Energy Utilization of Growing Chicks in Various Nutritional Conditions

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ABSTRACT : For the last two decades, energy utilization of growing chicks has been studied more and more. This paper focuses on the energy utilization estimated by the metabolizable energy (ME) values and the efficiency at which ME is used for growth of chicks under various nutritional environment. Degree of saturation of dietary fats is responsible for nitrogen-corrected apparent metabolizable energy (AMEn) of fats. The effect of dietary fat sources on heat production depends on the kind of unsaturated fatty acids as well as the degree of saturation. Medium chain triglyceride shows lower AME and net energy than long chain triglyceride. Phytase as feed additives increases the AME values of the diet along with improvement of the phosphorous utilization. Ostriches have higher ability to metabolize the energy of fiber-rich foodstuffs than fowls. Their higher ability seems to be associated with fermentation of fiber in the hindgut. Proportions of macronutrients in the diets have influenced not only the gain of body protein and energy but also the oxidative phosphorylation of the chicken liver. Essential amino acids deficiency reduces ME/GE (energy metabolizability) little, if any. Growing chicks respond to a deficiency of single essential amino acids with the reduction of energy retained as protein and increased energy retained as fat. Thus, energy retention is proportional to ME intake despite deficiency, and efficiency of ME utilization is not affected by deficiency of amino acids. Effect of oral administration of clenbuterol, a beta-adrenergic agonist, on the utilization of ME varies with the dose of the agents. Although the heat production related to eating behavior has been estimated less than 5% of ME, tube-feeding diets decreases HI by about 30%. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 6 : 903-909)***

Key words: Metabolizable Energy, Heat Increment, Protein, Fat, Amino Acids, Chicks

INTRODUCTION

Utilization of energy by animals (partition of dietary energy into combustible energy and metabolic heat) has been studied since Lavoisier had understood that heat in animals results from oxidation of organic matters (nutrients) in the late 18 century. Animals have to ingest energy-yielding compounds and protein to maintain their life. Adequate quality and quantity of carbohydrate and fat as energy sources and protein as body constitute sources support reasonable animal production.

The partition of the food energy (gross energy: GE) is summarized in Figure 1. When animals eat feed, they cannot convert all the energy of feed into the energy of products which are useful for human. Part of ingested food energy is lost in the form of feces, urine and gases. The remaining energy is referred to metabolizable energy (ME) which is used to maintain the life and to produce milk, meat, and eggs. Efficiency of GE utilization has been estimated as the energy metabolizability (ME/GE) in the poultry. The energy metabolizability depends on mainly digestibility of GE and varies with species and age of animals, and foodstuffs or nutritional balances (Miller, 1974).

Efficiency of ME utilization in animals is defined as the relationship between energy retention or balance and ME consumption. The efficiency of ME utilization and heat increment (HI) is complementary. Heat increment of feeding is heat energy which is released on the processes of digestion and metabolism. The efficiency of ME utilization varies with the factors such as species, age, sex, physiological status (maintenance and production), environmental conditions (temperature, humidity and lighting), foodstuffs and quality and quantity of nutrient (De Groote, 1974). This paper focuses on the relationship between nutritional conditions and the energy metabolizability of diets or foodstuffs as well as the efficiency of ME utilization in growing chicks based on the literature appeared for the last 20 years.

DIETARY FATS AND OILS AND ENERGY UTILIZATION

Various fats and oils have been used as sources of energy and essential fatty acids. Fatty acid components of dietary fat are incorporated into poultry meat and eggs, and fat sources rich in polyunsaturated fatty acids are used in order to produce meat and eggs containing these fatty acids. It has been interested that fat sources with different fatty acids composition affect utilization of energy of diets in broiler chicks.

Young (1961) observed that AME values were generally higher for intact fat than for their respective hydrolyzed products with free fatty acids (FFAs). The amount of FFAs and degree of saturation of FFAs in the mixture of tallow and tallow acid oil, palm and palm acid oil and soybean oil

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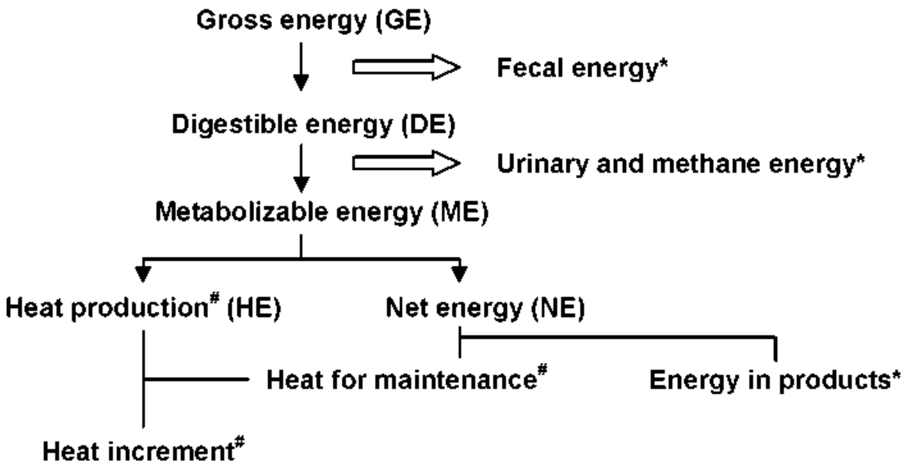

Figure 1. Energy partition in the body. * combustible energy. # metabolic heat

and soybean acid oil have been reported to reduce AME values of fats in broilers. The detrimental effect of degree of saturation seems to be more profound in the younger chicks (Wiseman and Salvador, 1991). Blanch et al. (1995) also have shown that soybean oil and linseed oil with high ratios of unsaturated to saturated fatty acids (U: S) had higher AME than those with lower ratios of U: S in 2-week-old broilers. Addition of small amounts of vegetable oils causes AMEn of the fat mixture higher than the expected calculated value (Sibbald, 1978). Ketels and De Groote (1989) observed that when fat sources are added to the basal diet from 2.5 to 12.5% of diet, AMEn of added fats increased with the U: S ratio up to 2.5. Thus it is conceivable that the degree of saturation of dietary fat is responsible for AMEn of fats.

The broiler diets have been formulated on the assumption that the absorbed fatty acids are used equally for metabolic purposes regardless of the degree of saturation of them. However, some studies have suggested that a diet containing much polyunsaturated fatty acids was oxidized more rapidly, which resulted in less body fat than a diet with saturated fatty acids in mammals. Incorporation of dietary fat to body fat is associated with energetic efficiency in chicks. Therefore, the effect of the degree of saturation of dietary fatty acids on the efficiency of ME utilization needs to be tested. Sanz et al. (2000) formulated diets with a constant energy to protein ratio and different ratios of unsaturated to saturated fatty acids. They found that total energetic efficiency (retained energy/AME intake) in broiler chicks was not significantly different between the lower ratio of U: S diet (mixture of tallow and lard) and the higher ratio diet (sunflower oil). The decreased degree of unsaturation of dietary fat by adding hydrogenated soybean oil to soybean oil lowered the energy metabolizability and increased heat production in broiler chickens (Dvorin et al., 1998). Rigoni et al. (2001) examined the effect of dietary polyunsaturated fatty acids on heat production of broiler cocks weighing 5 kg by feeding the cereal diets with soybean oil, linseed oil or fish oil at 2% of diets. Their results showed that cocks receiving the diet with fish oil have 8 to 15% larger daily heat productions (kJ/Wkg$^{0.75}$) than those on the other diets. This response may be partly associated with polyunsaturated fatty, because vegetable fats and fish oils differ in the kind of polyunsaturated fatty acids. Taking together these results, it is likely that the effect of dietary fat sources on heat production depends on the kind of unsaturated fatty acids as well as the degree of saturation.

Length of carbon chains in fatty acids has been responsible for their metabolic fate in the body. Medium chain fatty acids differ in absorption and metabolism from long chain fatty acids in mammals. Dietary medium chain triglyceride (glyceryl tricaprylate) affects lipid metabolism without reducing the efficiency of protein utilization (Furuse et al., 1992) and medium chain triglyceride per se has lower AME and net energy than long chain triglyceride (corn oil) in growing chicks (Furuse et al., 1992; Mabayo et al., 1992). Comparison of three soybean-corn type diets containing soybean oil (long chain triglyceride; LCT), coconut oil (medium chain triglyceride; MCT) or no fat source showed that coconut oil was used as much as soybean oil at the same dry matter intake (Danicke et al., 2001). These studies, however, consistently showed that *ad libitum* feeding the diet containing MCT or coconut oil suppressed food intake. This suppressive effect of MCT should be taken into account when it would be used as a dietary fat source.

Conjugated linoleic acid (CLA) has received attention according to anticarcinogenic properties in animals. Sell et al. (2001) has determined the AMEn values of CLA from two different sources for broiler chicks and observed that AMEn values of the CLA varied with the composition of fatty acid and dietary level of CLA. Relationship between the dietary CLA and the efficiency of energy utilization deserves study.

It is well known that addition of fat to diet has more beneficial effect on growth performance than expected on the basis of its energy value. This favorable effect is referred to 'extra-caloric' effect of fats and has been studied. Nitsan et al. (1999) have tried to determine the extra-caloric effect of the dietary fat with metabolizable and net energy systems in broiler chicks from 3 to 7 weeks of age. Soybean oil supplementation does not increase the ME values of diets. Addition of soybean oil to the diet containing 12.1 MJ/kg at the level of 30 g/kg increases net energy deposition but supplementation of the diet of 13.0 MJ/kg with soybean oil at the level of 60 g/kg slightly decreases net energy. It is likely that the extra-caloric effect of soybean oil depends on the amount of added fats and the dietary energy level.

IMPROVEMENT OF UTILIZATION OF ENERGY BY FEED ENZYMES

Various feed additives have been available not only for improving the dietary value or nutrient utilization but also for reducing the excretion of compounds polluting the environment. Feed enzymes, for example phytase, xylanase, and glucanase have become commercially used. Phytase is also expected to improve the utilization of dietary energy. AME values have been increased by addition of phytase to different types of poultry diets (wheat-based diet: Ravindran et al., 1999a; duck diets rich in rice bran: Farrell and Martin, 1998; corn-soybean broiler diet: Namkung and Leeson, 1999). The effects of supplemental phytase on AME seem to be associated with the digestibility of protein and amino acids (Ravindran et al., 1999b). The effects of xylanase and phytase on AME have been shown to be additive at lower levels of supplementation (Ravindran et al., 1999a). Other enzyme, cellulase supplementation has increased the AMEn of the broiler diets containing wheat, barley, naked oats and spring ryes (Friesen et al., 1992; Villamide et al., 1997).

SINGLE DEFICIENCIES OF ESSENTIAL AMINO ACIDS

Single deficiencies of essential amino acids have affected the metabolizability of dietary energy in growing chicks. Sugahara and his coworkers have determined the AME values of purified diets containing crystalline amino acids with deficiencies of some essential amino acids. Of the amino acids studied, lysine (Sugahara and Kubo, 1992a), tryptophan (Sugahara and Kubo, 1992b), isoleucine (Sugahara and Kubo, 1996) or histidine (Sugahara et al., unpublished) has no effect on the AME values with *ad libitum* feeding chicks. However, tube-feeding larger amount of the diets deficient in these amino acids than their *ad libitum* feed consumption decreases the AME values of corresponding diets. Furthermore, deficiencies of sulphur-containing amino acids (Sugahara and Kubo, 1992a) and arginine (Sugahara et al., 1985) decrease the metabolizability of the dietary energy regardless of feeding regimes. When early growing layer-type male chicks are fed a diet containing threonine at half the requirement, they cannot metabolize the dietary energy as much as chicks on the adequate diet (Kubo and Sugahara, 1995). These observations indicate that the inhibitory effect of deficiencies of the former four amino acids on the energy metabolizability of the diet is incidental to the food intake, and that of sulphur-containing amino acids, arginine and threonine is primary. Reduction of the concentration of threonine by 30% in the broiler diet decreases the AMEn value of the diet in males but not in females aged 45 and 53 days. Decreased AMEn values seem to be associated with limited amylase synthesis in the intestine due to inadequate supply of dietary threonine (Dozier et al., 2001).

OSTRICHES AND GUT MICROFLORA

Poultry feeds and feedstuffs have been estimated for their AME or AMEn values using mainly growing chicks and cockerels. These values have been applied to formulation of diets of other different poultry, such as, ducks, quail and turkeys. This application has hardly been proved till lately. Recently, some poultry species other than domestic fowl has higher ability to metabolize the dietary energy derived from fiber components. Jamroz et al. (2001) estimated the energy value of non-starch polysaccharides (NSP) for young broilers, ducks and geese on the diets with 14% of NSP and showed that NSP yielded about 3 kJ/g NSP ingested, and made up 3.5% of ME of the diets in three poultry species. Cilliers et al. (1997) reported that AMEn and true MEn values of maize, barley, oats and triticale are 10% higher for ostriches than for cockerels. When pollard, milled lucerne, milled Rhodes grass and milled wheat straw as fibrous sources were given to ostriches, emus and cockerels, twenty to 30% higher AME values were observed with ostriches than with others (Farrell et al., 2001). The higher ability to metabolize the dietary energy in ostriches seems to be associated with fermentation of fiber in the hindgut.

These findings lead us to examine the function of the fowl hindgut and microflora in the light of improving the nutritive value of fibrous foodstuffs, because some foodstuffs containing much fibrous components can be incorporated into the poultry feed. Chicks can obtain energy through the action of gut microflora (Hegde et al., 1982). Muramatsu et al. (1994) have studied the effect of the gut microflora on energy metabolism in growing chicks. Fasting heat production is lower in conventional chicks than in germ-free ones, implying that the presence of gut microflora prevents the host animals from losing energy as heat when dietary energy is not supplied. In contrast to this, the efficiency of ME utilization is lower in conventional chicks than in germ-free ones. These observations indicate that the gut microflora improves the energy metabolizability and exerts buffering action in ME utilization in growing chicks.

EFFICIENCY OF ME UTILIZATION AND MACRONUTRIENTS

The variations in composition of dietary carbohydrate, fat and protein have influenced the partition of dietary energy in animals including growing chicks. The combination of quite different proportions (from 0 to 100%) of these three nutrients in diets has been used to examine the response of ME, body protein gain and body energy gain (heat production) of growing chicks to changes in dietary composition (Toyomizu et al., 1985). Body protein gain reaches maximum at about 60% of protein energy of the dietary energy and thereafter slightly decreases. Body energy gain increases up to the level of 20% protein energy and then decreases toward 80% of protein energy. This implies that the responses of chicks to the dietary composition vary from body protein to body energy and increasing the dietary protein energy to more than 20% increases heat production. Dietary composition has modified not only the response of whole body but also bioenergetic function in the specific organ mitochondria of rats and chicks. Toyomizu et al. (1992) found that hepatic ATP synthesis significantly decreased with increasing dietary protein level from 7 to 61%, which was parallel to the decreased body fat content and suggested that the reduced oxidative phosphorylation in liver of chicks on a diet with higher proportion of protein partly contribute to the decreased deposition of body fat.

EFFICIENCY OF ME UTILIZATION AND AMINO ACID COMPOSITION

Dietary protein is used for mainly body protein deposition in growing animals and its quality or the composition of amino acids affects the efficiency of protein utilization. In addition, many studies have argued about that dietary levels of protein and protein quality or balance of amino acids of diets influence the efficiency of ME utilization for growth in growing chicks. Most of early studies has shown that the disproportion of dietary amino acids increased HI and decreased the efficiency of ME utilization for growth (Shoji et al., 1966; Tasaki et al., 1972; Ueda et al., 1981; Yanaka and Tasaki, 1980).

Some observations different from earlier studies have been reported. Sibbald and Wolynetz (1986) showed that the retention of energy as protein and as fat decreased and increased respectively as the dietary lysine increased in broiler chicks fed in a given amount of ME. Total energy retention increases with true ME intake at any dietary lysine level. Feeding diets containing some essential amino acids (arginine, lysine, methionine+cystine, tryptophan, threonine, isoleucine) at 50% of Illinoi's reference amino acid does not alter HI. Body energy gain is proportional to ME intake despite deficiency (Sugahara et al., 1985; Sugahara and Kubo, 1992a; 1992b; 1996; Kubo and Sugahara, 1995). Kino and Okumura (1986) have shown a similar observation when chicks are fed diets devoid of single essential amino acids in a given amount of feed. The results of studies show that amino acid deficiency affects the partition of ME into body protein and fat: the retention of energy as protein and as fat decreased and increases respectively. Furthermore, these observations disagree with Kleiber's concept stated as follows: "a diet is deficient in any nutrient whose addition decreases the calorigenic effect of the ration" (Kleiber, 1975).

Kim and MacLeod (2001) formulated the diets with different lysine: CP ratios to examine the variation of heat production associated with protein accretion. They observed that body weight increased as the lysine concentration increased, though heat production corrected for body weight difference was not significantly different among the diets. In connection to this, a two-fold difference in nitrogen excretion induced by the dietary manipulation of lysine concentration is followed by similar heat production (MacLeod, 1997). It has been recognized from these studies that disproportion of amino acids, especially deficiency of single essential amino acids, reduced body protein retention but increase neither heat production nor HI. The diet deficient in essential amino acid is used less efficiently for protein accretion and amino acids not available for protein deposition enter the pool of substrates as energy sources. These amino acids may be oxidized efficiently as much as other substrates such as carbohydrate and fat and not induce HI. Energy cost of uric aid formation may be provided through oxidation of excess amino acids (MacLeod, 1997) which are not used for protein synthesis and not enough to explain the increase in heat production (Yanaka and Tasaki, 1980).

Furthermore, energy expenditure required for protein synthesis makes up 10 to 20% of total heat production (Kita et al., 1993). There has been an inverse relationship between biological values of diets and the efficiency of ME utilization for growth in broiler chicks, because of the extra energy cost of protein deposition in chicks on the diet with higher biological value (Nieto et al. 1995). This observation is similar to that by Toyomizu et al. (1985) who found that body protein retention and energy retention in growing chicks reached maximum at 60% and 20% of the dietary protein energy respectively. The efficiency of ME utilization for energy retention depends on the partition of ME for protein retention and for fat retention and the energy cost of retained protein and fat.

EFFICIENCY OF ME UTILIZATION AND REPARTITIONING AGENTS

Oral administration of some beta-adrenergic agonists increases muscle and decreases fat accumulation in mammals and birds. These compounds are thought to be useful for preventing the birds from undesirable retention of body and abdominal fats (Dalrymple et al., 1984). Efficiency of ME utilization depends on partly the partitioning of the nutrient into protein and fat. Therefore, it is worth examining if feeding the diet containing beta-adrenergic agonist affect the heat production. When 7-day-old broiler chicks were fed the diet to which was added clenbuterol, a beta-adrenergic agonist, at 0.33 mg/kg for 14 days, they were able to metabolize the dietary energy and retain body energy as much as chicks on the diet without clenbuterol (Takahashi et al., 1993). Broiler chicks receiving the dietary clenbuterol (1mg/kg) have increased heat production and protein retention, and decreased energy retention and fat deposition (Xiyi et al., 1994). In this connection, Hamano et al. (1999) observed no effect of clenbuterol on hepatic oxygen consumption in broiler chicks. The effects of beta-adrenergic agonists on the body composition have been known to vary with species, breed, age, sex, and duration of supplementation (Buyse et al., 1991). It is likely that the effect of beta-adrenergic agonists on energy utilization also depends on these factors.

HEAT INCREMENT OF FEEDING AND FEEDING ACTIVITY

The increased heat production after ingestion of diets by fasted animals is estimated to be heat increment of feeding (HI). HI consists of mainly the heat resulting from digestive and metabolic process in the animal. It is worth examining if nutritional conditions or dietary composition of nutrients affects HI. In most studies on HI, contribution of eating activity to HI has been hardly estimated so far. Some studies have determined the magnitude of heat production related to eating behavior. Van Kampen (1976) reported that energy expenditure associated with eating behavior was 3% of the daily heat production by *ad libitum* fed hens. Li et al. (1991) has studied the HI with hens limited-access to diets and found that energy cost of eating activity was 0.8% of ME consumed when HI was estimated to be 16% of ME intake. MacLeod (1991) used the tube-feeding method to prevent cockerels from eating behavior and observed that HI (kJ/g food) was 30% lower in tube-fed birds than in *ad libitum*-fed ones. The difference seems to be explained by circumvention of feeding activity. In addition, Wang and Ito (2001) have shown that time spent eating has more pronounced effect on heat production than that of standing in growing broiler chicks using multi-regression analysis of heat production. Activity component of HI is larger in cockerels than in hens if the specific dynamic effect of the diet is similar between sexes (Balnave, 1974). Dietary composition or nutritional disproportion has received little attention with respect to feeding behavior. Recently, Sugahara et al. (unpublished) have shown that when growing chickens were fed *ad libitum* a lysine-free diet for 8 hours, they pecked and ate less the diet and spent more time in standing than the control birds. These observations indicate that variations of eating behavior should be considered to estimate HI.

CONCLUSION

Many informations on the ME values and the efficiency of ME utilization of the familiar foodstuffs for poultry have been accumulated. In the future, technological developments including manipulation of nutrient content of crops and recycling the discarded materials would make various materials to be available for poultry foodstuffs. These novel foodstuffs will be evaluated from the viewpoint of energy utilization for the reasonable animal production.

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