Roles of amino acids in the regulation of food intake by animals

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I. Introduction

Traditional Classification of Amino Acids in Animal Nutrition
Traditional Classification of Amino Acids (AA)

Amino Acids

Nutritionally essential (EAA)

Nutritionally nonessential (NEAA)

EAA: AA whose carbon skeletons cannot be made or whose synthesis is insufficient.

NEAA: AA which can be synthesized sufficiently to meet the needs of animals.

Synthesis of NEAA from EAA in Animals

Acetyl-CoA \quad \text{Threonine} \quad \text{Glycine}

\text{Pyruvate} \quad \text{Alanine} \quad \text{Serine}

\text{Oxaloacetate} \quad \text{Aspartate} \quad \text{Asparagine}

\text{\(\alpha\)-Ketoglutarate} \quad \text{Glutamate} \quad \text{Glutamine}

\text{NH}_3 \quad \text{NH}_3 \quad \text{BCAA}

\text{Proline} \quad \text{Arginine}

\text{Ile} \quad \text{Leu} \quad \text{Lys} \quad \text{Phe} \quad \text{Tyr}

\text{Trp} \quad \text{Ile} \quad \text{Met} \quad \text{Phe} \quad \text{Tyr} \quad \text{Val}

\text{Choline} \quad \text{\(CO_2 + NH_3\)}

\text{HYP} \quad \text{D3PG}

\text{Wu (2013) Amino Acids (CRC Press)}
Functional Amino Acids in Animal Nutrition

Amino acids that participate in and regulate key metabolic pathways to improve:

--- Health
--- Survival
--- Growth
--- Development
--- Lactation
--- Reproduction

of the organisms.

What Amino Acids (AA) Do in Animals?

- Proteins
- Nitrogenous metabolites
- Carbons
- Hormones
- Peptides (bioactive)
- Metabolism
- Nutrogenous metabolites
- Bioactive gases (e.g., NO)
- Polyamines
- Glutathione
- Neurotransmitters
- Creatine
- Others (e.g., carnosine)

II. Overall Review of regulation of Food Intake by Amino Acids
Animals depend on food intake for:
--- Health
--- Survival
--- Growth
--- Development
--- Lactation
--- Reproduction

For the same reason, food intake of animals must be regulated to:
--- Reject
--- Adapt
--- Maintain
Regulation of Food Intake by Amino Acids (AA)

Amino Acids → Food Intake

Factors Affecting Effects of AA
- Dietary factors
- Genetic backgrounds
- Physiological states
- Pathological states
- Environmental factors
- Management, Behavior

Nutritional Factors Affecting the Effects of Amino Acids on Food Intake by Animals

--- Amino acid (AA) content and proportion in diets
--- Dosage and type of supplemental AA
--- Energy content
--- Composition of carbohydrate, lipids, vitamins and minerals
--- Anti-nutritional factors and toxic substances
--- Ingredients used in formulating basal diets
--- Methods of food processing
--- Physical characteristics of diets (e.g., temp, particle size, color, smell, and taste)
--- Form of the food (liquid, pellet, or powder)
--- Water quality
Genetic Factors Affecting the Effects of Amino Acids on Food Intake by Animals

--- Species (e.g., cattle, fish, horse, humans, pigs, poultry, and sheep)

--- Breeds (leghorn vs. broiler chickens; Meishan vs. offspring of Landrace x Yorkshire gilts and Duroc x Hampshire boars)

--- Sex (males and females; boars vs sows)
Physiological and Metabolic Factors Affecting Effects of Amino Acids on Food Intake by Animals

--- Age, Pregnancy, and Lactation
--- Light, Circadian clock, and melatonin
--- Release of hormones and satiety signals from the gut & brain)
--- Concentrations of AA, glucose, fatty acids and their metabolites in plasma and brain
--- Motility of the gastrointestinal tract
Pathological Factors Affecting Effects of Amino Acids on Food Intake by Animals

--- Infection
--- Trauma
--- Neoplasia
--- Diabetes
--- Obesity
--- Cardiovascular disease
--- Fetal growth restriction
--- Nausea
--- Vomiting
Environmental Factors Affecting Effects of Amino Acids on Food Intake by Animals

--- Ambient temperature (e.g., heat stress, cold, local heating)
--- Ambient humidity
--- Air pollution (e.g., PM$_{2.5}$, ammonium sulfate, ammonia, H$_2$S, CO, and CO$_2$)
--- Sanitation
Management and Behavioral Factors Affecting Effects of Amino Acids on Food Intake by Animals

--- Frequency of meals
--- Weaning
--- Individual and group hygiene
--- Control of noise
--- Humane treatment of animals
--- Physical activity
--- Dietary habits
--- Social behavior
III. Effects of Either Deficiency or Excess of AA in Purified Diets on Food Intake by Animals
Either Deficiency or Excess of All AA in Purified Diets Affects Food Intake by Male Rats

d 0 = 30 days of age (Sprague-Dawley rats)
Values are means ± SEM, n = 10. a-b; P < 0.05.
Wu G (Texas A&M University)
Either Deficiency or Excess of All AA in Purified Diets Affects Growth of Male Rats

d₀ = 30 days of age (Sprague-Dawley rats)
Values are means ± SEM, n = 10. a-b; P < 0.05.
Wu G (Texas A&M University)
Animals Rejects A **Purified Diet Containing No EAA** (Either One EAA or A Group of EAA)

Birds, Pigs, and Rats:

Reject a purified diet containing no EAA.

Rats:

Rejection occurs between 15 and 30 min after starting consumption of the diet.

*Rose (1957) Nutr Abstr Rev Ser. 27:631-647*
*Gietzen et al. (2007) Annu Rev Nutr 27:63-78*
Repletion of EAA-Devoid Diets

Birds, Pigs, and Rats:

When the basal EAA-free diet is repleted with the missing EAA, animals continue to eat until satiation.

Rats:

The threshold for sensing EAA in diet: ~100 ppm.

Rose (1957) Nutr Abstr Rev Ser. 27:631-647
Choices Among EAA-Deficient and Adequate Diets

Birds, Pigs, and Rats:

If choices are given, animals do not consume an EAA-deficient diet, forage diets containing some EAA, and select a diet containing sufficient EAA.

Foraging

0%  5%  25%  100%  50%
Percent of Dietary Lysine Requirement

Animals Eat Less When Fed A Purified Diet Containing Excessive EAA (Either One or A Group)

Birds, pigs & rats eat 25-60% less if a diet contains:

2% Trytophan
3% Histidine, Methionine, Phenylalanine, Threonine or Lysine
4% Leucine, Isoleucine, or Valine

Either Deficiency or Excess of A Synthesizable AA in Purified Diets Affects Feed Intake (Arginine for Rats)

d 0 = 30 days of age (Sprague-Dawley rats)
Values are means ± SEM, n = 10. a-b; P < 0.05.
Wu G (Texas A&M University)
Either Deficiency or Excess of A Synthesizable AA in Purified Diets Affects Growth (Arginine for Rats)

d₀ = 30 days of age (Sprague-Dawley rats)
Values are means ± SEM, n = 10. a-b; P < 0.05.
Wu G (Texas A&M University)
Either Deficiency or Excess of A Synthesizable AA in Purified Diets Affects Feed Intake (Glycine for Pigs)

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Supplemental Glycine in Diet (%)</th>
<th></th>
<th></th>
<th></th>
<th>Pooled SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>0.5</td>
<td>1.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>d 0-7</td>
<td>33.1(^c)</td>
<td>35.6(^b)</td>
<td>36.4(^b)</td>
<td>38.8(^a)</td>
<td>0.79</td>
</tr>
<tr>
<td>d 7-14</td>
<td>32.6(^c)</td>
<td>34.8(^b)</td>
<td>36.0(^b)</td>
<td>38.1(^a)</td>
<td>0.66</td>
</tr>
</tbody>
</table>

n = 8. Pigs were fed a casein-based diet between 14 and 28 days of age. d 0 = 14 days of age. a-b: P < 0.05.

Wang et al. (2014)
IV. Effects of Either Deficiency or Excess of AA in Complex Diets on Food Intake by Animals
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Animals eat Less when fed a Severely EAA-deficient complex diets (either one or a group of EAA).

However, responses to mild EAA-deficient diets depend on individual amino acids:

↑ Feed intake: e.g., Lysine, Methionine, and Threonine
↓ Feed intake: e.g., Tryptophan

# Effects of Dietary Protein and Methionine (EAA) Levels on Feed Intake by Lactating Cows

<table>
<thead>
<tr>
<th>Variable</th>
<th>Crude Protein</th>
<th>Rumen-Protected Met</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.8%</td>
<td>17.1%</td>
<td></td>
</tr>
<tr>
<td>DM Intake (kg/day)</td>
<td>24.4</td>
<td>25.5*</td>
<td>0.37</td>
</tr>
<tr>
<td>Milk yield (kg/day)</td>
<td>40.0</td>
<td>41.7*</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0 g/d</td>
<td>9 g/d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24.6</td>
<td>25.3*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>41.4†</td>
<td></td>
</tr>
</tbody>
</table>

Holstein cows were fed corn silage-based experimental diets for 4 weeks.

* P < 0.05; † P = 0.10.

Animals Eat Less When Fed **Complex Diets** Containing **Excessive EAA** (Either One or A Group)

Birds, pigs & rats eat 10-55% less if a diet contains:

- 4% **Tryptophan**
- 4% **Histidine, Methionine, Phenylalanine, Threonine** or **Lysine**
- 6% **Leucine, Isoleucine, or Valine**

Weanling Pigs (8 kg) Eat Less When Fed Corn- and Soybean Meal-Based Diets (Complex Diets) Supplemented with An Excessive EAA

Edmonds and Baker (1987) J Anim Sci 64: 1664-71. a-c; P < 0.05
Self-selection of Corn- and Soybean Meal-Based Diets (Complex Diets) by Young Pigs Supplemented with or without An Excessive EAA

Young Chicks Eat Less When Fed Corn- and Soybean Meal-Based Diets (Complex Diets) Supplemented with An Excessive EAA

Edmonds and Baker (1987) J Anim Sci 65: 699-705. a-c; P < 0.05
Either Deficiency or Excess of A Synthesizable AA in A Complex Diet Affects Food Intake (Glycine for Pigs)

Means ± SEM, n = 8. Pigs were fed a corn- and soybean meal-based diet between d 28 and 42. d 0 = 28 days of age (weaning).

Wang et al. (2014)
Effects of Dietary Supplementation with Glutamine or Glutamate on Feed Intake by Weanling Pigs

<table>
<thead>
<tr>
<th>AA</th>
<th>Dietary Supplementation (%)</th>
<th>Pooled SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Glutamine</td>
<td>348&lt;sup&gt;a&lt;/sup&gt;</td>
<td>353&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Glutamate</td>
<td>352</td>
<td>356</td>
</tr>
</tbody>
</table>

n = 12. Values (g/d) are for the 2<sup>nd</sup> week postweaning. Pigs were weaned at 21 days of age to a corn- and soybean meal-based diet containing 21%. a-b: P < 0.05.

*Wu G. Texas A&M University*
IV. Mechanisms Responsible for Effects of Dietary Amino Acids on Food Intake by Animals
The brain integrates signals from the stomach, intestine, liver and blood to regulate food intake.

**ARC:** Arcuate nucleus (hypothalamus)
**DMX:** Dorsal motor nucleus of vagus nerve
**IML:** Intermediolateral cell column
**nTS:** Nucleus tractus solitarii (brainstem)
**NPY:** Neuropeptide Y
**OEA:** Oleoylethanolamide (fatty acid)
**POMC:** Pro-opiomelanocortin
**PYY:** Peptide YY (36-AA peptide)
Neurotransmitters

ARC, Arcuate; CCK, Cholecystokinin; DMH, Dorsomedial hypothalamus; LH, Lateral hypothalamus; PVN, Paraventricular nucleus; NTS, Nucleus tractus solitarius; VMN, ventromedial nucleus

Nutrients in the lumen of GIT (AA, protein, FA & Gluc)

Diet

Taste & texture

GIT distention

Mechano- and chemical sensors in GIT

GIT

Pancreas

WAT

Hormones

Diet

Taste & texture

GIT distention

Mechano- and chemical sensors in GIT

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Acknowledgments

Collaborators
Graduate Students
Postdoctoral Fellows
Research Assistants

Texas A&M University