digestibility values. On the contrary, the true digestibilities of cystine, threonine and serine of pearl millet and histidine of maize were higher in intact birds. This observation suggested significant degradation of these amino acids by the microflora in the hindgut of intact birds, thereby overestimating the digestibility values of these amino acids. Literature relevant to apparent or true digestibilities of amino acids of millet grains is very scarce. The digestible amino acid contents of maize and finger millet grains observed in this study using caecectomized cockerels were similar to the values reported by degussa laboratories in broilers. However, the digestible leucine content of low tannin sorghum was higher (1.04 vs. 0.92%) by 11.5% as compared to that reported by degussa laboratories (Fontaine, 2006). Due to lack of related literature, it is difficult to compare and interpret the digestible amino acid contents of pearl millet.

The present study revealed that the apparent digestibility of amino acids of sorghum could be determined using intact birds, while caecectomized birds are preferred for maize, finger millet and pearl millet grains. On the other hand, it would be appropriate to determine the true digestibility of amino acids of all four cereal grains using caecectomized cockerels. Further, the results indicated that the digestibilities of amino acids of finger millet were lower as compared to other cereal grains, while pearl millet was comparable to maize and sorghum.

## REFERENCES

AOAC. 1995. Official Methods of Analysis of AOAC International, 16th edn. (Arlington, VA, Association of Official Analytical Chemists).

Austic, R. E. 1983. The availability of amino acids as an attribute of feeds (Ed. G. E. Robards and R. G. Packham). Feed information and animal production proceedings 2nd Symposium International Network of Feed Information Centres. pp. 175-189 (Commonwealth Agricultural Bureaux, U.K).

Farrell, D. J. 1978. Rapid determination of metabolisable energy of foods using cockerels. Br. Poult. Sci. 19:303-308.

Fernandez, S. R., Y. Zhang and C. M. Parsons. 1995. Dietary formulation with cottonseed meal on a total amino acid versus a digestible amino acid basis. Poult. Sci. 74(7):1168-1179.

Fontaine. 2006. Analytical report, Animal Nutrition Services, Degussa AG, Rodenbacher Chaussee, Hanau, Germany.

Green, S., S. L. Bertrand, M. J. C. Duron and R. Maillard. 1987. Digestibilities of amino acids in maize, wheat and barley meals, determined with intact and caecectomized cockerels. Br. Poult. Sci. 28:631-641.

Huang, K. H., X. Li, V. Ravindran and W. L. Bryden. 2006. Comparison of apparent ileal amino acid digestibility of feed ingredients measured with broilers, layers and roosters. Poult. Sci. 85:625-634.

Kessler, J. W. and O. P. Thomas. 1981. The effect of caecectomy and extension of the collection period on the true metabolizable energy values of soybean meal, feather meal, fish meal and blood meal. Poult. Sci. 60:2639-2647.

Lemme, A., V. Ravindran and W. L. Bryden. 2004. Ileal digestibility of amino acids in feed ingredients for broilers. World's Poult. Sci. J. 60(12):423-435.

Llames, C. R. and J. Fontaine. 1994. Determination of amino acids in feeds: Collaborative study. J. Assoc. Off. Anal. Chem. Int. 77:1362-1402.

Mandal, A. B., P. K. Tyagi and A. V. Elangovan. 2004. Utilization of nutritious cereals and by-products of oilseed based cropping systems for poultry production. Technical Bulletin Central Avian Research Institute, Izatnagar, p. 3.

McNab, J. M. 1973. The avian caeca: A Review. World's Poult. Sci. J. 29:251-263.

McNab, J. M. 1994. Amino acid digestibility and availability studies with poultry, (Ed. J. P. F. D'Mello). Amino acids in Farm Animal Nutrition. pp. 63-98 (Wallingford, UK, CAB International).

Moore, S. 1963. On the determination of cystine as cysteic acid. J. Biol. Chem. 238:235-237.

National Research Council. 1994. Nutrient requirements of poultry. 9th revised edn, National Academy Press, Washington, DC.

Parsons, C. M. 1984. Influence of caecectomy and source of dietary fibre or starch on excretion of endogenous amino acids by laying hens. Br. J. Nutr. 51:541-548.

Payne, W. L., R. R. Kifer, D. G. Snyder and G. F. Combs. 1971. Studies of protein digestion in the chicken. 1. Investigation of apparent amino acid digestibility of fish meal protein using caecectomized, adult male chickens. Poult. Sci. 50:143-150.

Ravindran, V., L. I. Hew, G. Ravindran and W. L. Bryden. 1996a. A comparison of ileal digesta and excreta analysis to determine the digestibility of amino acids for poultry. In: 'Proceedings XX World's Poultry Congress, volume IV'. p. 150. (World's Poultry Science Association: New Delhi).

Ravindran, V., L. I. Hew, G. Ravindran and W. L. Bryden. 1996b. Ileal digestibilities of amino acids for broilers. In: 'Proceedings Tenth Australian Poultry and feed convention, Melbourne'. pp. 209-215.

Sibbald, I. R. 1976. A bioassay for true metabolizable energy in feedstuffs. Poult. Sci. 55:303-308.

Sibbald, I. R. 1979. Bioavailable amino acids and true metabolizable energy of cereal grains. Poult. Sci. 58:934-939.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical methods. 7th edn., Oxford and IBM Publishing Company, Calcutta.