14 Bioavailability of Amino Acids, Lipids, and Carbohydrates in Feedstuffs

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Introduction

To formulate efficient swine diets, fundamental knowledge on energy and nutrient requirements, energy and nutrient contents of feedstuffs, and bioavailability of energy and nutrients in feedstuffs is required. Because not all of the energy and nutrients in feedstuffs are available to pigs, expressing the requirements and formulating diets based on the available or digestible energy and nutrients, rather than total concentrations of energy and nutrients, is more effective in precisely satisfying the pig's needs. However, it is questionable whether there is sufficient information on the nutritive value of individual feed ingredients to achieve this objective, and there is no agreement on how to address the bioavailability issue in practice.

Part of the difficulty is that the availability of the energy-containing nutrients (i.e., proteins, lipids, and carbohydrates) in feedstuffs is rather difficult and expensive to measure. For practical purposes, therefore, values for the digestibility of energy and nutrients are usually measured and used as an indicator of the bioavailability, even though it is recognized that digestibility may not always be equal to availability. Nevertheless, formulation of diets based on digestible energy and nutrients is an improvement over formulation on the basis of total energy and nutrients because pigs can utilize only the energy and nutrients that are available to them. It is also likely that formulation of diets based on digestible energy and nutrients will contribute greatly to the development of environmentally friendly, optimum feeding strategies for successful and sustainable pig production. In this chapter, the bioavailability of amino acids (AA), lipids, and carbohydrates will be reviewed briefly, and the bioavailability of minerals and vitamins will be discussed in Chapter 15.

Amino Acid Bioavailability

Amino acids (AA) are needed for synthesis of body proteins that are used for maintenance or production of meat or milk. Most feed ingredients contain some AA, but in most commercial diets fed to swine, the majority of the AA are supplied by soybean meal or another oilseed meal. Often, synthetic sources of Lys, Met, and Thr are also used to balance AA needs of the animals. However, not all AA in the diets are absorbed and can be utilized, and differences among feed ingredients exist in their ability to supply digestible AA. It is, therefore, important to assess the availability of AA in feed ingredients used in diets fed to swine.

Sustainable Swine Nutrition, First Edition. Edited by Lee I. Chiba.

Relative Amino Acid Bioavailability

Only AA that can be incorporated into tissue proteins are bioavailable. Bioavailability is defined as the proportion of dietary AA that is absorbed in a chemical form that is suitable for protein synthesis (Batterham, 1992; Lewis, 1992). Bioavailability of AA may be measured using slope ratio techniques, in which the response of an animal to the intake of graded levels of an AA is measured (Batterham, 1992). The response variables are most often whole-body protein deposition (Batterham, 1992) or AA oxidation (Moehn et al., 2005). The response to the addition of AA from a test-feed ingredient is compared with the response to feeding a standard source of AA, and results are expressed as the relative bioavailability of AA.

Diets used for this procedure need to be deficient in only the AA in question and all levels of this AA need to be fed below the requirement of the animal. It is assumed that the response to the increased intake of the AA is linear. The slope ratio procedure is tedious and costly, and the determined values for AA availability are unique only to the experimental procedures used and may not be additive in a mixed diet (Gabert et al., 2001). For practical feed formulation, AA availability values measured by the slope ratio technique are, therefore, not used. Instead, the digestibility of AA is measured and used as an indication of the quantities of dietary AA that are available to the animal (Stein and Nyachoti, 2003).

Amino Acid Digestibility

The term "AA digestibility" does not refer to the digestion of AA; it refers only to the digestion of the peptide bonds connecting AA in a dietary protein (Fuller, 2003). Because the AA of undigested dietary proteins entering the large intestine may be fermented or metabolized by hindgut microbes before they are excreted from the animal in the fecal material, values for total tract digestibility of AA are not accurately predicting AA absorption by the animal (Sauer and Ozimek, 1986). To avoid the manipulation by hindgut microbes, the digestibility of AA by nonruminant animals is most correctly measured at the end of the small intestine and is referred to as ileal digestibility values (Sauer and de Lange, 1992). This creates a need for using techniques that allow for collection of ileal fluids at the end of the small intestine. Several techniques have been proposed for this, and comprehensive reviews of these techniques have been published (Gabert et al., 2001; Moughan, 2003). In North America, the installment of a T-cannula in the distal ileum of pigs (10–15 cm prior to the ileo-cecal valve) is the procedure of choice. This procedure has proven to be accurate and has a minimal trial-to-trial variation. Because the T-cannula, like most other procedures that are used for ileal fluid collections, does not allow for the total collection of the ileal output from the animal, an indigestible marker needs to be included to calculate changes in AA concentrations. Chromic oxide is often used for this purpose, but other markers exist. Ileal digestibility values are calculated using Equation 14.1 (Stein et al., 2007):

$$\text{AID}\ (\%) = (1 - [(\text{Aad}/\text{AAf}) \times (\text{Mf}/\text{Md})]) \times 100 \qquad (14.1)$$

where AID is the apparent ileal digestibility of an AA, AAd is the AA concentration in the ileal digesta DM (g/kg DM), AAf is the AA concentration in the feed DM (g/kg DM), Mf is the marker concentration in the feed DM (g/kg DM), and Md is the marker concentration in the ileal digesta DM (g/kg DM).

Amino acid digestibility values calculated using this procedure are called "apparent ileal digestibility values" to reflect the fact that these values are calculated simply by subtracting the ileal AA output from the intake of AA (Nyachoti et al., 1997; Mosenthin et al., 2000; Stein et al., 2007). The ileal output of AA that is used to calculate values for the AID of AA contain undigested dietary AA along with AA of endogenous origin. Endogenous AA are AA that were absorbed from the small intestine and then secreted into the intestinal tract in the form of endogenous proteins. Because of the presence of endogenous protein in the ileal output of AA, values for AID do not accurately represent the digestibility of the dietary proteins.

Endogenous AA

Endogenous AA mainly consist of AA from digestive enzymes, mucoproteins, desquamated cells, serum albumin, peptides, free AA, amines, and urea (Moughan and Schuttert, 1991). The main sources of endogenous protein are saliva, gastric secretions, pancreatic juice, bile acids, and intestinal secretions (Low and Zebrowska, 1989; Tamminga et al., 1995). The intestinal secretions account for more than 60% of total endogenous secretions (Low and Zebrowska, 1989) and consist mainly of desquamated epithelium cells and mucin secreted by the goblet cells, as well as other glycoconjugates secreted by the enterocytes (Lien et al., 1997). Saliva and gastric, pancreatic, and bile secretions each contribute 8–10% of total endogenous output. It has been estimated that 70–80% of the endogenous AA that are secreted into the gastrointestinal (GI) of an animal are hydrolyzed and re-absorbed before reaching the distal ileum (Souffrant et al., 1993; Krawielitzki et al., 1994; Fan and Sauer, 2002). The remaining endogenous AA are mainly from deconjugated bile salts and mucin glucoprotein because these components are largely resistant to proteolysis and, therefore, escape re-absorption (Taverner et al., 1981; Moughan and Schuttert, 1991; Lien et al. 1997). Glycine accounts for more than 90% of the total AA content of bile acid, and mucin glycoprotein is rich in Pro, Glu, Asp, Ser, and Thr. There is also evidence that Pro, Gly, Thr, Ser, Asp, and Glu are absorbed more slowly from the intestinal lumen than are most other AA (Taverner et al., 1981). These AA are mainly absorbed as constituents of small peptides and are subsequently hydrolyzed in the enterocyte. However, this process is slow and, therefore, the net absorption rates of these AA is less than those of other AA (Holmes et al., 1974). It also has been suggested that the activity of pyrroline-5-carboxylate reductase (the enzyme that catalyzes Pro synthesis) is greater than that of the Pro degrading enzyme, Pro oxidase (Mariscal-Landin et al., 1995). Therefore, Pro, along with Gly, will accumulate in the enterocytes and diffuse into the lumen (Gardner, 1975). Because of these mechanisms, endogenous protein usually has a relatively high content of Pro, Gly, Thr, Ser, Asp, and Glu. Several estimates of the AA composition of endogenous protein have been published (Wünsche et al., 1987; Boisen and Moughan, 1996; Stein et al., 1999b).

The endogenous AA that are secreted into the intestinal tract may be divided into basal endogenous secretions and diet-specific endogenous secretions (Jansman et al., 2002; Stein et al., 2007). The basal endogenous AA consist of AA that are secreted into the gastrointestinal tract of fasted animals in addition to AA that are secreted in response to the DMI of the animals. These losses are usually measured as grams per kilogram dry matter intake (DMI). Recent evidence suggests that the quantity of endogenous losses (measured in g/kg DMI) depends on the DMI of the animal and declines as DMI increases. The reason for this decrease is that the fasting endogenous loss contributes a decreasing quantity of AA per kg DMI as DMI increases (Moter and Stein, 2004). As a consequence, only values for endogenous losses that are measured in animals given free access to feed are applicable for growing pigs and lactating sows, whereas values for endogenous losses of