Manipulation of Amino Acid Supply to the Growing Ruminant

Neal R. Merchen and Evan C. Titgemeyer

Department of Animal Sciences, University of Illinois, Urbana 61801

ABSTRACT: Quality of protein (indicated by amino acid [AA] composition) that enters the small intestine (SI) of growing ruminants is dictated largely by the AA composition of microbial protein. The AA supply is well-balanced and, although individual AA can be experimentally determined to be first- or second-limiting, it seems that several AA (sulfur AA, lysine, histidine, and possibly threonine, valine, and isoleucine) may be co-limiting in many circumstances. Quality of the postruminal AA supply can be altered by increasing (maximizing) net microbial protein synthesis, manipulating supplemental protein source, or feeding ruminally protected AA. Defaunating the rumen increases postruminal AA supply by increasing flow of both bacterial and nonbacterial AA. Defaunation has little effect on proportions of individual AA entering the SI. Different feed proteins vary greatly in the quantity of individual AA that they supply for absorption from the SI. Most proteins are a poor source of at least one essential AA; feeding combinations of proteins may be the most practical approach to supplying AA in optimal proportions. Feeding individual ruminally protected AA can alter the profile of AA reaching the SI, but work is needed to identify dietary conditions under which use of such products will be most beneficial.

Key Words: Amino Acids, Microbial Proteins, Supplementary Feeds

Introduction

Like all mammals, ruminants require an exogenous source of essential amino acids (EAA). However, because ruminal fermentation leads to production of microbial protein, ruminants are usually not perceived to have dietary requirements for EAA. When microbial protein production is limited or when amino acid (AA) requirements are high, ruminally produced microbial protein may not meet the AA needs of the host. Under these conditions, production may be less than optimal unless AA of nonmicrobial origin are supplied.

There has been a recent surge of interest in formulating diets and/or supplements for ruminants to provide a given supply or array of AA to the small intestine (SI). This is a difficult task because the AA entering the SI usually bear little resemblance, either quantitatively or qualitatively, to dietary AA due to transformations that occur in the rumen. Formulation of diets for AA requires reliable estimates of quantities of 1) microbial AA reaching the SI, 2) dietary AA entering and being absorbed from the SI, and 3) AA requirements for maintenance and production. Presently, the database from which the supply of AA to the ruminant can be estimated is much larger than that from which AA requirements can be estimated.

Several reviews have explored factors that influence ruminal escape of protein (Chalupa, 1975a; Stern and Satter, 1982; NRC, 1985; Satter, 1986) and it is not the objective of this review to repeat those efforts. Rather, this review will focus on factors that may affect the quality of the postruminal AA supply and on recent attempts to alter the AA profile provided to the growing animal.

Limiting Amino Acids for Growing Cattle

There may be sufficient information emerging to allow reliable formulation of protein supplements for ruminants that provide given quantities and
profiles of EAA. For this approach to be useful, the appropriate array of AA that are deficient and must be supplemented must first be identified.

Using N balance, Richardson and Hatfield (1978) demonstrated that methionine was the first-limiting AA when the only source of protein available to growing Holstein steer calves was of microbial origin. Lysine and threonine were found to be the second and third most limiting AA, respectively. In studies with lambs fed by intragastric infusion, Storm and Ørskov (1984) likewise found that methionine and lysine were most likely to limit N retention in lambs when microbial protein served as the only protein source. Arginine and histidine also seemed to be potentially limiting in this work.

Most diets consumed by beef cattle contain some protein that escapes ruminal degradation and provides some AA to the host. The quality of this undegraded protein may influence which AA are most limiting. Fenderson and Bergen (1975) demonstrated that methionine was first-limiting for steers fed diets containing 80% barley, a protein source that is extensively degraded (80%; NRC, 1985) in the rumen. It might be expected that, when the diet contains a large proportion of ruminally degradable protein, the composition of AA reaching the SI will approximate that of microbial protein and that AA limitations will be similar to those observed for microbial protein. In contrast, responses to postruminal infusions of lysine by steers fed diets based on corn (Burris et al., 1976; Titgemeyer et al., 1988) suggest that lysine is probably first-limiting when these diets are fed. This would not be surprising; a large fraction (65%; NRC, 1985) of corn protein escapes ruminal breakdown, and corn is a relatively good source of sulfur AA and a poor source of lysine. Consequently, postruminal AA supply reflects this and alters the order in which individual AA are limiting.

Responses to postruminal infusions of whole proteins and(or) mixtures of AA often indicate that no single AA stands out as solely limiting in the postruminal protein supply. Improvements in N retention have been achieved when casein or mixes of all EAA are abomasally infused in growing steers (Chalupa et al., 1972, 1973; Chalupa, 1975b; Chalupa and Scott, 1976). In these studies, it was observed that N retention was rarely improved unless methionine was included in the AA mixture; however, responses to methionine alone were much lower than responses to methionine in combination with several other EAA. It is likely, then, that methionine was most limiting but only slightly more so than several other EAA. Other attempts to define limiting AA for growing cattle have led to conflicting results. Oltjen et al. (1970) showed that N retention by steers fed a urea-supplemented diet was improved by abomasal infusion of mixtures containing valine, isoleucine, leucine, and phenylalanine. Research by Chalupa et al. (1973) and Chalupa and Scott (1976) indicated that infusion of threonine, histidine, and lysine led to the largest increases in N retention by steers. Lysine and methionine infused together were shown to increase N retention by steers by 5 to 7 g/d (Chalupa and Chandler, 1975). These results imply that several EAA are often colimiting for growth of steers, such that maximal response is achieved when whole proteins are provided postruminally rather than when one or two critical AA are supplied.

A comparison of EAA profiles of mixed ruminal bacteria, duodenal digesta collected from animals fed different basal diets (corn silage, alfalfa, or concentrate) containing either no supplemental protein or only nonprotein N, and some estimated AA requirements is presented in Table 1. Generally, proportions of individual EAA in duodenal digesta (across basal diets) are not greatly divergent from those in ruminal bacteria, except for leucine and lysine. Some divergence occurs as a result of the nature of the basal diet. For example, the proportions of threonine in digesta from animals fed alfalfa are higher and the proportions in digesta from animals fed concentrate are lower than the proportion of threonine in EAA of ruminal bacteria. Proportions of the sulfur-containing AA are lower in digesta of animals fed alfalfa than in ruminal bacteria. Proportions of isoleucine are higher in animals fed corn silage or alfalfa than proportions of isoleucine in ruminal bacteria. These variations in composition are reflective of differential composition of AA from escaped dietary protein compared to bacterial protein and indicate that the basal diet has a modest effect on the profile of EAA presented to the host animal. The similarity in profile between bacterial protein and duodenal digesta is not surprising; microbial protein provided 60 to 80% of the total AA at the duodenum in these studies. It can be generalized that the EAA composition of duodenal digesta in animals fed either only nonprotein N or no supplemental protein is dictated by that of ruminal microbial protein. Therefore, any opportunity for altering the profile of EAA available to the animal must rely on supplying appropriate EAA from supplemental sources.

To predict how supplemental protein must affect the EAA supply to optimize AA utilization by the host, an attempt to determine EAA needs of the animal must be made. This is difficult because few direct determinations have been made of the AA requirements of beef cattle growing at rates representative of those observed in practice. Estimated EAA requirements in Table 1 were obtained...
Table 1. Comparison of essential amino acid (EAA) profiles of ruminal microbes and duodenal digesta of animals fed different basal diets and some estimated EAA requirements for steers

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Mixed ruminal bacteria&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Corn silage-based diets&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Alfalfa-based diets&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Concentrate-based diets&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Requirements&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of total EAA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threonine</td>
<td>10.13</td>
<td>9.97</td>
<td>11.04</td>
<td>8.88</td>
<td>9.14</td>
</tr>
<tr>
<td>Valine</td>
<td>10.05</td>
<td>10.97</td>
<td>11.14</td>
<td>11.56</td>
<td>10.96</td>
</tr>
<tr>
<td>Total sulfur (Met + Cys)</td>
<td>7.76</td>
<td>7.45</td>
<td>6.72</td>
<td>7.26</td>
<td>8.05</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>9.46</td>
<td>10.79</td>
<td>11.21</td>
<td>9.94</td>
<td>10.39</td>
</tr>
<tr>
<td>Leucine</td>
<td>14.30</td>
<td>17.76</td>
<td>17.58</td>
<td>19.99</td>
<td>16.01</td>
</tr>
<tr>
<td>Histidine</td>
<td>4.10</td>
<td>3.92</td>
<td>3.88</td>
<td>4.51</td>
<td>6.02</td>
</tr>
<tr>
<td>Lysine</td>
<td>15.29</td>
<td>13.39</td>
<td>13.80</td>
<td>12.10</td>
<td>15.52</td>
</tr>
<tr>
<td>Arginine</td>
<td>8.47</td>
<td>8.51</td>
<td>8.97</td>
<td>8.48</td>
<td>5.59</td>
</tr>
<tr>
<td>Total aromatic (Phe + Tyr)</td>
<td>17.47</td>
<td>17.25</td>
<td>19.02</td>
<td>17.32</td>
<td>15.09</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>2.83</td>
<td>ND&lt;sup&gt;f&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
<td>2.25</td>
</tr>
</tbody>
</table>

<sup>a</sup>Compiled from data of Purser and Buechler (1966), Bergen et al. (1988), Ibrahim and Ingalls (1972), Smith and McAllan (1974), Arambel et al. (1982), Storm and Ørskov (1983), John (1984), Cecava et al. (1986), Titgemeyer et al. (1986), and Cecava et al. (1990).

<sup>b</sup>Compiled from data of Cottrill et al. (1982) and Titgemeyer et al. (1988). Diets contained ≥ 80% corn silage and no supplemental true protein.

<sup>c</sup>Compiled from data of Merchen and Satter (1983), Merchen et al. (1986), and Atwell et al. (1991). Diets contained ≥ 75% alfalfa hay or silage and no supplemental true protein.

<sup>d</sup>Compiled from data of Merchen et al. (1986), Spicer et al. (1988), and Titgemeyer et al. (1988). Diets contained ≥ 75% cereal grain and no supplemental true protein.

<sup>e</sup>Estimated from Owens (1986) and Bergen (1986) for maintenance and 1 kg/d gain for a 250-kg steer. Requirements are for net AA deposition.

<sup>f</sup>ND = not determined.

from reports by Owens (1986) and Bergen (1986) and represent requirements for maintenance and 1 kg/d gain by a 250-kg steer. Bearing in mind the limitations inherent in making such estimates, it seems that undegraded supplemental protein must provide increased proportions of sulfur AA, lysine, and histidine to create an EAA profile at the duodenum that approximates the needs of this animal. However, the importance of other AA (particularly threonine, valine, and isoleucine) cannot be overlooked or they may rapidly become limiting. The balance and constancy of EAA supply at the duodenum imposed by ruminal microbial protein synthesis is the reason that postruminal supplementation of whole proteins usually elicits a much greater response than does supplementation with a single AA, even if it is ascertained that the AA is first-limiting.

The response in N retention of growing steers to postruminal infusions of a single AA (methionine, predicted to be first-limiting) vs casein has been investigated in our laboratory (Titgemeyer and Merchen, 1990). Growing steers (312 kg, gaining 0.91 kg/d) were fed a diet based on ammoniated corn cobs, cornstarch, molasses, and urea to minimize postruminal flows of nonmicrobial protein. The steers were infused abomasally with graded levels (100, 200, or 300 g/d) of either casein or a mixture of crystalline L-AA, which simulated the nonsulfur AA pattern of casein. Responses in N retention to these treatments were measured in the presence or absence of 12 g/d of abomasally infused L-methionine. Effects of treatment are illustrated in Figure 1.

An increase in N retention of approximately 17% was obtained when methionine alone was infused vs control animals (no protein or AA in infusate), indicating that methionine was the first-limiting AA under these conditions. However, the magnitude of the response to infusion of casein was much greater with increases in N retention of about 33, 63, and 108% observed with infusion of 100, 200, and 300 g of casein (these levels provide approximately 3, 6, and 9 g of sulfur AA). This suggests, as discussed previously, that although methionine may be first-limiting, one or more additional AA are likely to be co-limiting such that provision of a full complement of EAA maximizes response by the animal. Responses to methionine supplementation of casein were modest (average 14% across casein levels). When methionine was infused in addition to the crystalline AA mixture containing no sulfur AA, responses in N retention were more pronounced with increases of 29, 34, and 25% observed when methionine was supplemented to 100, 200, and 300 g/d of the AA mixture, respectively. Thus, even though methionine alone improved N retention in this study, increases in N retention were much greater when intact proteins or combinations of all EAA were infused postruminally. It is likely that, in many circumstances, optimization of diets to meet AA
Figure 1. Nitrogen retention by steers abomasally infused with graded levels of casein or crystalline amino acids (simulated casein) in the presence or absence of abomasally infused L-methionine (Titgemeyer and Merchen, 1990).

needs of rapidly growing steers may require supplementation with combinations of AA rather than with one or two of the most-limiting AA.

Effects of Defaunation on Amino Acid Supply

Three strategies exist by which the quantity and quality of the AA supply to the ruminant might be altered. These include 1) maximizing net production of microbial protein, 2) manipulating the AA composition and ruminal degradability of supplemental protein, and 3) feeding ruminally protected AA. The first of these possibilities is intriguing and is being actively investigated in a number of laboratories. Several dietary and ruminal factors have been identified that have some influence on net production of microbial protein (Johnson and Bergen, 1982; Leng and Nolan, 1984; NRC, 1985; Sniffen and Robinson, 1987). Predictive equations have been developed from a large database (NRC, 1985) and provide a means of estimating net microbial protein production for different diets. However, there is limited opportunity to alter quality of AA supply by altering microbial protein production within a given diet.

Efficiency of net ruminal microbial protein production is believed to be influenced dramatically by extensive intraruminal recycling of N (e.g., ammonia to microbial nitrogenous compounds to ammonia). It has been suggested that as much as 50% of the ruminal ammonia flux may be recycled in this manner (Leng and Nolan, 1984). Through their role as bacterial predators, ruminal protozoa are major contributors to this recycling process and the inefficiencies associated with it (Coleman and Sandford, 1979; Wallace and McPherson, 1987). Although protozoa are central vectors in this breakdown of bacterial protein intraruminally, they make only minor contributions to postruminal protein supply. Ruminal protozoa are selectively retained in the rumen (John and Ulyatt, 1984; Veira, 1986) and, consequently, do not contribute to postruminal AA supply in proportion to their contribution to the total ruminal biomass.

Defaunation can decrease N recycling within the rumen and usually improves efficiency of net bacterial protein synthesis (Kayouli et al., 1986; Meyer et al., 1986; Ushida et al., 1986). Veira (1986) reviewed seven experiments in which bacterial protein synthesis was measured in defaunated animals and reported an average 41% improvement in efficiency. The improved efficiency is reflected in increased net bacterial protein production of 16 to 39% (Rowe et al., 1985; Kayouli et al., 1986; Meyer et al., 1986; Ushida et al., 1986).

In addition to positive effects on bacterial protein synthesis, defaunation has been demonstrated to decrease the extent of ruminal degradation of dietary protein (Veira et al., 1983; Ushida and Jouany, 1985; Kayouli et al., 1986; Ushida et al., 1986). Ruminal fluid from defaunated animals has been reported to have lower activities of microbial aminopeptidases, deaminases, and trypsin-like proteases (Wallace et al., 1987), and this results in reduced proteolysis of dietary proteins. Thus, it seems that defaunation may serve as a strategy for increasing postruminal AA supply and improving utilization of dietary protein via reduced degradation of dietary protein and increased microbial protein supply.

Selected data from the report by Hsu et al. (1991; Table 2) show the effects of defaunation on postruminal AA supply. Sheep were defaunated by administration of alkanate SSL3 as described by Hsu et al. (1989). In this work, identical diets containing soybean meal (SBM) as the primary protein source were fed to either faunated or defaunated sheep and postruminal CP and AA flows were measured. In addition to these treatments, defaunated sheep were fed a diet in which a combination of corn gluten meal and blood meal (CGM-BM) replaced SBM as the major protein source. Corn gluten meal and BM are sources of ruminally undegradable protein (NRC, 1985; Titgemeyer et al., 1989) with complementary AA profiles (Cecava et al., 1990).

Defaunation increased postruminal flow of CP by 18% by increasing flows of both bacterial CP (14%) and nonbacterial CP (25%). The apparent extent of ruminal degradation of dietary CP decreased in sheep fed SBM from approximately 83% for faunated animals to 55% for defaunated
animals. Efficiency of net ruminal bacterial protein synthesis was increased by 21% due to defaunation. The ratio of ruminally degraded CP to duodenal bacterial CP was 1.40 for faunated animals fed SBM vs 1.05 for defaunated animals fed the same diet, indicating improvements in efficiency of capture of degraded CP into a form that can be utilized by the host. Feeding the less-degradable protein sources (CGM-BM) to defaunated sheep resulted in an additional increase of 21% in duodenal CP supply compared to defaunated animals fed SBM. Most of this increase was attributable to a 31% increase in nonbacterial CP, but there was also a slight improvement (10%) in bacterial CP flow when CGM-BM was fed.

Duodenal EAA flows were increased by 19% due to defaunation and by an additional 28% when CGM-BM replaced SBM. Although quantity of EAA was increased, there was a virtually identical profile of EAA entering the SI of defaunated compared with faunated animals when fed SBM (i.e., there was no change in quality of the postruminal AA supply). This constancy in AA profile of duodenal digesta due to defaunation might be anticipated. Supplies of both bacterial and nonbacterial AA are increased by defaunation, and this would predictably have little effect on AA profile. The lack of effect of defaunation on quality of postruminal AA supply is illustrated in Figure 2, in which the average AA profiles of digesta from defaunated and faunated sheep from several studies (Veira et al., 1983; Kayouli et al., 1986; Hsu et al., 1991) are compared.

It seems that defaunation could enhance the supply of AA to the ruminant and improve the efficiency with which dietary CP is utilized. Further work is warranted; in particular, development of techniques that could be used to defaunate animals in a reliable and routine manner in practical situations will be important. It also must be ascertained that such treatments will not have extended negative effects on the ruminal bacterial population or on other ruminal characteristics.

**Altering Amino Acid Supply with Supplemental Protein Sources**

The strategy that is currently most feasible for altering postruminal AA supply to the growing ruminant is manipulation of the AA composition and ruminal degradability of the supplemental protein. In fact, this approach is indirectly used by some feed formulators who prepare supplements containing combinations of protein sources that are resistant to ruminal degradation. Such approaches are hampered by a relative lack of information regarding the quantity and postruminal
Recent studies in our laboratory have evaluated several feedstuffs as sources of ruminally undegraded AA that disappear in the SI. In these experiments, animals were fed basal diets that contained little true protein and protein sources were substituted at several levels for ingredients containing little or no crude protein (chemically treated wheat straw or corn starch). Flows of AA from the SI for each kilogram of CP in the protein source tested are presented in Table 3. Soybean meal and alfalfa were least effective in providing absorbable individual AA to the animal. Therefore, if lysine was either first-limiting or colimiting for production, supplementation of similar quantities of CGM or SBM protein would be expected to result in similar responses even though CGM provides much more undegraded protein. Generally, the supply of absorbable individual EAA from the five protein sources was similar to that of total EAA (e.g., CGM = BM > FM > SBM = alfalfa), with several exceptions: 1) CGM, as noted, was a poor source of lysine and an excellent source of sulfur AA (methionine + cysteine) and leucine, 2) BM was a poor source of methionine, isoleucine, and tyrosine and an excellent source of lysine and histidine, and 3) FM was a poor source of cysteine.

Three factors contribute to the quantity and profile of AA disappearing from the SI for each protein source. First, the profile is determined largely by the AA composition of the original protein source. Protein sources, especially those resistant to ruminal degradation, usually provide quantities of individual AA relative to the proportion found in the original protein. Second, the fraction of dietary protein that reaches the SI as AA (e.g., ruminal escape) is the major determinant of the quantity of AA delivered to the animal. In these evaluations, quantities of total AA N entering the SI were equal to approximately 15, 72, 80, 50, and 19% of N consumed from SBM, CGM, BM, FM, and alfalfa, respectively. These values correspond well to previously reported ruminal es-

### Table 3. Quantities of individual and total essential amino acids (EAA) and total nonessential amino acids (NEAA) that disappeared from the small intestine of steers or wethers fed different protein sources

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Protein source*</th>
<th>g/kg of CP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBM&lt;sup&gt;b&lt;/sup&gt;</td>
<td>CGM&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lysine</td>
<td>11.8</td>
<td>11.5</td>
</tr>
<tr>
<td>Methionine</td>
<td>0</td>
<td>10.2</td>
</tr>
<tr>
<td>Cysteine</td>
<td>0</td>
<td>7.4</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Arginine</td>
<td>8.3</td>
<td>24.5</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.4</td>
<td>19.8</td>
</tr>
<tr>
<td>Valine</td>
<td>10.2</td>
<td>46.6</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>9.9</td>
<td>28.8</td>
</tr>
<tr>
<td>Leucine</td>
<td>5.8</td>
<td>127.7</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>7.0</td>
<td>49.9</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>8.5</td>
<td>35.0</td>
</tr>
<tr>
<td>Total EAA</td>
<td>64.2</td>
<td>373.1</td>
</tr>
<tr>
<td>Total NEAA&lt;sup&gt;d&lt;/sup&gt;</td>
<td>25.8</td>
<td>373.4</td>
</tr>
<tr>
<td>Total AA</td>
<td>89.9</td>
<td>746.5</td>
</tr>
</tbody>
</table>

<sup>a</sup>SBM = soybean meal (CP = 52.9%); CGM = corn gluten meal (CP = 71.2%); BM = blood meal (CP = 95.6%); FM = fish meal (CP = 84.3%). All CP values are expressed as a percentage of DM.

<sup>b</sup>Titgemeyer et al. (1989).

<sup>c</sup>Atwell et al. (1991).

<sup>d</sup>NEAA = nonessential amino acids (Ala, Asp, Glu, Gly, Pro, and Ser).
cape values summarized by NRC (1985) for these protein sources. Third, some variation occurs in the proportion of AA entering the SI that disappear at that site (i.e., SI availability). This factor accounts for less difference among protein sources than either of the first two factors but is still important. Disappearance coefficients of undegraded total protein may suffice to improve performance. Certain protein sources may be superior in their ability to supply these AA. Similarly, feeding complementary protein sources (CGM and BM) on the quantity and quality of AA supplied to wethers fed low-protein basal diets. Diets were isonitrogenous and were supplemented with SBM, CGM, or BM, or combinations (33:67, 67:33) of CGM and BM. Total quantities of amino acids (AA) from the small intestine were lower when diets were supplemented with urea or SBM. In those experiments, protein sources had complementary AA profiles and were resistant to ruminal degradation. Other studies have indicated that AA composition of effluent from continuous culture (Blake and Stern, 1988; Bas et al., 1989) or of duodenal digesta (Santos et al., 1984; Waltz et al., 1989) can be manipulated by dietary protein source.

Cecava et al. (1990) investigated the effects of feeding complementary protein sources (CGM and BM) on the quantity and quality of AA supplied to wethers fed low-protein basal diets. Diets were isonitrogenous and were supplemented with SBM, CGM, or BM, or combinations (33:67, 67:33) of CGM and BM. Diets containing CGM and(or) BM contained urea (30% of supplemental protein) such that animals fed those diets consumed less true protein than those fed SBM.

Table 4. Net disappearance of amino acids (AA) from the small intestine of sheep fed soybean meal (SBM), corn gluten meal (CGM), or blood meal (BM) alone or in combinationa

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Protein sourceb</th>
<th>SBM</th>
<th>CGM</th>
<th>2C1B</th>
<th>1C2B</th>
<th>BM</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysinec</td>
<td></td>
<td>8.1</td>
<td>6.4</td>
<td>7.9</td>
<td>8.9</td>
<td>0.5</td>
<td>.38</td>
</tr>
<tr>
<td>Methioninec</td>
<td></td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>.8</td>
<td>.15</td>
</tr>
<tr>
<td>Histidinecd</td>
<td></td>
<td>1.9</td>
<td>2.0</td>
<td>3.0</td>
<td>3.5</td>
<td>3.9</td>
<td>.15</td>
</tr>
<tr>
<td>Arginine</td>
<td></td>
<td>4.2</td>
<td>3.9</td>
<td>4.3</td>
<td>4.4</td>
<td>4.3</td>
<td>.19</td>
</tr>
<tr>
<td>Threonine</td>
<td></td>
<td>3.9</td>
<td>4.0</td>
<td>4.1</td>
<td>4.4</td>
<td>4.2</td>
<td>.28</td>
</tr>
<tr>
<td>Valinecd</td>
<td></td>
<td>4.4</td>
<td>4.9</td>
<td>5.9</td>
<td>6.4</td>
<td>6.5</td>
<td>.29</td>
</tr>
<tr>
<td>Isoleucinec</td>
<td></td>
<td>3.0</td>
<td>3.6</td>
<td>2.9</td>
<td>2.7</td>
<td>2.3</td>
<td>.28</td>
</tr>
<tr>
<td>Leucinecd</td>
<td></td>
<td>7.8</td>
<td>14.9</td>
<td>14.5</td>
<td>13.3</td>
<td>11.4</td>
<td>.58</td>
</tr>
<tr>
<td>Phenylalaninecd</td>
<td></td>
<td>4.2</td>
<td>6.1</td>
<td>6.3</td>
<td>6.0</td>
<td>5.5</td>
<td>.24</td>
</tr>
<tr>
<td>Tyrosinecd</td>
<td></td>
<td>2.7</td>
<td>3.7</td>
<td>3.4</td>
<td>3.3</td>
<td>2.7</td>
<td>.28</td>
</tr>
<tr>
<td>Total EAAe</td>
<td></td>
<td>41.2</td>
<td>50.8</td>
<td>53.6</td>
<td>54.2</td>
<td>51.1</td>
<td>2.36</td>
</tr>
<tr>
<td>Total NEAAf</td>
<td></td>
<td>37.9</td>
<td>52.6</td>
<td>51.4</td>
<td>49.6</td>
<td>44.7</td>
<td>2.49</td>
</tr>
<tr>
<td>Total AAg</td>
<td></td>
<td>79.1</td>
<td>103.6</td>
<td>105.0</td>
<td>103.8</td>
<td>95.8</td>
<td>4.81</td>
</tr>
</tbody>
</table>

aFrom Cecava et al. (1990).

b2C1B = 33 CGM:67 BM; 1C2B = 33 CGM:67 BM.

cSBM vs other supplements (P < .05).

dLinear effect of CGM or BM in diets containing those protein sources (P < .05).

eEAA = essential amino acids (Arg, His, Ile, Leu, Lys, Met, Phe, Thr, Val, and Tyr).

fNEAA = nonessential amino acids (Ala, Asp, Glu, Gly, Pro, and Ser).
The effective use of the duodenum of wethers and, in a concurrent resistant to ruminal degradation and has a high proportion of dietary CP is provided by supplemental sources. Changes in the profile of AA at the duodenum of wethers and, in a concurrent study, improved growth performance of lambs compared with supplementation with SBM or DDG alone. The results of these studies help confirm that improvements in performance of cattle fed combinations of protein sources as described previously were due to changes in AA supply.

Altering intestinal AA profile via protein source selection is feasible, particularly when diets based on feeds low in CP are fed. In such cases, a large proportion of dietary CP is provided by supplemental sources. Changes in the profile of AA at the duodenum can be measured most easily when flows of AA from escaped dietary protein override the constancy in the duodenal AA profile imposed by flows of bacterial protein. The effective use of protein sources with complementary AA profiles to alter the quantity and profile of AA supplied to the host animal depends on satisfying the following criteria: 1) microbial protein synthesis must be maintained by including urea or a ruminally degradable protein source in the diet to provide NH$_3$ N and other products of protein breakdown to microbial populations in the rumen and 2) complementary proteins must be resistant to ruminal degradation yet available in the SI.

**Ruminally Protected Amino Acids in Beef Cattle Diets**

The use of ruminally protected AA (RPAA; specifically, methionine and lysine) has been investigated as a method of improving performance of growing beef cattle. Feeding RPAA has been shown to increase the supply and alter the profile of EAA entering the SI of beef cattle (Titgemeyer et al., 1988). However, results of growth studies have been generally disappointing; more research will be needed to determine how effective this strategy may be in influencing animal performance.

Strasia et al. (1986) detected no responses in gain or feed efficiency when growing steers were supplemented with as much as 20 g/d of RP methionine. Some improvements in gain or feed efficiency were measured when RP methionine and lysine were supplemented (Deetz et al., 1985; Oke et al., 1986; Wright and Loerch, 1988), but these results demonstrated neither consistent responses to graded levels of supplementation nor large improvements in performance. In the study discussed previously (Titgemeyer and Merchen, 1990), postruminal supplementation with methionine alone led to only a modest increase (17%) in N retention, perhaps explaining the inability of RP methionine to alter substantially the performance of growing steers, despite the conclusion that methionine was the most-limiting AA. Furthermore, it is likely that responses due to one or two AA may be even less evident when diets more typical of those used for growing cattle are fed.

The use of RPAA may be more promising when they are added to diets supplemented with protein sources that are deficient in certain EAA. For example, diets supplemented with CGM may provide deficient amounts of lysine, and the response to RP lysine may be efficacious in those situations. Likewise, BM supplies the ruminant with large amounts of many of the EAA but is a poor source of methionine and isoleucine, and provision of these AA may be necessary to optimize response to BM-supplemented diets. Systematic approaches should be taken to identify which AA are likely to be limiting in cattle fed typical growing diets (e.g., diets based on hay, corn silage, or corn). It should also be determined whether supplementation with one or more RPAA would allow feeding of lower levels of CP while maintaining production (as in swine and poultry diets) and thus improve the cost-effectiveness of such products. Improved technology for production and increased demand will likely improve the economics of use of these materials by producers and feed manufacturers.

**Implications**

The amino acid composition of protein reaching the small intestine of growing ruminants fed diets not supplemented with protein is similar to that of microbial protein. Defaunation is one strategy that seems to increase total amino acid supply to the animal but does not alter amino acid composition. Amino acid composition of digesta from animals fed low-protein basal diets can be altered by feeding protein supplements selected to provide increased quantities of specific amino acids. Be-
cause the supplies of several amino acids (colimiting amino acids) may limit performance when typical diets are fed, feeding individual ruminally protected amino acids seems to have limited potential.

Literature Cited


