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Review of Research in Duck Nutrient Utilization

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Abstract: The duck has a great potential in helping to meet the growing demand for high quality protein in human diets. In order for ducks to meet their potential, more research is needed to establish their dietary requirements. Feeding and excreta collection techniques developed at Purdue University that minimize loss of excreta during collection, the first step towards precise dietary requirement quantification, are described. Using the techniques that were developed, energy and amino acid utilization of White Pekin ducks were evaluated in several studies. Diets supplying 3, 000 kcal ME/kg, 0.6% Methionine, and 1.2% Lysine are adequate to meet duck's requirement for optimum growth in the first week of life. Predicted ME of diets based on utilization values of individual ingredients was compared with the measured ME in the diets, the result showed that the energy in the feedstuffs had additive when compounded into a diet for ducks. In the case of amino acids, some essential amino acid showed significant associative effect. Enzymes likes xylanase and phytase improved performance and bone mineralization when used in ducks diet. The effect was demonstrated to be due to reduction in digesta viscosity and increased P availability as a result of the use of xylanase and phytase, respectively, the effects being more pronounced in younger ducks. There is need for more research to be done in the areas of amino acid nutrition in ducks and the evaluation of non-traditional feedstuffs.

Key words: Ducks, excreta collection, enzymes, nutrient requirement

Introduction

There continues to be increased demand for animal protein to meet the nutritional requirements of growing world population of humans. Protein from poultry meat is an indispensable component of meeting this growing need to satisfy human nutritional requirements for high-quality protein. Meat-type ducks is an important poultry meat with growing market potential. Ducks are one of the fastest growing and most efficient producers of animal protein. When properly fed, a fifty-gram, one-day old duck attains body weights of 260 g and 790 g at 7-d and 14-d old, respectively; and is capable of a feed efficiency of 45 g of body weight gain per 100 g of feed consumption at 42-d old and 3,100 g body weight (Adeola, 2003b). This compares with a thirty-eight-gram, one-day old broiler chicken that attains body weights of 152 g and 376 g at 7-d and 14-d old, respectively; and capable of a feed efficiency of 56 g of body weight gain per 100 g of feed consumption at 42-d old and 2,100 g body weight (NRC, 1994). The phenomenal growth and feed efficiency are positive consequences of improvements in genetics, nutrition, and husbandry of White Pekin ducks. Furthermore, these stated attributes have resulted in a striking and continued growth of the duck industry. In studies reported in the literature, four breeds predominate in majority of the studies conducted: White Pekin, Muscovy, Mule (Sterile: ½ Muscovy (from male side) ¼ White Pekin, and ¼ white domestic ducks), and Mallard.

For the attainment of growth and feed efficiency potential, the duck requires an enabling environment, a fundamental component of which is proper nutrition. In this context, energy, protein for the supply of amino acids, mineral elements, and vitamins must be supplied in the diet in adequate amounts and appropriate ratio. During the last decade, research at Purdue University has provided information on energy and nutrient utilization in a variety of feed ingredients for ducks (Adeola *et al*., 1994, 1997; Adeola, 1998; King *et al*., 1997, 2000; Ragland *et al*., 1997, 1998, 1999; Orban *et al*., 1999; Hong *et al*., 2001, 2002a,b; Adeola, 2003a,b; Adeola and Bedford, 2004; Norberg *et al*., 2004; Adedokun and Adeola, 2005; Adeola, 2005; Schinckel *et al*., 2005). Ducks consume water in much greater quantities than chickens (Siregar and Farrell, 1980) and the result is a highly liquid excreta. Traditional excreta collection methods (Ostrowski-Meissner, 1984) utilizing collection pans are subject to errors from contamination with feathers and losses due to splatter when the forcefully-ejected excreta make contact with the collection pan. The consequences of utilizing pan collection are sample loss and contamination of sample with orts, dander, and feathers; the overall effect of which is a reduction in the accuracy of estimation of bioavailable nutrients. Techniques were developed, at Purdue University, to circumvent these problems (Adeola *et al*., 1997; Ragland *et al*., 1997). The techniques developed offer means of precise feeding of known

amounts of feed and accurately collecting contaminant-free voided excreta which are fundamental for acquiring reliable energy and nutrient utilization values. One or a combination of the feeding and or excreta collection techniques are being employed in research to generate energy and nutrient utilization data on a number of feed ingredients for ducks. In a 1987 publication, Elkin (1987) reviewed research in duck nutrition. This review of duck nutrition research will summarize the digestive system, methodological considerations in energy and nutrient utilization assays, and provide recent data on evaluation of energy and amino acid utilization in feed ingredients.

Gastrointestinal system of ducks: Retrieval of nutrients from diets represents the central function of the gastrointestinal system. In the duck, the gastrointestinal system is composed of the bill, mouth, esophagus, pseudo-crop, proventriculus, gizzard, midgut (duodenum, jejunum, and ileum) and hindgut (colon, ceca, rectum and cloaca) as presented in an earlier publication (Adeola, 2003b). The developmental patterns of some intestinal digestive functions in White Pekin ducks killed at 1, 3, 5 and 7 weeks old were reported by King *et al.* (2000a).The slope of least-square regression line relating log intestinal weight (W_I) to log body weight (W_B) was a 0.74 ± 0.04. Intestinal growth was allometric and described by the equation: $W_I = 0.61W_B^{0.74\pm 0.04}$, where W_I is intestinal weight in grams and $W_B$is body weight in grams (Fig. 1). Metabolic live weight is defined as the body weight$^{0.75}$ because the metabolic rates of vertebrates are related to body weights$^{0.75}$. Therefore, intestinal weight was directly proportional to metabolic live weight. When the log surface area was plotted against log body weight the slope was 0.54 ± 0.08. This slope was lower than the coefficient for metabolic weight. In the White Pekin duck, intestinal growth is in direct proportions to the age-related increases in metabolic rates. Also, at the same time the ducks grow, smaller percentages of total body tissues are devoted to intestinal tissues. It appears that the intestines of ducks grow in direct proportion to the age-related increases in metabolic rates and patterns of intestinal growth appear to be correlated with patterns of whole body growth rates. The rapid intestinal hyperplasia is a prerequisite for sustained rapid posthatch growth in ducks.

The gastrointestinal system in ducks starts with the bill, a structure that is flatter than the chicken's beak and has a protrusion on the upper tip known as a bean. Toothless mouth and a tongue adapted for collection, manipulation and swallowing of feed follow the bill. There are numerous conical papillae in the root of the tongue and mucosa of the pharynx, which appear to facilitate the movement of food caudally. Following the pharynx is the esophagus, whose main function is to pass food from mouth into the proventriculus. Unlike chickens, ducks have a spindle-shaped widening of the esophagus, and fusiform proventriculus that may promote a quicker transit rate of ingesta (Das *et al.*, 1965). The enlarged diverticulum of the esophagus in the duck lacks definite musculature for the control of feed passage (entry into and exit therefrom); and thus there is NO true crop in the duck. The pseudo-crop in the duck serves as a temporary storage organ for lubrication and softening of feed. Following the pseudo-crop is the proventriculus together with a mucosa endowed with an abundance of two main types of glands – tubular and gastric glands – that elaborate secretions for initiating protein digestion. When feeding is initiated, mucus is released by the tubular glands; and pepsin and hydrochloric acid are secreted by the gastric gland when feed reaches the proventricular lumen. When compared with the chicken, contractions of the thoracic esophagus and the glandular stomach are more active in ducks (Pastea *et al.*, 1968). Located at the posterior end of the proventriculus is the gizzard, a highly muscular organ capable of exerting very high pressure on resident feed. The function of the gizzard is to grind feed for the reduction of feed particle size and thus increase the surface area of feed that is brought in contact with pepsin and hydrochloric acid. The gizzard is the site for the first major digestion that accommodates a specific proteolysis. The gizzard mucosa is endowed with numerous deep tubular glands that secrete protein-rich fluids. The fluids form characteristic horny plates known as koilin which functions both as a grinding plane and for the protection of the underlying mucosa from acid and pepsin.

At the posterior end of the gizzard is the proximal portion of the midgut – the duodenum, which forms a loop around the pancreas. The cystic, hepatic, and pancreatic ducts empty secretions of the gall bladder, liver, and pancreas , respectively into the duodenum via a common papilla. These secretions, consisting of amylase, trypsin, chymotrypsin, elastases, carboxypeptidases, lipase, cholesterol esterase, and bile, hydrolyze starch, proteins, and fat into monomeric units for transport and absorption into the enterocytes. Anatomically, the jejunum extends from the common papilla to the Meckel's diverticulum, a vitelline diverticulum that represents the remnant of the yolk sac and a carry-over from embryonic development. Jejunum, located anterior to the ileum of the midgut, is the principal site for absorption of the products of digestion of nutrients needed by the duck in support of its phenomenal growth. The last portion of the midgut, the ileum, stretches from the Meckel's diverticulum to the ileo-ceco-colonic junction; and functions both as an enzymatic digestion/absorptive site and microbial-based digestion region for enzyme-resistant feeds. Posteriorly, a relatively short colon and two long ceca retrieve nutrients remaining in the digesta from the ileum prior to

Table 1: Body weight, metabolic body weight $kg^{0.67}$., length of gut segments and weight of organs in Mallard ducks at 21 and 42 days of age expressed in absolute units and in relation to metabolic body weight (Jamroz *et al.*, 2001)

	Absolute units		Units per $kg^{0.67}$Age	
	21 days	42 days	21 days	42 days
Body weight, kg	1.12	2.56	1.08	1.88
Length, cm				
Small intestine	163	195	151	104
Ceca	29	37	27	18
Colon	10	12	9.5	6.5
Total	203	244	188	130
Weight, g				
Small intestine	13	49	12	26
Ceca	2.9	5.0	2.7	2.7
Colon	3.2	5.2	3.0	2.8
Total	19	59	17	32
Organ weight, g				
Proventriculs	8.6	14	8.0	7.4
Gizzard	43	77	40	41
Pancreas 5.6	8.6	5.2	4.6	
Liver	38	77	35	41

Table 2: Pancreas protein concentration mg/g of pancreas weight. and enzymatic activity of pancreas u/mg of pancreas protein; Jamroz *et al.*, 2002

Days of life	Pancreas protein, mg/g pancreas weight	α-Amylase, u/mg of pancreas protein	Lipase, u/mg of pancreas protein
1	28.2	34	4.71
3	13.6	17	2.70
5	25.7	17	2.30
7	30.6	14	2.41
28	34.4	117	14.81
42	33.0	158	16.55

eventual expulsion from the digestive tract. The most important nutrients retrieved during digesta transit in the colon and ceca are electrolytes, volatile fatty acids (mostly from microbial fermentation), and water. In the duck and most avian species, the rectum is very short and indistinguishable from the colon. The last part of the digestive system is represented by the cloaca, a three-compartment (coprodeum, ureodeum, and proctodeum) organ that performs storage function for urine and feces prior to excretion.

Jamroz *et al.* (2001, 2002) presented information on several aspects of the development of digestive system of Mallard ducks. These information, given in Table 1 and 2, show increase in absolute lengths and weights of midgut and hindgut as well as the weights of digestive organs from 21 to 42 days of age. However, expression on a metabolic body weight basis show a decrease in intestinal length from 21 to 42 days of age. As the duck grows in age and size, pancreatic protein concentration increases reaching a peak at 28 days of life. There is an increase in pancreatic α-amylase and lipase activity with a characteristic rise in pancreatic α-amylase after 28 days of life (Jamroz *et al.*, 2002).

Diets for starter and grower ducks: During the period from hatching to market weight of the production meat-type ducks, two main types of feed are usually fed – Starter and Grower-finisher. Table 3 outlines recommended dietary nutrient specifications for meat-type ducks based on a two-week supply of starter diets and a four-week supply of grower-finisher diets. It must be emphasized that these are recommendations for White Pekin ducks that may vary with changes in genetics, husbandry practices and conditions in the physical environment in which ducks are being raised. In this regard, it is imperative that these nutrients be present in diets in proper amounts without excessive surfeit. The propensity of ducks to deposit fat is an attribute that requires consideration in dietary energy recommendations.

Examples of diets for meat-type broilers are provided in Table 4.

One of the most expensive components in the diets of meat-type ducks is energy. The duck, or any other animal, will consume an amount of energy required for maintenance including the support of basal metabolism and body temperature regulation, regular activity, and normal growth. Because maintenance has priority, normal growth occurs if the feed eaten in the course of consuming the said amount of energy contains adequate quantities of protein (amino acids), minerals and vitamins required for growth of body tissues. Efficient growth requires, in addition to adequacy, balance of the essential amino acids, the vitamins and minerals. Metabolizable energy recommendations indicated in Table 3 are NOT based on empirical studies, but from synthesis of literature information and studies conducted at Purdue University using White Pekin ducks from hatch to 42 days of age. During the first seven days of life, there is evidence that a duck would not consume more than a total of 350 grams and energy requirement is somewhat less than 1 Mcal during this period. At Purdue University, we were not able to demonstrate a significant improvement in body weight gains and efficiency of feed utilization when diets are formulated to contain more than 3,000 kcal/kg.

It is imperative to customize the protein and amino acid requirements of each period of growth of the duck to husbandry practices and specific market demands. When started from hatch at dietary protein that is inadequate for genetic potential for growth, ducks may exhibit compensatory growth later in life. However, the economics of production would dictate avoiding dietary protein inadequacy at early ages. Because the purpose of adding protein to the diet is to provide amino acids that serve as building blocks of body tissue protein, essential amino acid recommendations are listed in

Table 3: Dietary specifications g/kg. for commercial meat ducks adapted from Leeson and Summers 1997.

Approximate protein level, g/kg	Starter		Grower-finisher	
	230	205	175	150
Amino acids, g/kg of diet				
Arginine	12	10.4	9.4	8.5
Lysine	12	9.6	8.6	7.8
Methionine	6	5.5	4.5	3
Methionine+cysteine	9.5	8.5	7.5	6
Tryptophan	2.2	1.8	1.6	1.5
Histidine	4.4	3.7	3.3	2.9
Leucine	15.6	12.8	11.6	10.4
Isoleucine	8.4	6.9	6.3	5.6
Phenylalanine	7.8	6.4	5.8	5.2
Phenylalanine+tyrosine	15.2	12.4	11.2	10.1
Threonine	7.6	6.2	5.6	5
Valine	9.3	7.7	6.9	6.2
Metabolizable energy, kcal/kg	2,825	2,875	3,050	3,075
Calcium	12	10	9	8
Total Phosphorus	9.5	8.5	7.5	6
Non-phytate phosphorus	6	5.5	4.5	3
Sodium	2.2	1.8	1.6	1.5
Vitamins, per kg of diet				
Vitamin A, I.U.		6,000		
Vitamin D_3, I.U.		2,500		
Choline equivalents, mg		800		
Riboflavin, mg		4.0		
Pantothenic acid, mg		12.0		
Vitamin B_{12}, mg		0.010		
Folic acid, mg		0.5		
Biotin, mg		0.2		
Niacin, mg		60.0		
Vitamin K, g		1.5		
Vitamin E, I.U.		20.0		
Thiamine, mg		2.0		
Pyridoxine, mg		3.0		
Trace minerals, per kg of diet				
Manganese, mg		60		
Iron, mg		80		
Copper, mg		8		
Zinc, mg		60		
Selenium, mg		0.2		
Iodine, mg		0.4		

Table 3. These essential amino acid recommendations assume adequate dietary supply of nonessential amino acid to satisfy the nonessential nitrogen need. For most duck diet formulations, methionine, lysine, threonine, and tryptophan are likely to be the most limiting amino acids. In diets formulated with corn and soybeans as the main sources of protein, methionine is likely to be the first limiting amino acid for maintenance and growth performance of ducks. In addition, adequate amounts of cysteine must be provided in the diets to efficiently meet the total sulfur amino acid needs of the duck and spare the use of methionine for *de novo* synthesis of cysteine. Again, there is limited data on amino acid requirements of ducks. Published research and in-house data from several duck studies at Purdue University show that ducks do not require more than 0.60% methionine and 1.2% lysine during the first week of hatch (Table 3). Corresponding values for weeks 2 to 6 during growth to market weight are 0.55 and 1.00%, 0.45 and 0.90%, and 0.3 and 0.8% (Table 3).

The efficient growth of ducks requires adequate amounts of minerals like calcium, phosphorus, and other mineral elements, and vitamins. Recommended amounts are provided in Table 3. Calcium is a divalent cation with a diverse array of functions within the animal. One of the major roles of extraskeletal calcium, mostly in the ionized form or bound to albumin, is regulation of metabolic and physiological processes (Underwood and Suttle, 1999). This regulation may occur as a simple binding to a protein, therefore causing conformational and/or functional changes, or in a classical stimulus-response relationship through cell signaling where calcium functions as a second messenger (Weaver, 2001). Calcium is also necessary for proper muscle

Table 4: Example duck starter and grower diets in g/kg

	Starter	Grower-Finisher
Corn	570	734
Soybean meal 48%.	360	205
Soy oil	30	25
Limestone	16	14
Calcium phosphate	14	12
Salt	4	4
Vitamin:mineral premix[1]	3	3
Methionine	3	2
Lysine.HCl	0	1
Calculated analyses		
Crude protein	230	160
Metabolizable energy, kcal/kg	3,000	3,150
Calcium	9.5	8.2
Nonphytate phosphorus	4	3.3
Arginine	14.5	9.9
Lysine	12.9	9.1
Methionine	6.4	4.6
Methionine+cysteine	10.4	7.4
Threonine	8.2	6
Tryptophan	3	2
Valine	10	7.5[1]

Use vitamin-mineral premix with the following minimum specification per g of premix: Vit. A, 1828 IU; Vit. D_3, 881 ICU; Vit E,3.67 IU; Menadione sodium bisulfite,1.46 mg; Riboflavin, 1.83 mg; d-pantothenic acid, 3.67 mg; Niacin, 14.69 mg; Choline chloride, 257 mg; Vit B_{12}, 4.4 ug; Biotin, 18.4 ug; Thiamine mononitrate, 735 ug; Folic acid, 330 ug; Pyridoxine hydrochloride, 1.1 mg; I, 370 ug; Mn, 22.02 mg; Cu, 1.48 mg; Fe, 14.69 mg; Zn, 14.69 mg; Se, 100 ug.

contraction (Lobaugh, 1995) elicited through exocytosis of neurotransmitters (such as acetylcholine) into a neuronal synaptic cleft. This process is initiated by an action potential (also requiring calcium for propagation) and causes neurotransmitter vesicle fusion with the membrane. Much in the same manner, calcium acts to release hormone molecules such as insulin by causing vesicle fusion with the lipid membrane and expulsion of contents into the target medium. Finally, calcium is required for proper blood clotting and as a cofactor in many enzymatic reactions (Underwood and Suttle, 1999). Phosphorus is an essential element, for which most vertebrate animals have a dietary requirement second only to calcium. Hayes *et al.* (1979) reported that approximately 75% of the pig's phosphorus is stored in the skeleton. It is stored as a principal component of hydroxyapatite ($Ca_{10}[PO_4]_6[OH]_2$), the major building block of bone. Phosphorus in the skeleton not only functions as the framework around which the body is constructed, but also as a reservoir of phosphorus for the roles it plays in almost every aspect of metabolism. Of the 25% of body phosphorus not tied up in the skeleton, some are contained in nucleic acids like DNA, RNA, and ATP; in phospholipids such as phosphoglycerides, and sphingomyelin; in high-energy compounds like phosphoenolpyruvate, 1,3-bisphosphoglycerate, and creatine phosphate; as well as in phosphorylated proteins where it is a means of enzyme regulation.

Table 5: Feeding and excreta collection protocol

Time h.	Operation
0	Feed is withdrawn
24	Each bird is fed dextrose solution 25 to 30 g/100 mL water.
30	Each bird is fed dextrose solution 25 to 30 g/100 mL water.
48	Birds are fed appropriate feedstuff 25 to 30 g/100 mL water. Birds used for fasting energy loss, fasting nitrogen and amino acid loss calculation are fed dextrose solution 25 to 30 g/100 mL water. Collection bags are screwed into affixed lids.
54	Birds are fed appropriate feedstuff 25 to 30 g/100 mL water. Birds used for fasting energy loss, fasting nitrogen and amino acid loss calculation are fed dextrose solution 25 to 30 g/100 mL water. Collection bags are screwed into affixed lids.
60	Excreta is collected and frozen, new collection bags are screwed into lids.
72	Excreta is collected and frozen, new collection bags are screwed into lids.
84	Excreta is collected and frozen, new collection bags are screwed into lids.
96	Excreta is collected and frozen, new collection bags are screwed into lids.
102	Excreta is collected and frozen, lids are removed from the ducks.

Some inorganic phosphorus are found in cells where it plays an important role in maintaining acid-base balance.

A common metabolic link between calcium and phosphorus is the means by which each is regulated. Three hormones involved in the delicate regulation of these minerals are parathyroid hormone, 1,25-dihydroxycholecalciferol; the active form of vitamin D and calcitonin (Bronner, 1997). In general, parathyroid hormone and 1,25-dihydroxycholecalciferol modulate plasma calcium and phosphorus in the following manner. Hypocalcemia leads to an increase in parathyroid hormone release which then stimulates production of 1,25-dihydroxycholecalciferol by the kidney. Ultimately, uptake of dietary calcium from the gastrointestinal tract, increased reabsorption in the renal distal tubules and calcium release from bone serve to increase plasma calcium. Concurrently, parathyroid hormone induces phosphaturia by reducing reabsorption in the renal proximal tubules to maintain proper plasma calcium to phosphorus ratio. In contrast, elevated levels of calcium serve to reduce parathyroid hormone release and 1,25-dihydroxycholecalciferol production thereby attenuating hypercalcemia by reversal of the aforementioned paths. Calcitonin works in a similar manner to reduce plasma calcium though in response to more extreme hypercalcemic conditions.

Considerations in Energy and Nutrient Utilization Assays for Ducks: Of necessity, experiments for determining the utilization of energy and nutrients in feed

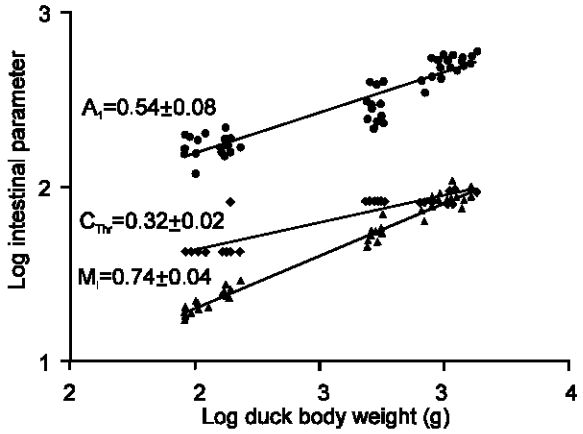

Fig. 1: Allometric changes in intestinal parameters during development in White Pekin ducks (King *et al.*, 2000b). Solid circles represent intestinal surface area $A_I = 0.80W_B^{0.54 \pm 0.08}$ where A_I is intestinal area in square centimeters and W_B is body weight in grams. Open diamonds represent threonine uptake capacities $C_{thr} = 0.82W_B^{0.32 \pm 0.02}$ where C_{thr} is threonine uptake capacities pmol/mg protein•s. and W_B is body mass in grams. Solid triangles represent intestinal weight $W_I = 0.61W_B^{0.74 \pm 0.04}$ where W_I is intestinal weight in grams and W_B is body weight in grams.

ingredients by ducks, require accurately measuring and relating feed intake and output of excreta. With the use of an indigestible marker such as chromic oxide or titanium oxide, requirement for accurately measuring and relating feed intake and output of excreta can be obviated. Regardless of whether total collection or indigestible marker method is employed, total feed intake can be difficult to measure because of inherent feed wastage. Furthermore, collection of excreta during feed evaluation assays in ducks poses special challenges. Ducks drink a lot of water, a low proportion of which is retained in the body. The ratio of water:feed consumed by ducks is 4.2:1; this compares with 2.3:1 for broilers (Scott and Dean, 1991). The consequence of the consumption of high water:feed ratio and low retention is a highly liquid excreta. Another issue in collecting excreta is the often forceful ejection of excreta by ducks (Adeola *et al.*, 1997). Traditional excreta collection methods (Ostrowski-Meissner, 1984) utilize collection pans, which are subject to errors from contamination with feathers and losses due to splatter when the forcefully ejected excreta contact the pan. The consequence of utilizing pan collection is that sample loss and contamination result in reduced accuracy of estimation of bioavailable nutrients (Adeola *et al.*, 1997). Feeding and excreta collection methods for nutrient utilization assays in feed ingredients for ducks were developed at Purdue University. The approach adopted was to use, in part, the modified TME bioassay described by McNab and Blair (1988), which differs from the method described by Sibbald (1976) in several aspects. The modifications to the bioassay described by Sibbald include: feed deprivation of all birds for 48 h prior to feeding test ingredients; administration of dextrose to all birds during the 48-h period without feed; 48-h period of excreta collection; and birds assigned for determination of endogenous losses are administered dextrose instead of no feed at all. These modifications to the Sibbald (1975) method appear to improve the precision of the assay as well as decrease the stress on the birds used for determination of endogenous losses. In preliminary studies, these modifications considerably reduced the variation in endogenous losses of energy and nutrients. In each experiment, male, White Pekin ducks are sorted according to weight, placed in individual cage (0.66 m x 0.66 m), and assigned to each of test ingredients or dextrose for estimation of endogenous losses of nitrogen and energy.

Feeding procedure: The tube-feeding apparatus consist of a 60-mL catheter-tip syringe, to which a 35 cm section of Nalgene tubing™ (8 mm inside diameter) is attached to facilitate delivery of the test ingredients to the ducks' pseudo-crop. Forty-eight hours prior to feeding the test ingredients, feed is withdrawn from all ducks. At 8 and 32 h post-feed withdrawal, all ducks are tube-fed 25 to 30 g of dextrose in 100 mL of distilled water and allowed to purge their gastrointestinal tracts. At 48 and 54 h post-feed withdrawal, all ducks are tube-fed 25 to 30 g of their assigned test ingredients in 100 mL of distilled water. All test ingredients are ground through a 0.5 mm screen prior to feeding. In preliminary studies to standardize the feeding methodology, birds were observed to regurgitate generous portions of test ingredients if too much was force-fed at one time. Based on these observations, standard protocol now involve two 25- to 30-g feedings of test ingredients in order to prevent exceeding the capacity of the duck's pseudo-crop due to the volume of water required to sufficiently mix the ingredients. Based on the necessity of the two feedings 6 h apart, the collection period is extended for an additional 6 h to 54 instead of the original 48 h. At 48 and 54 h post-feed withdrawal, the ducks assigned to receive dextrose for estimation of endogenous losses are also tube-fed 25 to 30 g of dextrose in 100 mL of distilled water. All ducks are fitted with their respective collection vessels at the time of the first feeding of test ingredients and throughout the total collection of excreta for 54 h. The standard protocol is summarized in Table 5.

Excreta collection techniques: The collection apparatus is constructed using materials from a Playtex™ baby nurser set (Fig. 2). Prior to placement in cages, birds

Fig. 2: Excreta collection device fabricated from a Playtex™ baby nurser set.

Fig. 3: Device fabricated from plexiglass and used as a restraint.

are surgically fitted with modified plastic retainer lids which serve as part of the collection apparatus. The plastic retainer lids from the nurser set are modified by drilling twelve holes, 2 mm in diameter in the ring similar to the twelve points on a clock. Surgical fixation of the retainer lids is accomplished by restraint of the duck in a plexiglass restraint box (Fig. 3) and local anesthesia of the vent area with 2% lidocaine hydrochloride. Surgical attachment of a collection apparatus to the vent of the ducks is considered a more suitable method because it provided better security against excreta loss. The collection apparatus do not appear to create any discomfort or impair the mobility of the birds in any way. Ducks are restrained in the plexiglass box (Fig. 4) and a 5-cm zone of feathers adjacent to the vent is removed to expose the skin. The skin is then sanitized with a dilute solution of chlorhexidine diacetate (Nolvasan). The area to be sutured is then infused in the dorsal, ventral and lateral quadrants around the vent with 2% lidocaine hydrochloride to desensitize the skin for suturing (Fig. 5). The retainer lids are then sutured to the vent area using a continuous suture pattern with the retainer lid anchored in place by passing the needle and suture through holes placed in the retainer lid as the needle exited the skin. The plastic bottle of the nurser set is measured and cut to a length of 3 cm below the threads on the bottle. Whirl-pak bags (480-mL size) are placed through the bore of the bottle and the flaps of the bag overlaid to the sides of the bottle covering the threads. The bottle and Whirl-pak bag are then screwed onto the retainer ring attached to the bird with the threads of the ring and bottle securing the bag in place and completing the collection apparatus as depicted in Fig. 6. The Whirl-pak bags containing excreta are changed within the first 6 h and every twelve hours thereafter during the 54-h collection period.

The tube-feeding and excreta collection methods described above have, in our experience, worked very well in precisely feeding known amounts of ingredients and accurately collecting contaminant-free voided excreta. This is extremely vital for obtaining reliable values from energy and nutrient utilization assays. In mathematical model for utilization of nutrient in feed ingredients, digestion experiments can be classified into direct, difference, and regression methods (Adeola, 2001). With the direct method, the assay diet is formulated in such a manner that the assay feedstuff provides the sole source of nutrients in diets. This method is the most commonly used assay, but it has the limitation of not being suitable for use in evaluating low protein and poor palatability feedstuffs, such as barley (Fan and Sauer, 1995). The difference method is based on the assumption that there are no interactions between the basal ingredient and test ingredient. It involves the formulation of both a basal and an assay diet. The basal diet contains the basal feedstuffs, which provides the sole source of nutrients; the assay diet consists of a mixture of the basal and assay feedstuffs. The digestibility values of the assay feedstuffs can be measured by difference. This method facilitates the evaluation of feed ingredients characterized by low protein, and high fiber content. The regression method measures simultaneously the digestibility values of nutrients in a basal and an assay diet. The basal diet and test ingredient are mixed at graded levels in a series of assay diets. If there are no interaction between the basal diets and test ingredients, the digestibility values of assay diets and the contribution levels of the

Fig. 4: Duck in the plexiglass restraining device prior to being fitted with a plastic retainer lid.

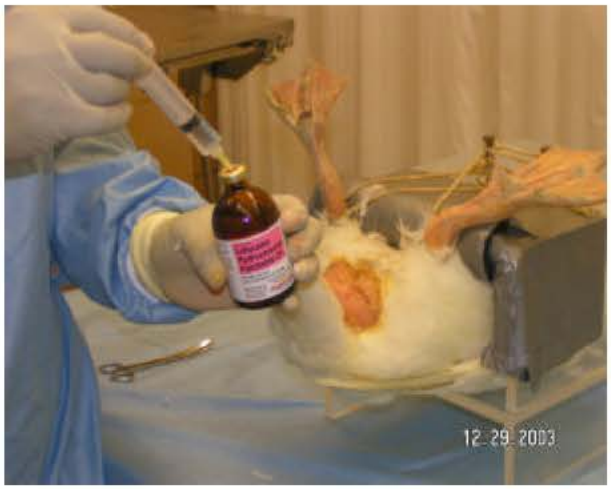

Fig. 5: The skin is then sanitized with a dilute solution of chlorhexidine diacetate Nolvasan. The area to be sutured is then infused in the dorsal, ventral and lateral quadrants around the vent with 2% lidocaine hydrochloride to desensitize the skin for suturing.

test ingredients to the assay diets can be fitted to a simple linear regression model. However, in order to apply the regression method successfully to the determination of apparent digestibility of amino acids, it is essential that there be sufficiently large differences in the digestibility values of amino acids between the basal diet and the assay diets or test ingredients.

Feed Evaluation for Energy and Amino Acid Utilization: Feed energy is primarily stored in carbohydrates, proteins and fats components. The amount of heat produced when a known quantity of the feed is combusted completely to gases in an oxygen-rich condition is termed the gross energy (GE). The fraction of this gross energy that is eventually available to the duck for the support of body metabolic processes is dependent on several factors including the duck's capacity to digest the feed and inherent quality attributes of the feed. The partition of this gross energy of feed in poultry nutrition is shown in Fig. 7. The voiding of undigested feed energy, as fecal energy, together with urinary energy in the excreta has made metabolizable energy the standard measure of useful feed energy in avian species. Determination of digestible energy in avian species would require surgical exteriorization of the ureters for the separation of urine from feces – a situation rarely necessary in routine feed evaluation for energy value.

The energy value determined is termed apparent metabolizable energy - AME (gross energy in feed minus gross energy in the collected excreta). In feed evaluation for energy utilization, a part of the excreta energy does NOT originate directly from the feed under evaluation. The part of excreta energy that does not originate directly from the feed under evaluation has come to be known as endogenous energy loss (EEL) and are fecal and urinary in origin. The EEL consists of energy in abraded intestinal lining, unabsorbed enzymes, unrecycled bile secretions, and products of whole body metabolism excreted in the urine. The correction of excreta energy for EEL gives true metabolizable energy - TME (gross energy in feed minus (gross energy in the collected excreta minus EEL). As depicted in Fig. 7, EEL per unit of feed intake is added to AME (kcal/kg) to obtain TME (kcal/kg). The relationship between AME and TME, originally described by Guillaume and Summers (1970), shows a strong dependence of AME on feed intake and that TME is unaffected by feed intake. Thus, the EEL assumes a large proportion of excreta energy at low feed intake (less than 50% of maintenance); but feeding above 50% maintenance, the EEL per unit feed intake represents between 2 and 5% of AME (McNab, 1990).

The nitrogen status of the duck during feed evaluation studies for energy utilization has effects on energy retention. Thus, it is common to correct AME or TME for changes in nitrogen retention by the bird during the study. The rationale behind this correction rests in the fact that excretion of stored body protein as uric acid is an energy-dependent process. For example, a bird that is depositing protein is spared the energy required to excrete the nitrogen as uric acid resulting in less energy in the excreta. Whereas, another bird fed the same diet but not depositing protein expends more energy to excrete nitrogen as uric acid resulting in more energy in the excreta and would have a lower AME (or TME) than the first bird for the same diet. In order to make the AME (or TME) independent of the conditions under which it was derived, the common practice is to correct AME (or

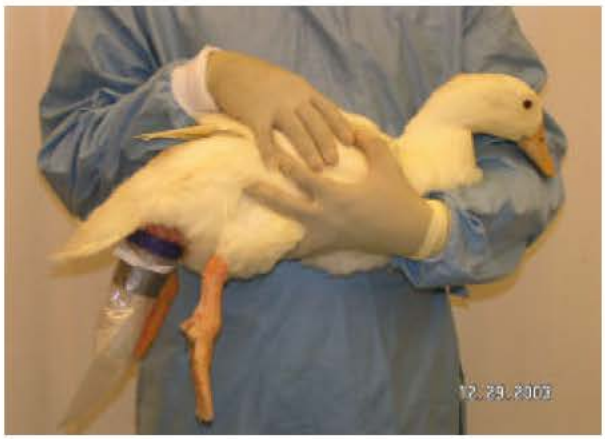

Fig. 6: Duck fitted with a plastic retainer lid, plastic bottle of the nurser cut to a length of 3 cm below the threads on the bottle, an inner 480-mL Whirl-pak bag placed through the bore of the bottle and the flaps of the bag overlaid to the sides of the bottle covering the threads, and an outer480-mL Whirl-pak bag

TME) to zero nitrogen retention and the adjusted value is termed nitrogen-corrected metabolizable energy (AMEn or TMEn). The correction factor of 8.22 kcal per gram of nitrogen retained or excreted as uric acid is used (Hill and Anderson, 1958). For birds retaining nitrogen, the correction (per unit feed intake) is subtracted from AME, thus AMEn will be less than AME. For birds in negative nitrogen balance, the correction (per unit feed intake) is added to AME, thus AMEn will be more than AME. In correcting TME for nitrogen retention, the same situation applies except that true rather than apparent nitrogen retention is used.

Dietary amino acid concentrations are useful but inadequate for the optimal use of feed ingredients in formulating diets that are efficiently used by the bird to meet its amino acid requirements. This is because amino acids in feed ingredients will not be totally digested, thus the amounts of amino acids that are used by the bird are frequently much lower than that contained in feed ingredients. As described above with energy utilization, feed evaluations for amino acid utilization often involve digestibility and therefore collection of excreta (feces + urine). Amino acid utilization data collected through this approach do not meet the strict definition of digestibility due to confounding influence of urine. It is common to ignore the urinary component of excreta due to observations of low amino acid concentration of urine and its unresponsiveness to the nature of the diet. Experiments reported by Bragg *et al.*, (1969); Yamazaki *et al.*, (1977); and Yamazaki, (1983) compared amino acid digestibilities from normal and colostomized (to separate feces from urine) birds. The data showed no differences in amino acid digestibilities between normal and colostomized suggesting that amino acid contribution of the urine is insignificant. The determination of glycine utilization presents special consideration due to the yield of glycine, from uric acid, during acid hydrolysis of excreta.

The discussion above for endogenous energy losses is also relevant and applicable to endogenous amino acid losses (EAAL). Therefore, the correction of apparent amino acid digestibility (AAAD) for EAAL gives true amino acid digestibility (TAAD). Proteins that escape digestion in the midgut become substrates for hindgut microbial fermentation. In digestibility assays, the unknown and variable effects of hindgut microbes on excretion of amino acids is of concern and estimates of approximately 25% of excreta amino acids being of microbial origin have been advanced (Parsons *et al.*, 1982). Products of hindgut microbial fermentation of proteins are incorporated into microbial proteins or released as ammonia. Therefore, disappearance of amino acids in the hindgut is of little value to the bird (coprophagy is hardly practiced) – giving rise to inflated digestibility values for amino acids. Attempt to eliminate this confounding issue has led to the use of birds whose ceca are surgically removed (cecectomized birds) in digestibility assays. Cecectomy reduced amino acid digestibility in some studies, but had little or no effect in others (Green *et al.*, 1987a,b; Ragland *et al.*, 1999). The effect of surgical removal of the ceca on amino acid digestibility may therefore vary with the type of feed ingredient. Furthermore, cecectomy increases endogenous amino acid losses and could conceivably affect true amino acid digestibility (Parsons, 1984; 1985; Ragland *et al.*, 1999).

Data on Energy Utilization in Feed Ingredients for Ducks: At Purdue University, several studies have been conducted through the years to determine energy utilization in a variety of grains, meals, and byproducts for ducks. Details of the number of studies, dry matter, gross energy, and nitrogen contents of the feed ingredients used in the studies are presented in Table 6. The range of gross energy and nitrogen are 3,862-5,033 kcal/kg and 1.09-8.63%, respectively. The range of AME, AMEn, TME, and TMEn (kcal/kg) of feed ingredients for White Pekin ducks determined in several studies are presented in Table 7. Again, all values presented were determined using the feeding and excreta collection techniques described above. When comparing values in Table 7 among various feed ingredients, a general trend is that energy values for most of the grains are greater than those in meals resulting after oil extraction. Of the grains examined thus far, barley, rye and triticale have significantly lower energy values for ducks than corn, sorghum or wheat. In diet formulation, it is generally assumed that the utilization of energy in individual feedstuffs can be added together to match the required

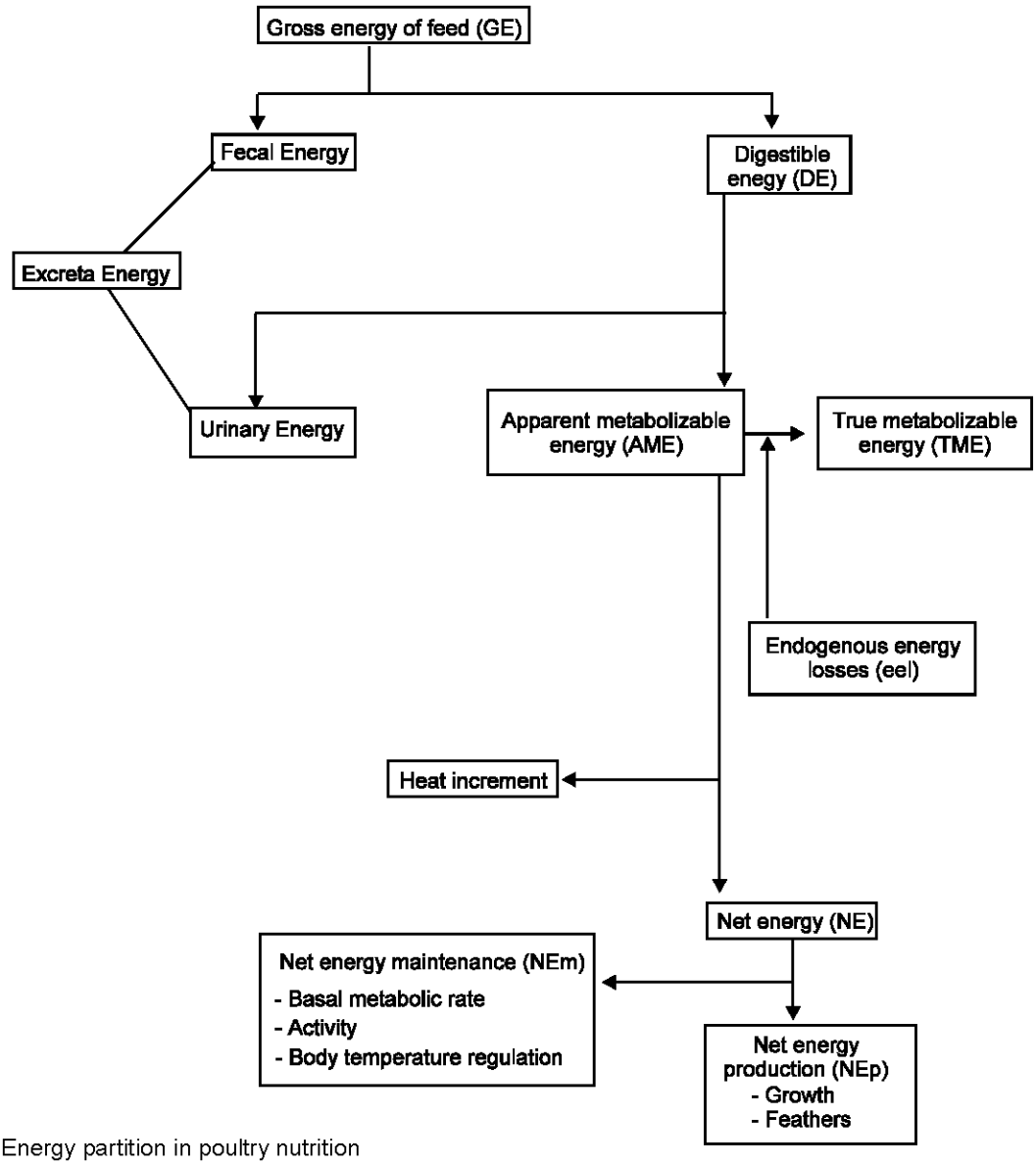

Fig. 7: Energy partition in poultry nutrition

energy supplied by the diet. This assumption was recently tested in barley-canola meal (complete) diet (Hong *et al.*, 2001) and corn-wheat red dog-soybean meal (complete) diet (Hong *et al.*, 2002b). The differences between observed metabolizable energy in complete diet and predicted values from measurements determined with individual ingredients (barley and canola meal) were compared. Predicted values were calculated from the digestibility values determined with the individual ingredients and relative to their proportions in the complete diet. The respective AME, AMEn, TME, and TMEn values observed for the complete diet were 0.065, 0.083, 0.016, and 0.023 (kcal/g) higher than predicted values (Hong *et al.*, 2001). These differences between observed and predicted values were not significant, which indicated that the AME, TME, AMEn, and TMEn of barley and canola meal were all additive and did not have any significant associative effects in ducks. Furthermore, the differences between observed metabolizable energy values in complete diet and predicted values from measurement determined with individual ingredients (corn, red dog, and soybean meal) for the respective AME, AMEn, TME, and TMEn were 0.059, 0.049, 0.081,and –0.008 kcal/ g (Hong *et al.*, 2002b). These differences between observed and predicted values were not significant, which also indicated that the AME, AMEn, TME, and TMEn of corn, red dog, and soybean meal were all additive and did not have any significant associative effects in ducks. These results indicated that energy for the individual feed ingredients evaluated were additive when included in complete diets for ducks.

Table 6: Dry matter, gross energy, and nitrogen contents of feed ingredients evaluated for energy utilization

Ingredients	Number of studies	Dry matter, %	Gross energy, kcal/kg	Nitrogen, %
Grains				
Barley	2	88.10 - 92.71	3,875 – 3,958	1.74 - 1.91
Corn	11	87.42 - 89.72	3,877 – 4,091	1.09 - 1.37
Low-phytin corn	1	89.08	4,057	1.38
High-oil corn	1	88.80	4,177	1.44
Oats Dehulled	1	87.75	4,091	1.75
Pearl millet	1	89.91	4,257	2.09
Rice	1	90.32	3,862	1.61
Rye	1	89.16	3,919	1.71
Sorghum	3	85.79 - 91.15	4,070 – 4,183	1.26 - 1.75
Triticale	1	90.16	3,938	1.85
Wheat	1	87.22	3,886	2.10
Meals and byproducts				
Bakery meal	3	89.80 - 91.57	4,276 – 4,2801.72	- 2.02
Canola meal	1	90.47	4,305	5.29
Corn gluten meal	1	92.26	5,033	8.63
Meat and bone meal	1	92.12-99.07	3,493-4,732	7.95-9.91
Low-phytin soybean meal	1	92.43	4,126	8.46
Wheat middling	1	89.07	4,093	2.52
Wheat red dog	4	86.12 - 90.06	3,905 – 4,106	2.66 - 2.87

Data on Amino Acid Utilization in Feed Ingredients for Ducks: Nitrogen and amino acid contents of feed ingredients evaluated for amino acid digestibility are presented in Table 8. The dataset is less for amino acids than for energy. The range of true digestibilities of amino acids in feed ingredients for ducks presented in Table 9 were obtained from studies using feeding and excreta collection techniques described above. Dataset for amino acid utilization in feed ingredients for ducks is considerably fewer than for energy utilization and calls for more research to provide this important information required for formulating diets that match the need of the duck with dietary supply. A comparison of digestibility coefficients for the indispensable amino acids in corn, barley, bakery meal, canola meal, soybean meal and wheat red dog reveals a considerable variation. A portion of the variation probably reflects the differences in amino acid composition and location, structure and distribution of proteins in the feed ingredients. In general, true digestibility of the indispensable amino acids is lower in barley than in corn; and much lower in canola meal than in soybean meal. Digestibility coefficients for most of the indispensable amino acids in canola or soybean meals are greater than 80%. The assumption of additivity of individual feed ingredients amino acid utilization values in complete diets was also tested for barley, canola meal, corn, wheat red dog, and soybean meal (Hong *et al.*, 2001, 2002b). While the true digestibilities were additive for most amino acids, significant exemption was observed for arginine, histidine, lysine, tryptophan, and aspartate. Thus true digestibilities of some amino acids are not additive, demonstrating some associative effects that vary with the ingredient matrix (Hong *et al.*, 2001, 2002b).

The energy, nitrogen and amino acid contents of low-phytin corn and soybean meal, and high-oil corn (Tables 6, 8, and 10) show some differences from those values reported by the National Research Council (1994). Differences in the AA concentration for the normal (Table 8) and low-phytin (Table 10) soybean meal ranged from 0 (phenylalanine) to 11.9 (glutamate) g/kg. Average true digestibility of all amino acids does not differ among the normal, low-phytin, and high-oil corn. True amino acid digestibility of the low-phytin soybean meal ranged from 87.1 for cysteine to 98.1 for tryptophan. The similarity in true amino acid digestibility among normal, low-phytin, and high-oil corn with ducks is consistent with another study with chickens (Han *et al.*, 1987), where it was reported that no differences in protein efficiency ratio or in net protein ratio between the normal and high-oil corn. The lowest true amino acid digestibility in corn is for lysine, presumably due to lysine being mainly deposited in the poorly digested aleurone layer. These observations indicate that the energy and amino acids in high-oil corn, low-phytin corn, and low-phytin soybean meal are well utilized by ducks. Furthermore, the metabolizable energy content of high-oil corn is higher than that of normal corn and low-phytin soybean meal has a higher energy value as well as digestible essential amino acid concentration than normal soybean meal for ducks.

Response to energy, nutrients, and enzymes: Adedokun and Adeola (2005) reported the results of experiments conducted with 3.4-kg White Pekin ducks to determine the apparent metabolizable energy (AME) and nitrogen-corrected AME (AME_n) values of 12 samples of meat and bone meal. The gross energy (GE), crude protein (CP), crude fat (CF), ash, Ca, and P contents of the meat and bone meal samples, on per kg dry matter

Table 7: Apparent metabolizable energy AME., nitrogen-corrected apparent metabolizable energy AMEn., true metabolizable energy TME., and nitrogen-corrected true metabolizable energy TMEn. kcal/kg. of feed ingredients for White Pekin ducks

Ingredients	Number of studies	AME	AMEn	TME	TMEn
Grains					
Barley	2	2,622-2,753	2,726-2,730	2,973-3,205	2,863-2,960
Corn	11	3,111-3,377	3,100-3,372	3.310-4,014	3,271-3,833
Low-phytin corn	1	3,412	3,391	4,050	3,847
High-oil corn	1	3,563	3,501	4,201	3,959
Oats Dehulled.	1	3,563	3,482	3,761	3,642
Pearl millet	1	3,392	3,350	3,612	3,484
Rice	1	3,421	3,452	3,740	3,612
Rye	1	2,633	2,691	2,952	2,851
Sorghum	3	3,021-3,312	3,038-3,260	3,339-3,682	3,310-3,567
Triticale	1	2,800	2,757	3,170	3,065
Wheat	1	3,262	3,144	3,461	3,300
Meals and byproducts					
Bakery meal	3	3,731-3,760	3,755-3,796	4,130-4,158	3,896-3,933
Canola meal	1	2,181	2,186	2,764	2,439
Corn gluten meal	1	4,044	3,695	4,367	3,934
Meat and Bone meal	12	1,781-3,916	1,772-3,662	Not Determined	Not Determined
Low-phytin soybean meal	1	3,018	2,579	3,539	2,959
Wheat middling	2	2,208-2,478	2,149-2,385	2,711-2,859	2,502-2,673
Wheat red dog	4	2,385-2,571	2,519-2,592	3,117-3,213	2,900-2,948

basis, ranged from 3,493 to 4,732 kcal, 496.7 to 619.1 g, 91.1 to 151.2 g, 200.3 to 381.9 g, 54.3 to 145.8 g, 25.6 to 61.7 g, respectively. The AME of the 12 samples of meat and bone meal are shown in Fig. 8 and ranged from 1,781 to 3,916 kcal/kg dry matter. When corrected to zero nitrogen retention, the AME_n were between 1772 and 3,662 kcal/kg dry matter (Fig. 9). The variation in AME was described by the regression equation AME = -7,272 + 5.000 GE (kcal/kg) – 19.43 CP (g/kg) – 29.51 CF (g/kg) -297.17 P (g/kg) + 106.09 Ca (g/kg) + 17.03 Ash (g/kg) with R^2 of 0.552 and SD of 753. Corresponding equation for AME_n= -7,389 + 4.584 GE (kcal/kg) – 16.74 CP (g/kg) – 25.11 CF (g/kg) – 218.24 P (g/kg) + 97.29 Ca (g/kg) + 7.95 Ash (g/kg) with R^2 of 0.598 and SD of 586. The results reveal that variation in each of the chemical components of MBM alone is not the sole determinant of AME or AME_n value of meat and bone meal but that the interactions among these components influence energy utilization in MBM for ducks.

There are few recent studies targeted at the response of ducks to amino acids. Elkin *et al.* (1986) reported that day-old male ducklings require between 3.82 and 4.22 g methionine/kg diet during the first 12 days of life. A 1998 publication reported that dietary supplemental tryptophan (0.2 to 0.6 g/kg) from either L-tryptophan or soybean meal linearly increased weight gain and feed efficiency in 3-week-old White Pekin ducks fed a diet containing 1 g tryptophan/kg (Adeola, 1998). Furthermore, common-intercept, multiple linear regressions in slope-ratio methodology performed using weight gain and gain:feed ratio as dependent variables and grams of supplemental tryptophan/kg of diet as the independent variable provided 94 and 92% tryptophan bioavailability in soybean meal relative to L-tryptophan, respectively. In the same study, the author conducted a linear regression of tryptophan deposition in the carcass on tryptophan intake and showed that the efficiency of carcass tryptophan retention above maintenance is 21% for ducks from 21- to 42-days of age. He *et al.* (2003) fed diets containing 2.6 to 5.4 g methionine/kg to Chinese Tsaiya ducks and observed the dietary methionine requirement for optimum egg production to be 4.5 g/kg of the diet. Attia (2003) also presented lysine and phytase effects on growth performance of ducks and showed that these effects were more obvious in younger than older ducks. Xie *et al.* (2004), in a 4 x 5 factorial experiment containing 4 cystine levels (3.25, 4.06, 4.87, or 5.68g/kg) and 5 methionine levels (2.85, 3.85, 4.85, 5.85, or 6.85 g/kg) evaluated the interrelationship between methionine and cysteine in corn-peanut meal diet for White Pekin ducklings from hatch to 21 days of age. The methionine requirement for maximum efficiency of feed utilization (5.85 g/kg) was higher than for maximum weight gain (4.85 g/kg) and from a quadratic model, the optimal methionine requirement of White Pekin ducklings from hatch to 21 days of age was estimated at 4.81 g/kg (95% of the level at maximum response). The requirement for cysteine from hatch to 21 days of age was not more than 3.25 g/kg and there were no significant interactions between methionine and cysteine on growth performance, plasma uric acid, and plasma homocysteine.

In three elegant studies, Timmler and Rodehutscord (2003) examined the response of White Pekin ducks to supplements of L-valine during the three-week posthatching period, using diets with basal valine concentration of 6.8 g/kg containing 18% CP and 2,990

Table 8: Nitrogen %. and amino acid %. contents of feed ingredients evaluated for amino acid digestibility

Item	Corn	Barley	Bakery meal	Canola Meal	Soybean Meal	Wheat red dog
Number of studies	4	1	1	1	4	3
Nitrogen	1.18-1.25	1.74	1.72	5.29	7.04 - 7.69	2.18-2.87
Indispensable amino acids %.						
Arginine	0.35-0.42	0.62	0.47	2.21	3.37-3.73	0.94-1.12
Histidine	0.22-0.28	0.26	0.26	0.98	1.19-1.33	0.41-0.45
Isoleucine	0.25-0.28	0.40	0.43	1.41	1.99-2.24	0.48-0.49
Leucine	0.90-1.01	0.78	0.89	2.54	3.48-3.69	0.95-0.96
Lysine	0.24-0.28	0.43	0.24	2.01	2.85-3.05	0.57-0.63
Methionine	0.17-0.18	0.19	0.19	0.70	0.65-0.72	0.24-0.26
Phenylalanine	0.36-0.38	0.58	0.58	1.46	2.34-2.42	0.61-0.62
Threonine	0.27-0.29	0.38	0.35	1.46	1.79-1.88	0.46-0.49
Tryptophan	0.05-0.06	0.12	0.12	0.45	0.58-0.69	0.19-0.20
Valine	0.35-0.40	0.56	0.53	1.79	2.14-2.29	0.68-0.72
Dispensable amino acids %.						
Alanine	0.55-0.59	0.47	0.43	1.57	1.91-2.15	0.63-0.71
Aspartate	0.49-0.53	0.68	0.58	2.54	5.11-5.40	0.93-1.04
Cysteine	0.18-0.21	0.28	0.29	0.94	0.71-0.73	0.34-0.36
Glutamate	1.34-1.42	2.65	3.54	6.38	8.13-8.54	2.91-3.34
Proline	0.61-0.67	1.13	1.29	2.09	2.21-2.24	0.99-1.07
Serine	0.32-0.40	0.42	0.50	1.44	1.99-2.01	0.54-0.55
Tyrosine	0.22-0.34	0.32	0.30	1.01	1.62-1.79	0.38-0.40

Table 9: True digestibilities amino acids %. of feed ingredients for White Pekin ducks

Item	Corn	Barley	Bakery meal	Canola Meal	Soybean Meal	Wheat red dog
Number of studies	3	1	1	1	3	2
Indispensable amino acids %.						
Arginine	84.50-86.66	8016	89.90	90.13	95.24-96.10	90.40-91.48
Histidine	95.40-98.07	81.40	93.50	86.66	94.18-96.10	91.90-95.03
Isoleucine	79.60-80.50	78.89	94.10	83.34	89.83-92.30	85.43-86.90
Leucine	89.90-90.54	81.77	93.60	85.72	89.97-92.60	86.60-87.95
Lysine	77.51-79.30	68.32	65.10	82.49	92.58-94.20	77.80-82.86
Methionine	87.30-92.65	81.22	86.90	87.38	90.30-91.13	81.50-88.50
Phenylalanine	87.10-88.85	85.21	94.30	86.34	91.84-93.90	88.10-90.46
Threonine	83.78-85.10	79.77	98.50	80.98	88.97-91.70	85.27-89.20
Tryptophan	100.62-109.70	91.93	103.40	95.46	94.83-97.90	94.10-96.22
Valine	80.10-85.75	77.34	91.00	83.57	88.31-90.60	84.20-86.28
Dispensable amino acids %.						
Alanine	89.92-95.70	66.47	95.60	83.38	84.67-89.00	79.75-81.60
Aspartate	79.10-80.08	73.32	85.70	83.55	91.63-93.50	82.30-82.50
Cysteine	80.83-85.20	84.15	103.30	88.63	82.84-90.30	86.81-90.30
Glutamate	89.50-90.50	89.72	95.30	90.41	93.33-94.60	92.40-93.54
Proline	89.16-90.90	90.21	98.50	83.95	89.47-94.20	94.14-94.90
Serine	77.93-84.30	80.95	95.20	83.30	89.42-92.10	84.96-90.30
Tyrosine	85.00-86.21	83.85	91.80	84.69	91.63-93.30	85.20-87.64

kcal ME/kg. Body weight gain, feed efficiency, and body accretion of protein and amino acids were determined. Also, a 5-day nitrogen balance study was conducted and the response of ducks to increasing valine concentration was described by exponential functions. Ducks significantly responded to the increasing valine concentration in growth, feed/gain ratio, and protein accretion. Ninety-five percent of y_{max} in body weight gain and protein accretion were achieved with 8.0 and 7.9 g valine/kg, respectively. The content of protein in gained BW was, on average, 149 g/kg without a significant valine effect. The valine content in accreted body protein was also unaffected by dietary valine (4.1 g/16 g N on average), which suggested that a major shift in body protein fractions did not occur. The overall efficiency of valine utilization was affected by dietary valine concentration and showed a maximum of 49%. Data from the balance study showed basically the same response of ducks, but the estimated optimum in dietary valine concentration was lower (7.0 g/kg).

Orban *et al.* (1999) reported that 3-week-old White Pekin ducks fed finisher diet formulated to contain 160 g crude protein/kg diet and 1.8 g non-phytin phosphorus/ kg diet responded to dietary supplementation of phosphorus (0, 0.9, and 1.8 g/kg) in form of monosodium phosphate. They reported increases in weight gain, plasma

Table 10: Nitrogen % and amino acid % contents of low-phytin corn, high-oil corn and low-phytin soybean meal SBM and true digestibilities of amino acids % for White Pekin ducks

Item	Amino acid content , %			True digestibility of amino acids, %		
	Low-phytin corn	High-oil corn	Low-phytin SBM	Low-phytin corn	High-oil corn	Low-phytin SBM
Number of studies	1	1	1	1	1	1
Nitrogen	1.38	1.44	8.46			
Indispensable amino acids %.						
Arginine	0.39	0.41	3.93	90.1	92.1	97.0
Histidine	0.27	0.26	1.29	95.8	96.1	95.9
Isoleucine	0.27	0.29	2.50	87.1	90.1	95.7
Leucine	1.11	1.21	3.67	94.3	95.7	94.9
Lysine	0.26	0.28	3.14	81.6	81.3	95.7
Methionine	0.17	0.17	0.85	87.1	87.6	94.3
Phenylalanine	0.33	0.36	2.41	88.7	91.8	95.4
Threonine	0.27	0.27	1.93	85.3	86.1	93.4
Tryptophan	0.07	0.06	0.75	95.9	96.0	98.1
Valine	0.39	0.41	2.66	87.8	88.4	94.4
Dispensable amino acids %.						
Alanine	0.64	0.63	2.18	95.8	97.1	91.5
Aspartate	0.48	0.52	5.75	83.6	84.9	95.6
Cysteine	0.22	0.20	0.78	79.7	79.3	87.1
Glutamate	1.66	1.40	9.62	93.3	93.4	96.5
Proline	0.61	0.64	2.44	87.0	88.4	91.7
Serine	0.39	0.43	2.21	93.2	94.6	95.5
Tyrosine	0.35	0.32	1.91	86.6	87.2	93.8

phosphorus concentrations, tibia and femur ash, and tibia and femur breaking strength when White Pekin ducks were fed from 3 to 6 weeks of age. In a more recent study, Rodehutscord *et al.* (2003) showed that White Pekin ducks require a dietary non-phytin phosphorus level of 3.4 (Days 1 to 21) and 2.3 g/kg (Days 21 to 49) based on phosphorus retention data. The authors concluded that the phosphorus requirement of ducks largely depend on the response criterion chosen. Furthermore, the authors showed that the marginal efficiency of utilization of supplemental phosphorus from monocalcium phosphate or other inorganic salts is not affected by age in ducks.

The preponderance of literature to date indicates that, at high levels, non-starch polysaccharides in grains reduce nutrient utilization and growth performance. Results of several studies in broiler chicks investigating the effects of dietary addition of non-starch polysaccharide degrading enzymes to wheat-, barley-, or rye-based diets identified the reduction of intestinal digesta viscosity as one of the major reasons for the positive effects of these enzymes. In ducks, Farrell and Martin (1998a) showed that enzyme supplementation of a diet based on sorghum, wheat, and rye bran did not affect duck weight gains or feed efficiency. In a series of duck studies using wheat-, wheat/rye-, or wheat/triticale-based diets, Timmler and Rodehutscord (2001) supplemented the different diets with xylanase (a non-starch polysaccharide degrading enzyme) and in some instances, body weight gains of ducks were improved in the first 21 days by enzyme supplementation. Furthermore, supplementation of diets with xylanase reduced the viscosity of intestinal digesta. The authors concluded that no consistent effect of xylanase supplementation of wheat-, wheat/rye-, or wheat/triticale-based diets on weight gains and feed efficiency of ducks could be expected.

Nutrient utilization and growth performance responses of White Pekin ducks offered diets containing low- or high-viscosity wheat supplemented with xylanase were investigated in the results of studies reported by Adeola and Bedford (2004). High-viscosity wheat depressed true metabolizable energy, and xylanase supplementation improved the true metabolizable energy more so for high- than low-viscosity wheat. There was also an improvement in weight gain and feed efficiency with xylanase supplementation of the high-viscosity wheat-based diet. Adeola and Bedford (2004) reported that ileal digestibilities of nutrients and energy were higher for low- than high-viscosity wheat-based diets; and xylanase supplementation improved energy, fat, nitrogen, and starch digestibilities. Given that xylanase supplementation of high-viscosity wheat assuaged its anti-nutritional effect, the authors surmised that digesta viscosity plays a role in anti-nutritional effects in wheat-based diets for ducks. The results indicate that the reduction in growth performance of ducks fed high-viscosity wheat is related to an increase in viscosity of duodenal and ileal digesta and a subsequent decrease in utilization of nutrients. As such, viscosity may be a credible quality response criterion for estimation of the nutritive value of wheat for ducks. Further, supplementation of high-viscosity wheat-based diet with xylanase mitigated the growth performance

Fig. 8: Apparent metabolizable energy AME., showing standard error bars, of twelve samples of meat and bone meal for ducks adapted from Adedokun and Adeola 2005.

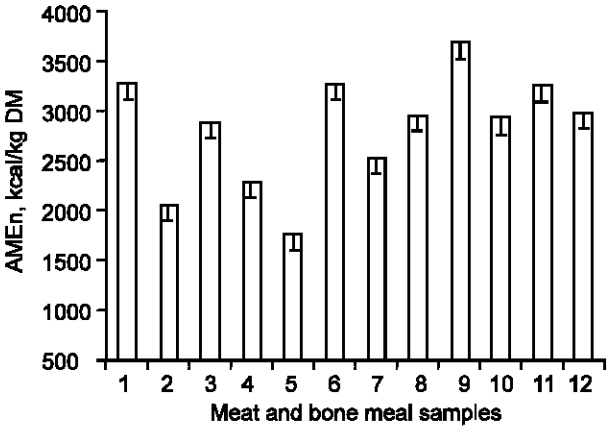

Fig. 9: Nitrogen-corrected apparent metabolizable energy AME_{n}., showing standard error bars, of twelve samples of meat and bone meal for ducks adapted from Adedokun and Adeola 2005.

reduction with accompanying decrease in duodenal and ileal digesta viscosity and a subsequent increase in nutrient utilization.

Growth performance, nutrient retention, and bone mineralization responses of ducks to dietary phytase supplementation have been reported (Farrell and Martin, 1998b; Martin *et al.*, 1998; Orban *et al.*, 1999; Attia, 2003). Feeding phytate-rich diets containing rice bran to White Pekin ducks from 2 to 19 days old, Farrell and Martin (1998b) observed that supplementation of these diets with phytase increased food intake and growth rate, whole-body retention of calcium and phosphorus, tibia ash, and magnesium retention in tibia ash. In another study, Martin *et al.* (1998) noted that the addition of phytase to these phytate-rich diets improved lysine and threonine digestibility in diets containing vegetable protein but not in diets with added animal protein added as fishmeal. Attia (2003) also presented lysine and phytase effects on growth performance of ducks and showed that these effects were more obvious in younger than older ducks. In two experiments conducted with White Pekin ducks from 21 to 42 days of age, Orban *et al.* (1999) observed that weight gain and feed intake increased with increased level of added dietary phytase. They also reported increased plasma phosphorus concentration response to dietary supplementation with phytase. In a detailed study of the effect of phytase on bone characteristics, Orban *et al.* (1999) observed that addition of phytase to the diets of White Pekin ducks improved bone mineralization as seen in increased mineral content and density of femur, tibia, and metatarsus (tibiotarsus). The authors noted that bone mineral content and density of the proximal epiphysis and diaphysis were improved when diets were supplemented with phytase. The proximal epiphysis is the growth plate region of the bone, where cell generation would be dominant resulting in the general lengthening of the bone and mineral mobilization and accretion in this area would be expected to be high. The diaphysis (shaft) consists of cortical bone with minerals bonded together; bone mineral content is a measure of Ca hydroxyapatite in grams per centimeter at a particular region along the length or width of bone; in this case at the midpoint of the shaft and the region of the proximal epiphysis. In the same report, dry matter, ash, breaking force, and several morphometric indices of femur, tibia and metatarsus of ducks were improved by phytase supplementation of diets. Using regression analysis, the authors estimated phosphorus equivalency of 750 phytase units for 21- to 42-day-old ducks at 500 or 600 mg phosphorus when plasma phosphorus concentration or bone characteristics, respectively were used as response criteria. The authors concluded that phytase can be used in finisher diets for ducks from 3 to 6 weeks of age to improve growth performance and leg bone development.

Worldwide, several non-traditional nutrient sources are available for formulation into the diets of ducks. Continued progress in efficient worldwide duck production requires, as a matter of urgency, nutritional evaluation of these non-traditional nutrient sources for the determination of optimal inclusion levels in diet formulations in order to attain safe, sustainable, and efficient production of duck meat that will contribute to meeting the growing need to satisfy human nutritional requirements for high-quality protein. The overview presented here as well as other studies demonstrate the need for more research to clarify the differences in nutrient utilization and bioavailability as it relates to ducks. The feeding procedure and method of excreta collection developed at Purdue University and described in this communication provides a viable alternative to pan collection and eliminates the pan-collection-derived

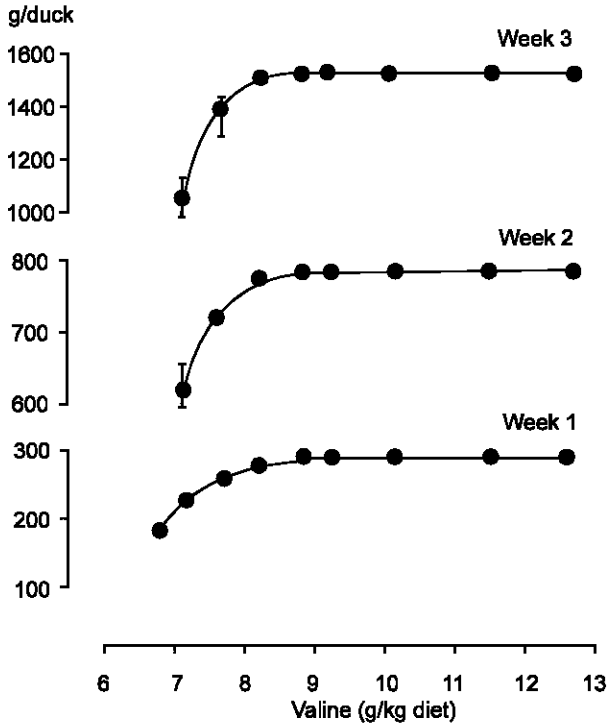

Fig. 10: Effect of increasing dietary valine concentration on BW of ducks at the end of each of the three wk on experiment Means and SEM, n = 3 pens of 14 ducks per treatment, 56 g initial BW. Parameter estimate resulted in the following functions:
wk 1: $y=288\times 1\text{-}e^{-1.452\times x-6.113}$, $r^2=0.90$, sy.x=11.3;
wk 2: $y=832\times 1\text{-}e^{-1.699\times x-6.278}$, $r^2=0.84$, sy.x=31.6;
wk 3: $y=1{,}528\times 1\text{-}e^{-2.169\times x-6.555}$, $r^2=0.89$, sy.x=58.1
Valine concentration needed to achieve 95% of the estimated plateau was 8.2, 8.0, and 7.9 g/kg for wk 1, 2 and 3, respectively (Timmler and Rodehutscord, 2003).

inherent errors associated with nutrient bioavailability research with ducks where collection and analysis of excreta is required. Furthermore, the procedures remarkably minimize the within-study variation in energy and nutrient utilization values in feed ingredients for ducks.

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