

BIBLIOGRAPHIC REVIEW

FORMULATION OF DIETS FOR POULTRY: THE IMPORTANCE OF PREDICTION EQUATIONS TO ESTIMATE THE ENERGY VALUES

FORMULACIÓN DE DIETAS PARA POLLOS: LA IMPORTANCIA DE USAR DE ECUACIONES DE PREDICCIÓN PARA ESTIMAR LOS VALORES DE ENERGÍA

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PALABRAS CLAVE ADICIONALES

Alimentación animal. Alimentos. Energía metabolizable. Balance de nutrientes.

SUMMARY

The search for more precise information about the energy values of diets is an important factor in the preparation of feed for poultry. There are several factors that can influence these values, such as the chemical composition of foods, processing ingredients or the age and sex of birds. Such variations are constantly leading to incorrect formulations that directly reflect on performance and carcass quality. In this sense, the use of prediction equations based on the chemical composition of foods has been of great value and have been replacing the use of tables of food energy composition, especially when considering the principle of meta-analysis in the development of these equations. Meta-analysis consists of a statistical methodology where different experimental conditions are taken into consideration, such as genetic, density of creation, age, among other. In the literature, different prediction equations can be found, however, further studies consisting new databases to fit these equations and studies of performance with poultry comparing different equations and tables to estimate the energy value of feedstuffs are important to check the efficacy of these equations. New lines of research should be directed to draft the most appropriate equations to meet the needs of birds in various conditions, like different phases of growth, genetic, processing of foods and others.

RESUMEN

En la actualidad, la búsqueda de información más precisa acerca de los valores energéticos de las dietas es un factor importante en la preparación de alimentos para pollos. Hay varios factores que pueden influir en estos valores, tales como la composición química de los alimentos, los ingredientes, la edad y sexo de las aves. Estas variaciones están constantemente dando lugar a formulaciones incorrectas que reflejan directamente en el rendimiento y calidad de la canal. En este sentido, el uso de ecuaciones de predicción basadas en la composición química de los alimentos ha sido de gran valor. Ellos han sido la sustitución del uso de las tablas de composición de alimentos de la energía, especialmente cuando se considera el principio de meta-análisis en el desarrollo de estas ecuaciones. Sin embargo, estas nuevas líneas de investigación debe ser dirigida a redactar las ecuaciones más adecuadas para satisfacer las necesidades de las aves en diversas condiciones de la creación.

INTRODUCTION

Regarding the development of new concepts in feed formulation, coupled with the rapid development of poultry industry in recent years, one of the major problems faced by nutritionists today is the correct balance of nutrients for birds in different

stages of production. The problem is further aggravated when one considers the advances in genetics, health and management, resulting in a great variety of production systems.

In order to adequately meet the nutritional requirements of animals for the expression of the maximum productive potential, it is necessary to formulate balanced diets and avoid excessive polluting elements, like N, P and K, in feces and improve the performance of the animals, reducing the cost of production. Thus, one of the crucial points of the feed formulation is to obtain accurate values of the energy composition of foods.

The energy is important from the standpoint of a balanced nutritional diet, due to its participation in the regulation of consumption. Excessive or deficient energy diets can reduce the performance due to the unbalance of nutrients in metabolism. Thus, the correct adjustment of energy level in diets is important to guarantee the efficiency of production. However, one of the biggest problems today is the knowledge of the actual composition of food energy, which directly interferes with the energy levels of feed and, consequently, in its balance of nutrients.

In the literature, several methodologies to estimate the energy values of foods for broilers are found, most of them using in vivo assays (Sibbald and Slinger, 1963; Sibbald, 1976; Farrel, 1978; Borges *et al.*, 2004; Dourado *et al.*, 2010). The biggest problem is that these techniques are time and costly consuming, which difficult their use in the poultry industry. Moreover, the use of tables (Janssen, 1989; NRC, 1994; Rostagno *et al.*, 2011) does not have the same precision, since the values given correspond to the average obtained from different studies. Moreover, recently, some studies (Nascimento *et al.*, 2009; Silva *et al.*, 2010; Alvarenga *et al.*, 2011) have tested different equations to predict the

energy value of foods before their use in feed formulation, which can be a promising technique in formulating diets for poultry.

Therefore, the main objective of this review is to present the main factors affecting the energy values of foods used in the preparation of diets for broilers and the major impacts caused by unbalanced diets. In addition, this review intends to propose alternatives to improve the performance, carcass quality and use of nutrients by birds.

ENERGY VALUE OF FOODS

The diversity of foods and subproducts used in feed formulation for poultry indicate the necessity of understanding their nutritional values, aiming its better utilization. The accuracy of the values of chemical composition, energy and digestibility of nutrients is essential to reducing costs and improving productivity.

One of the most important factors to consider in animal nutrition is the energy generated by the transformation of nutrients during metabolism. According to Duarte *et al.* (2007), the energy level of the diet can modulate the feed efficiency in two ways: first, with increasing dietary energy, the energy needs of birds are reached with lower consumption and second, the growth rate can be improved with higher levels of energy, directing the use of crude protein in diet for the deposition of muscle tissue instead of energy generation.

There are different ways of expressing the energy content of food. The most used is the metabolizable energy (ME), once the digestible energy is unusual for birds and the determination of net energy, besides being difficult to measure, may vary depending on the physiological conditions of the birds by taking into account the heat lost during digestive and metabolic processes of the body (NRC, 1994).

ME can be represented in two ways:

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apparent metabolizable energy (AME), which contains the energy present in the endogenous losses and true metabolizable energy (TME), which ignores the endogenous losses (NRC, 1994). The endogenous losses represent losses from sloughing of cells of the gastrointestinal tract and digestive enzymes. They are usually quantified in fasting birds, which does not represent the physiological state of the animal during the digestive process (Borges *et al.*, 2004). Thus, the most commonly used is the AME, especially because of the difficulty in determining the energy values of endogenous losses in normal birds (Dourado *et al.*, 2010).

In determining the AME of foods commonly used for birds, it is common to use the correction of the energy values for the nitrogen balance of zero. This is justified by the fact that nitrogen once retained in the body, if catabolized, it is excreted in the form of energy-containing compounds, such as uric acid (Sibbald, 1982). In other words, it is the demand for energy to metabolize stored nitrogen, if it is to be excreted. Hill and Anderson (1958) proposed a correction value of 8.22, which corresponds to the amount of gross energy (kcal) obtained by the complete combustion of 1 g of urinary N in the form of uric acid. This constant value has become universally used, since about 80 % of the nitrogen found in the urine of birds is in the form of uric acid (NRC, 1994). Thus, it is possible to obtain the apparent metabolizable energy corrected for nitrogen (AMEn). The more N retained by the bird, the greater the energy required to metabolize this compound in the form of uric acid, therefore, the lower the AMEn in relation to AME. Thus, the calculation of flows from one food should be close, regardless of the nitrogen balance of the bird.

DETERMINATION OF AMEn VALUES OF FOOD

The effectiveness of a formulation

depends on the precision and accuracy with which the energy values of foods are determined. Currently, several methods are available to evaluate the composition of food energy, often conflicting results are observed.

The methods used are biological assays (*in vivo*), which represent the traditional method of total excreta collection (Sibbald and Slinger, 1963), the precise feeding (Sibbald, 1976), the fast method (Farrell, 1978). In addition, non-biological tests can also be applied as *in vitro* digestibility or the use of prediction equations based on chemical composition of foods.

The problem of biological assays is the execution time and economic cost, in addition to the question of birds wellbeing. Currently, recent studies have shown greater applicability of using prediction equations (Silva *et al.*, 2010; Alvarenga *et al.*, 2011), since values of the chemical composition of foods can vary depending on several factors such as soil fertility, planting date, genetic and others. Through this technique, knowing only the chemical composition of a given food in the laboratory, it is possible to predict the AMEn of these foods. On the other hand, most of these techniques do not take into account values of digestibility of nutrients, considering that these values are the same, regardless of age and condition of the birds. Anyway, as the determination of energy values of foods is dependent on calorimetric bomb and a specific methodology with animals, the use of prediction equations can be of great value.

FACTORS THAT AFFECT THE VALUES OF AMEn OF FOOD

CHEMICAL COMPOSITION OF FOOD

The concentration of nutrients from food is the main factor that influences the values of AMEn of food. Foods with higher amounts of lipids, for example, have higher

values of AMEn (Zhou *et al.*, 2010). This is justified by the fact that lipids reduce gastric emptying by increased secretion of cholecystokinin in the duodenum, improving the digestibility of proteins. Moreover, the presence of this hormone in the bloodstream stimulates the secretion of digestive enzymes by the pancreas, thus contributing to higher digestibility of protein and carbohydrates.

Vieira *et al.* (2007), analyzing the energy values of 45 corn hybrids for broiler chickens, found that AMEn ranged from 3,405 to 4,013 kcal/kg. The authors concluded that this result may be related to different levels of lipids in these foods. Wang and Parsons (1998), evaluating energy values of corn with increasing levels of ether extract (from 5.9 % to 6.6 % and 9.5 % dry matter), also found positive relationship between the energy values and levels of oil in food.

Besides oil, the presence of non-starch polysaccharides (NSP) may also influence dietary AMEn of food. Tabooka *et al.* (2006) observed increased feed consumption when NSP was included at moderate levels in diets for chickens. Mourão *et al.* (2008), besides the increase in consumption also observed a reduction in weight gain of broilers at 35 days of age, when evaluating increased levels of NSP, represented by citrus pulp, 1.4 to 4.2 % in the dry matter. These fibrous components prevent the access of digestive enzymes to cellular components of food, reducing the efficiency of absorption. Moreover, they are able to retain water, stimulating the formation of gel and increasing the viscosity of the bolus. This somewhat reduces the residence time of digesta in the small intestine, which is the main site of absorption of nutrients.

Nunes *et al.* (2005) reported that the mineral matter content in food also influences the values of AMEn. These authors found that two samples of meat and bone showed distinct values for AMEn

(2.307 and 1.488 kcal/kg in DM) with different levels of mineral matter (25.54 % and 29.59 % in DM, respectively). Similar results were observed by Generoso *et al.* (2008), who affirmed it could be related to the low digestibility of this fraction food.

CONSUMPTION AND LEVELS OF SUBSTITUTION OF FOOD

Consumption by the bird is also directly related to the determination of the energy value of food. In a study by Borges *et al.* (2004) in order to evaluate the effect of food consumption by the method of feeding on the energy values of wheat and some of its products, it was found that the AME and AMEn values were higher with higher consumption. These authors reported that when consumption is high, the influence of endogenous losses is smaller and, on the other hand, when consumption is low, the endogenous losses may influence the energy values.

Another relevant factor is the level of inclusion of the tested food to the reference diet using the substitution method. In the traditional method for determining the values of AMEn, the substitution levels of plant and animal ingredients in reference diets generally range from 20 % to 40 % (Borges *et al.*, 2004; Nascimento *et al.*, 2005; Nunes *et al.*, 2005). These diets represent nutritionally unbalanced feed, which can interfere in determining the correct values. Nascimento *et al.* (2005) found that with increasing substitution levels (5, 10, 20, 30 and 40 %) of basal diet for poultry meal and feather, a decrease of the energy value of food was found.

PROCESSING OF THE INGREDIENTS

The process by which food is subjected interferes with the digestibility of nutrients and can change its energy value. Some processes such as extrusion, micronization and cooking have been used in order to modify the initial structure of the molecules

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of nutrients, providing better performance of the complex during the enzymatic digestion process (Moreira *et al.*, 2001).

Considering the type of processing, Café *et al.* (2000) observed that the AMEn values of extruded soybean were higher than those found for roasted soybeans by steam and also for soybean meal with oil. On the other hand, the main aggravating factor is the quality of processing, which can vary from one manufacturer to another. Carvalho *et al.* (2004), working with corn of different drying temperatures (80, 100 and 120 °C), found a reduction of the AMEn values, without changing the chemical composition and gross energy value of food. Thus, industrially processed foods may differ among themselves, contributing to energy imbalance in the diet.

Animal products are the ones that have variations in their energy values. Brugalli *et al.* (1999) evaluated different particle sizes of meat and bones and found that larger particles (59 mm) had lower levels of AMEn than fine (42 mm) and medium (51 mm) particles. Scapim *et al.* (2003), studying different ways of processing feather and blood flours, found no significant differences between the energy values, with lower values of AMEn with increasing processing time. In addition, Kim *et al.* (2010) observed that enzymatic milling during the processing of corn distillers dried grains can increase the energy values of this feedstuff used for broilers. These results suggest a search for information and studies that can predict the actual energy values of feed stuffs for broilers.

AGE AND SEX OF BIRDS

The age of the bird is also an important factor to determine the AMEn. Brumano *et al.* (2006) found that younger birds (21 to 30 days) have less capacity for digestion and absorption of nutrients in relation to older birds (41 to 50 days). According to the authors, the digestive system in young birds is still in development, while in older animals

it is larger and more developed. Kato *et al.* (2011) suggest that the activity of digestive enzymes, such as pancreatic and of adsorption increases with the age of the bird, reaching higher levels, on average, to ten days of age and, thereafter, becomes constant. Therefore, further studies should be conducted considering the influence of bird age and nitrogen balance on the values of AMEn for food.

The age of the birds is also related to their ability to use fiber, since older birds have higher microbial activity in the cecum. According to the reports by Batal and Parsons (2002), young birds (first or second week of age) are less efficient in the use of food fiber.

Kato *et al.* (2011), working with different corn and soybean meal, found that poultry between 21 and 42 days of age have the same ability to harness the energy content of food. Working with birds from 41 to 50 days old, Brumano *et al.* (2006) found energy values by 13 % higher for the period from 21 to 30 days. Mello *et al.* (2009) also observed that the age of birds influenced the values of AMEn of soybean meal and feather meal, and the values obtained within 10 to 17 days of age were lower than those found in other phases of growth (26 to 33 and 40 to 47 days) and roosters. Calderano *et al.* (2010) emphasize that the variation of the AME and AMEn values obtained for food with the birds at different ages shows that the use of a single value of ME for all stages of creation can lead to errors in energy values of diets, especially for birds in the first weeks of age.

Regarding gender, there is a consensus in the literature relating to its effects on the utilization of nutrients. Nascif *et al.* (2004) found 2 % higher energy values of some types of oils and superior fats for male broilers compared to females. Ravindran *et al.* (2004) also observed the effect of gender on the values of AMEn feed when working with birds from the third week of age. In fact, Dozier *et al.* (2011), considering the perfor-

mance during 36 to 42 days of age, observed that male broilers responded more to higher AMEn levels in diet than female broilers.

PERFORMANCE AND NUTRIENT UTILIZATION IN TERMS OF DIETARY ENERGY LEVELS

One of the biggest challenges nowadays is to match the energy levels of the feed requirements for poultry. As previously noted, many are the factors that can lead to errors in designing and may lead to different responses of animals. Errors in the estimation of energy values of food can lead to diets with lower or higher energy levels, or lipids, which in turn also has direct relation with the performance of birds.

Several studies show the relationship of energy and lipid levels with the performance of birds. When evaluating the performance of broilers from 1 to 49 days of age receiving diets with different levels of oil and energy, Rosa *et al.* (2000) found that energy values ranging from 2900 and 3200 kcal/kg did not affect weight gain, but have a direct relationship with consumption and feed efficiency. Albuquerque *et al.* (2003) studied two energy levels (3200 and 3600 kcal/kg) from 21 to 56 days of age and found that the highest level reduced weight gain, probably due to lower feed consumption and nutrients.

Rocha *et al.* (2003) reported that levels of ME ranging from 2850 to 3000 kcal/kg did not affect the performance or the digestibility of dry matter and nitrogen in broiler chicks in phase one to seven days old. Similar results were observed by Maiorka *et al.* (1997) that evaluated diets containing 2900, 3000 and 3100 kcal/kg for poultry in the same age. As for the period from 7 to 14 days, these authors observed greater weight gain and better feed efficiency in birds fed with higher levels of energy. The explanation for these results is that birds in the first week still have influence of the yolk and still are in a transition phase between the use of

endogenous nutrients (yolk sac) and exogenous (diet).

Mendes *et al.* (2004), when considering the effects of dietary energy ranging from 2900 to 3200 kcal/kg, observed that there was a higher feed consumption and worst feed efficiency in the period of 1 to 42 days of age, as it reduced the level of energy in feed. In addition, there was a linear increase in abdominal fat, although no effect on carcass yield and cuts.

When evaluating diets with varying levels of AMEn 3050 to 3350 kcal/kg for broilers from 22 to 43 days old; Sakomura *et al.* (2004) observed that the highest energy level improved performance. The authors explain that this fact can be attributed to the extracaloric effect of oil, which represents the increased availability of nutrients from food. The mean value (3200 kcal/kg) showed a better efficiency of energy utilization for protein deposition and, consequently, better quality of carcass, although the values of carcass and breast yield were not affected by energy levels in the diet.

Duarte *et al.* (2007) evaluated different energy levels (3200 and 3600 kcal/kg) on performance and carcass quality of broilers between 42 and 57 days old. The authors found that the energy levels did not determine significant differences in carcass quality, but noted that the highest ME level improved performance of birds.

Most studies show that ME levels ranging from 2900 to 3200 kcal/kg did not show significant results in the quality of carcass, but changes in performance can be verified (Albuquerque *et al.*, 2003; Mendes *et al.*, 2004; Duarte *et al.*, 2007). Based on information in the literature, it is assumed that with energy levels above or below this range, losses in performance occur and the quality of carcass worsens.

ESTIMATION OF ENERGY VALUES BY PREDICTION EQUATIONS

For years, the possibility of using

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equations to estimate the energy values of foods has been investigated. Several researchers have obtained equations to estimate ME through the chemical composition of foods (Borges *et al.*, 2003; Robbins and Firman, 2006 and Nascimento *et al.*, 2009). This is due mainly to the difficulty of assessing the availability of energy and the importance of knowing the energy content of food.

According to Sakomura and Silva (1998), the concentration of nutrients found in various cereals food composition tables are not reliable for the formulation of diets, being the variety of cultivars the main factor that determines the diversity of values. Borges *et al.* (2003) reported that with so many variations in energy values, it is not safe for the industries to use the table values. However, it would be extremely costly and difficult to submit all items of raw materials to *in vivo* assays in order to obtain the values of all energy from food. On the other hand, it would be possible to get the chemical compositions, such as crude protein, fiber, ether extract, among others. In this case, the use of prediction equations considering the chemical composition of food could be of great value.

Currently, many studies have presented equations for predicting the energy values of feedstuffs for broilers, however, not every attempt to relate chemical composition and energy has been successfully obtained (Zonta *et al.*, 2004; Nascimento *et al.*, 2009; Alvarenga *et al.*, 2011). Many seemingly well-adjusted equations to the original data, often do not respond satisfactorily when tested in practice, since the equations are based only on the chemical composition of foods, not taking into consideration, for example, the age of the birds and the digestibility of nutrients in each food. In this case, one of the criticisms of the prediction equations is the fact that proteins, carbohydrates and lipids are considered equally digestible in all foods. As previously

noted, several factors can affect the digestibility of nutrients in birds, which can reduce the reliability of the use of the equations.

For the development of a prediction equation or evaluation of its quality, numerous factors highlighted above must be taken into consideration. The use of two equations with four variables may provide greater easiness, since they require fewer laboratory tests. Ideally, the variable constituents should come from simple and routine analysis. However, there are some equations that depend on costly equipment as determined by the equations of Robbins and Firman (2006) that rely on calorimetric and atomic absorption spectrophotometer.

Several studies with prediction equations can be found in the literature. Based on data from several experiments in Europe, Janssen (1989) developed the European Table of Energy Values for Poultry Food, in which are presented series of prediction equations for AMEn values for various food groups. However, the author points out that, for food whose chemical composition ranges far beyond the average presented, the equations can lead to different prediction results. Although many factors may affect the precision or applicability of an equation, Zonta *et al.* (2004) concluded that the equation proposed by Janssen (1989) specific for soybean meal (AMEn = 37.5 CP + 46.39 EE + 14.9 NFE) showed good applicability.

In work done by Dolz and De Blas (1992), the best equation for predicting energy values of foods of animal origin (AMEn = -910 + 44.8 CP + 83.6 EE; $R^2 = 0.96$) were obtained when two variables were used, protein and fat, which were responsible for explaining more than 96 % of the total variability in the estimates of AMEn values for meat and bones.

Nunes *et al.* (2001), working with the grain of wheat and some by-products, obtained equations to predict the AMEn

content of these foods, noting that the equation composed of crude protein and neutral detergent fiber (NDF) was the best fit ($AMEn=4754.02 - 48.38 CP - 45.32 NDF$; $r^2=0.98$).

Borges *et al.* (2003), working with equations to estimate energy values ($AMEn=4337.0 - 202.0CF - 156.8EE$; $R^2=0.93$) and wheat by-products, observed that the crude fiber was the variable that best correlated (negatively) with the values of metabolizable energy, however, alone does not lead to a good fit of the equation. By other hand, Amerah *et al.* (2009) concluded that the broiler performance depending on the fiber particle size and this effect can be related to the energy use of the feedstuffs.

Robbins and Firman (2006) discuss that the prediction equation for true metabolizable energy corrected for nitrogen ($TMEn$) using variables such as gross energy, iron, calcium, potassium and mineral mix ($TMEn=-486 + 71.2 \text{ moisture} + 0.9 GE - 0.2 Fe + 67.7 Ca^2 + 1036.7 K^+$; $R^2=0.98$) is more effective in determining the energy from poultry by-product flours. Although requiring sophisticated equipment, it is still worthy since there is no need of animal use.

Regarding corn, Rodrigues (2000) determined the $AMEn$ of 19 hybrids, and by-products of corn, millet and soy products using both methods of collection of excreta with broilers and forced feeding of roosters. Thus, equations were adjusted to predict the energy values of corn food group ($AMEn=4021.8 - 227.55 Ash$; $R^2=0.92$) and soybean by-products ($AMEn= - 822.33 + 69.54 CP - 45.26 ADF + 90.81 EE$; $R^2=0.92$, being $ADF=$ acid detergent fiber). Although, they were not suitable in some cases, such equations composed of one to four variables, made good predictions in most cases for the energy values of foods in the group of corn and soybean.

Unlike earlier studies, Nascimento *et al.* (2009) established equations for predicting energy values of concentrate used for broilers, using the principle of meta-

analysis. This principle uses records of sex and age of the birds, which seems to be feasible in the development of new equations. The advantage of this technique is the development of equations that can be applied to birds in different physiological phases. The authors pointed equations ranging from two to five factors, all considering, at least, neutral detergent fiber and ether extract (EE). Recently, Alvarenga *et al.* (2011) showed that all the equations properly estimated the $AMEn$ from various food protein and energy concentrates, but the equation $AMEn= 4101.33 + 56.28 EE - 232.97 Ash - 24.86 NDF + 10.42 ADF$; $R^2=0.84$ showed the best results. Also Rochell *et al.* (2011) showed some $AMEn$ prediction equations but no validation studies were found until then.

Undoubtedly, advances in estimation procedures and the development and validation of new methodologies for predicting the energy values of feedstuffs for poultry will be of great value. In the future, new techniques of elaborating the equations will predict more accurately the energy values of foods.

CONCLUSIONS

The advance of modern techniques to estimate the energy values of feedstuffs for poultry has been considerable in recent years. The applicability of prediction equations formulated by the modern techniques of analysis has replaced the use of tables to know the values of $AMEn$ of food. Recent studies have been shown that some equations are efficient in estimate this energy values. However, the use of these equations requires studies of validation using poultry maintained in several conditions of environment. Moreover, studies of chemical composition and energy values of different foods used in poultry production are important, generating a database for future prediction equations.

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