# Amino Acids from Animal Feedstuff Proteins for Aquaculture Species

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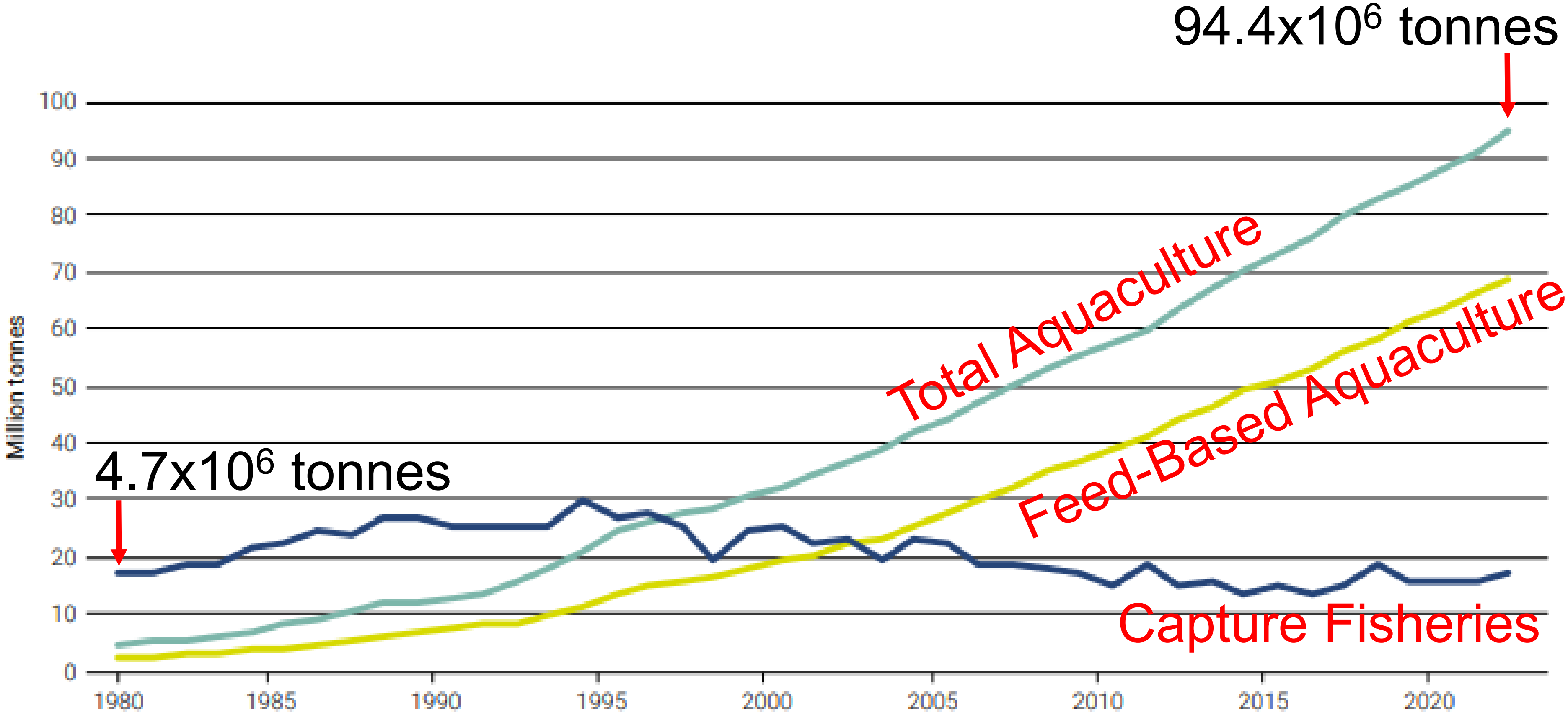
# An Increasing Role of Aquaculture in Providing High-Quality Animal Protein for Human Consumption, 1980—2022

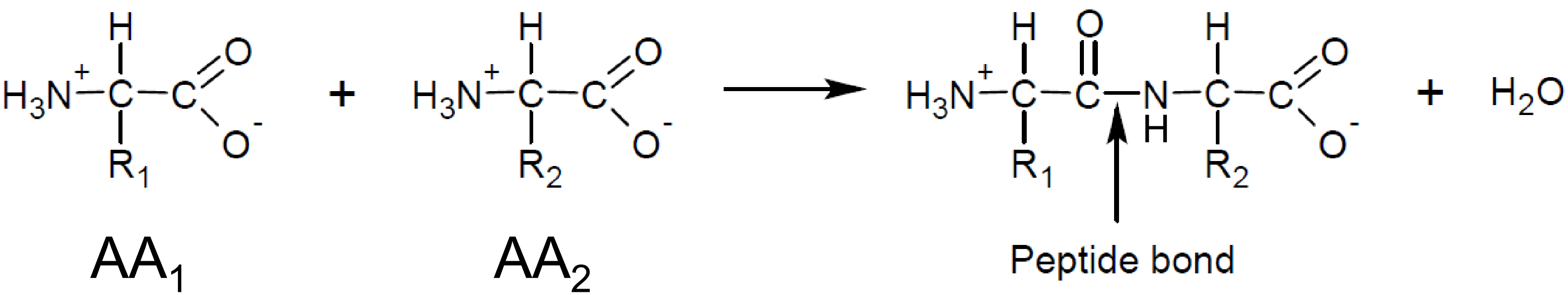



**Globally, aquaculture has been the fastest growing protein sector over the past 20 years.**

FAO 2025. Responsible Use of Fishmeal in Aquaculture.

# What Is Protein?

**Protein:** A polymer of amino acids (AAs) joint together via peptide ponds. $AA_1$-$AA_2$-$AA_3$-$AA_4$ .........$AA_n$



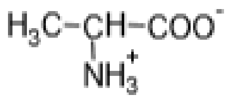

--- Protein is the most expensive ingredient in animal diets.

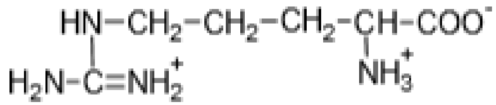
--- Protein is the most abundant non-water nutrient in animals, including fish, shrimp, and crabs.

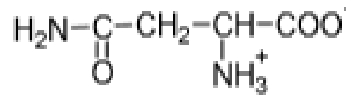
--- Dietary protein is the source of amino acids that are essential for the growth, development, reproduction, immune responses, health, and survival of all animals.

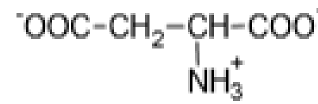
Wu, G. 2022. Amino Acids: Biochemistry and Nutrition. CRC Press, Boca Raton, FL

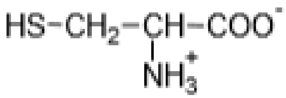
# Amino Acids in Protein (Proteinogenic Amino Acids)

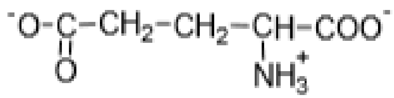

Alanine (Ala, A)
MW: 89.09

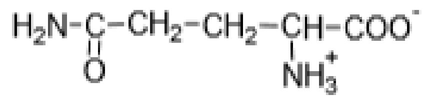

Arginine (Arg, R)
MW: 174.20

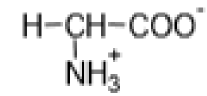

Asparagine (Asn, N)
MW: 132.12

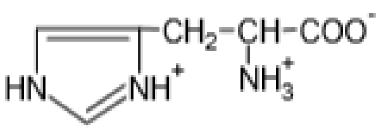

Aspartate (Asp, D)
MW: 133.10

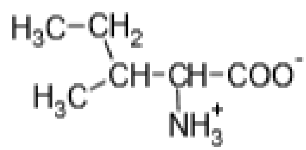

Cysteine (Cys, C)
MW: 121.16

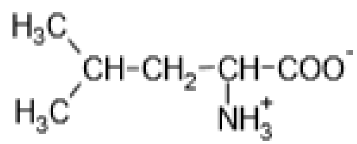

Glutamate (Glu, E)
MW: 147.13

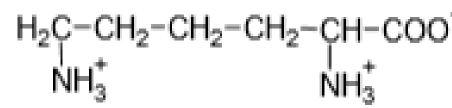

Glutamine (Gln, Q)
MW: 146.14

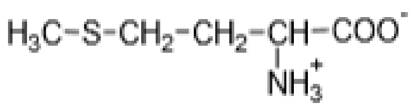

Glycine (Gly, G)
MW: 75.07

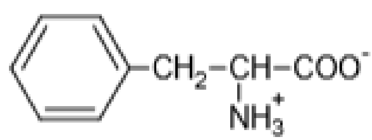

Histidine (His, H)
MW: 155.15

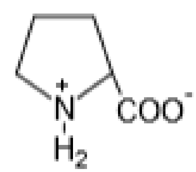

Isoleucine (Ile, I)
MW: 131.17

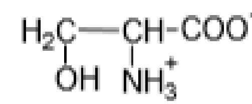

Leucine (Leu, L)
MW: 131.17

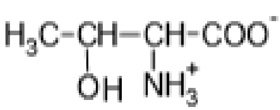

Lysine (Lys, K)
MW: 146.19

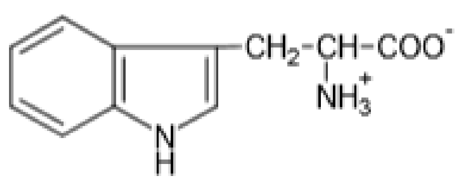

Methionine (Met, M)
MW: 149.21

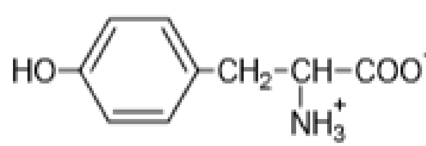

Phenylalanine (Phe, F)
MW: 165.19

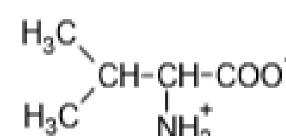

Proline (Pro, P)
MW: 115.13


Serine (Ser, S)
MW: 105.09


Threonine (Thr, T)
MW: 119.12


Tryptophan (Trp, W)
MW: 204.22


Tyrosine (Tyr, Y)
MW: 181.19


Valine (Val, V)
MW: 117.15

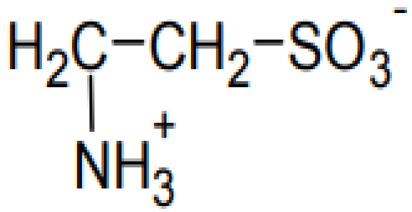
## Historical Classification of Amino Acids (AAs) for Aquatic Animals*

| Nutritionally Essential AA | Nutritionally Nonessential AA |
|---|---|
| Arginine | Alanine |
| Histidine | Asparagine |
| Isoleucine | Aspartate |
| Leucine | Cysteine |
| Lysine | Glutamate |
| Methionine | Glutamine |
| Phenylalanine | Glycine |
| Threonine | Proline |
| Tryptophan | Serine |
| Valine | Tyrosine |

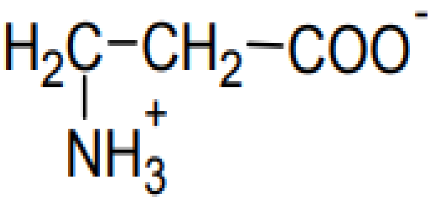
* Based on animal growth.

Li P et al. 2011. Amino Acids 37:43-532.

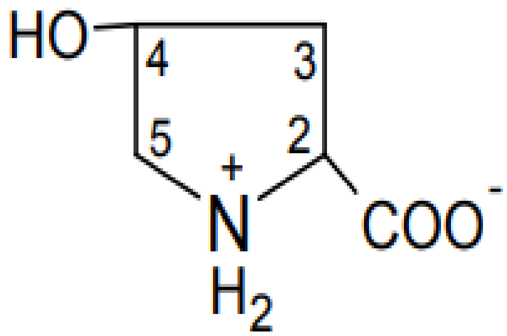
# Animal products also contain non-proteinogenic amino acids that are nutritionally and physiologically essential or beneficial for aquatic species



Taurine



β-Alanine

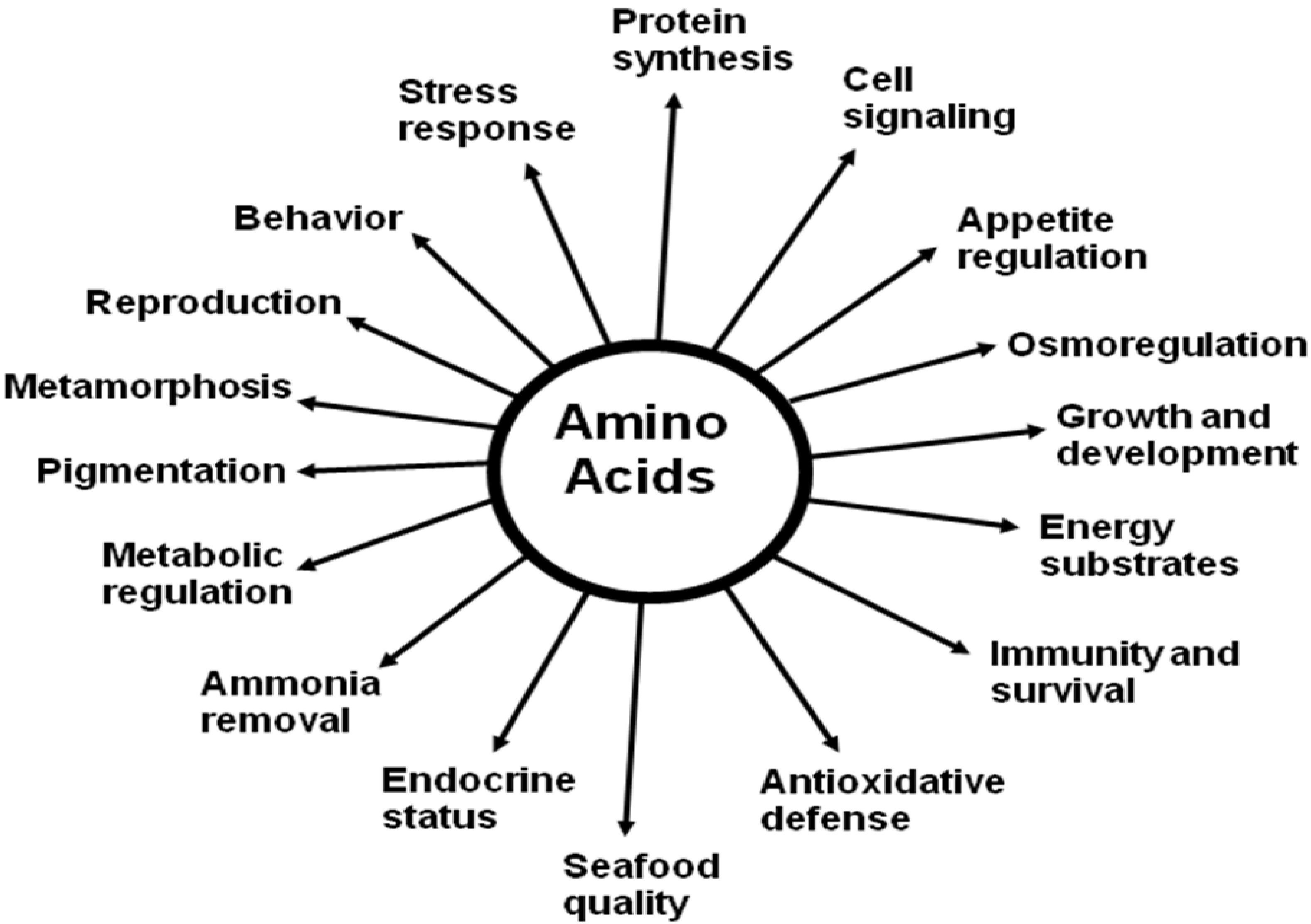


4-Hydroxyproline

Non-proteinogenic amino acids = amino acids that do not serve as substrates for protein synthesis.

Wu, G. 2022. Amino Acids: Biochemistry and Nutrition. CRC Press, Boca Raton, FL

# Roles of Amino Acids in Growth, Development, Health, Survival, Reproduction, and Seafood Quality of Aquatic Animals




Li P et al. 2009. Amino Acids 37:43-32.

# Functional Amino Acids in Animal Nutrition

Functional amino acids: Amino acids that participate in and regulate key metabolic pathways to improve health, survival, growth, development, and reproduction of animals.

Examples: Arginine, Glutamate, Glutamine, Glycine, Leucine, Proline, 4-Hydroxyproline, and Taurine.

They are among the most abundant amino acids in the body and serve as signaling and antioxidative molecules for the functions of the animal.

Wu, G. 2010. Adv. Nutr. 1:31-37.

# Fish and Shrimp Have Particularly High Requirements for Dietary Proteins

Fish: 25 to 50% of protein in diets (on a dry-matter basis).

Shrimp: 30 to 55% of protein in diets (on a dry-matter basis).

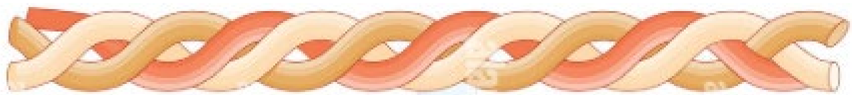
Pigs: 14 to 18% of protein in diets (on a dry-matter basis).

Poultry: 16 to 20% of protein in diets (on a dry-matter basis).

National Research Council (NRC 1994). Nutrient Requirements of Poultry. Washington, DC.;
National Research Council (NRC 2011). Nutrient Requirements of Fish and Shrimp. Washington, DC.
National Research Council (NRC 2012). Nutrient Requirements of Swine. Washington, DC.

# Unusual Abundance of Collagen in Fish and Crustaceans

Collagen is the most abundant protein in animals (including fish, shrimp, and crabs) and accounts for 1/3 of total protein in the body.

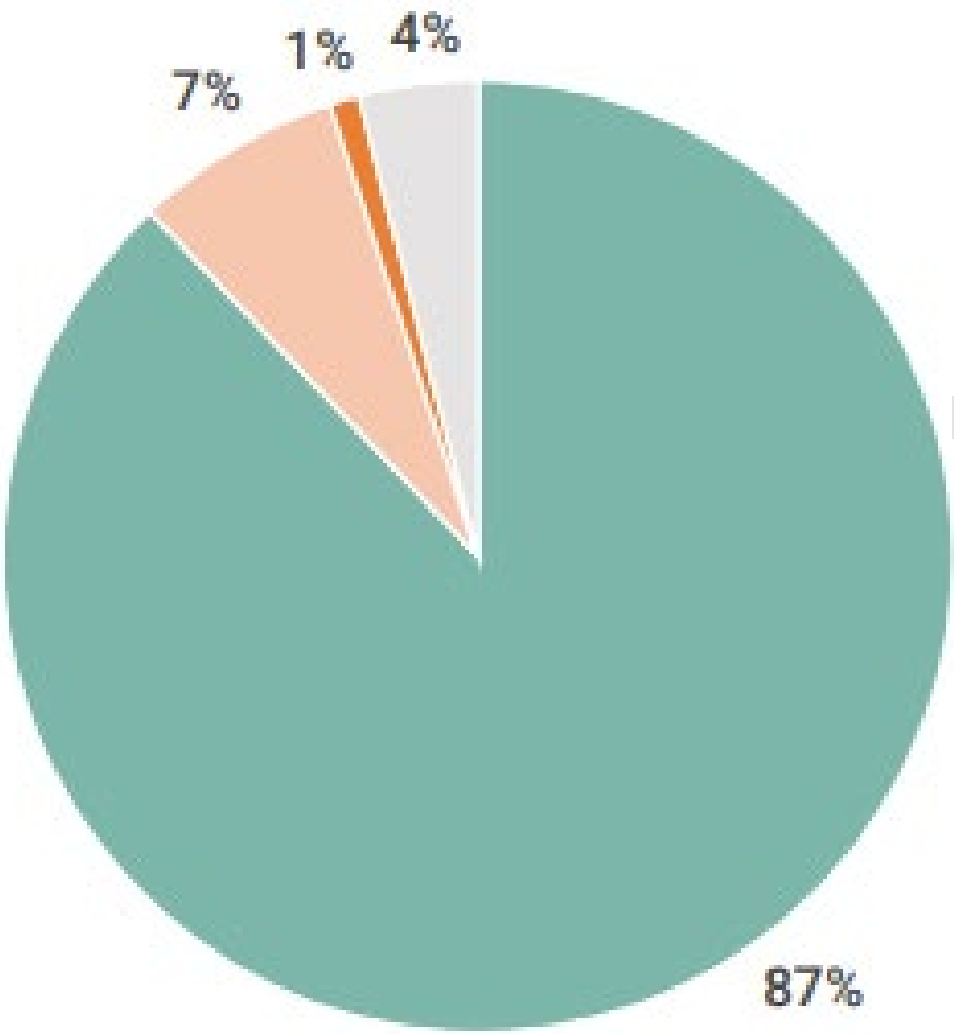


Collagen contains 1/3 glycine and 1/3 proline plus 4-hydroxyproline.

These three amino acids are highly abundant in animal-sourced protein but are deficient in soybean meal and other plant-sourced proteins.

Li, P. and G. Wu. 2018. Amino Acids 50:29-38.

# Traditionally, Fishmeal Has Been the Major Source of Dietary Protein for Fish, Shrimp, and Crabs in Aquaculture




FAO 2025. The State of World Fisheries and Aquaculture 2024.

| Protein or AA | Fish Meal | |
|---|---|---|
| **Protein** | **63.4** | |
| Ala | 5.07 | |
| Arg | 4.85 | |
| Asn | 2.92 | |
| Asp | 4.34 | |
| **Cys** | 0.67 | |
| Glu | 6.01 | |
| Gln | 3.94 | |
| **Gly** | **6.58** | **10.4%** |
| His | 1.51 | |
| **Hyp** | **1.86** | |
| Ile | 3.26 | |
| **Leu** | **5.24** | **8.3%** |
| **Lys** | **5.29** | **8.3%** |
| **Met** | **2.02** | |
| Phe | 2.78 | |
| **Pro** | **4.25** | **Pro + Hyp = 9.6%** |
| **Ser** | 2.80 | |
| Trp | 0.70 | |
| **Thr** | **4.11** | |
| Tyr | 2.36 | |
| **Val** | **3.80** | |
| **Taurine** | **1.01** | **Plant = 0** |
| **Total Cr** | **1.17** | **Plant = 0** |

Cr, creatine; Hyp, 4-hydroxyproline;

Fishmeal is an abundant source of feed protein with balanced ratios of amino acids for aquatic animals, particularly glycine, leucine, lysine, methionine, proline, threonine, and valine.

Fishmeal also provides high amounts of functional nutrients (4-hydroxyproline, taurine, and creatine) for aquatic animals.

Li XL et al. 2011. Amino Acids 40:1159-1168; Li P and Wu G. 2020. Amino Acids 52:523-542.

# It Is Not Sustainable to Feed Fish with Fishmeal in Aquaculture.

Fishmeal is an expensive feed ingredient.

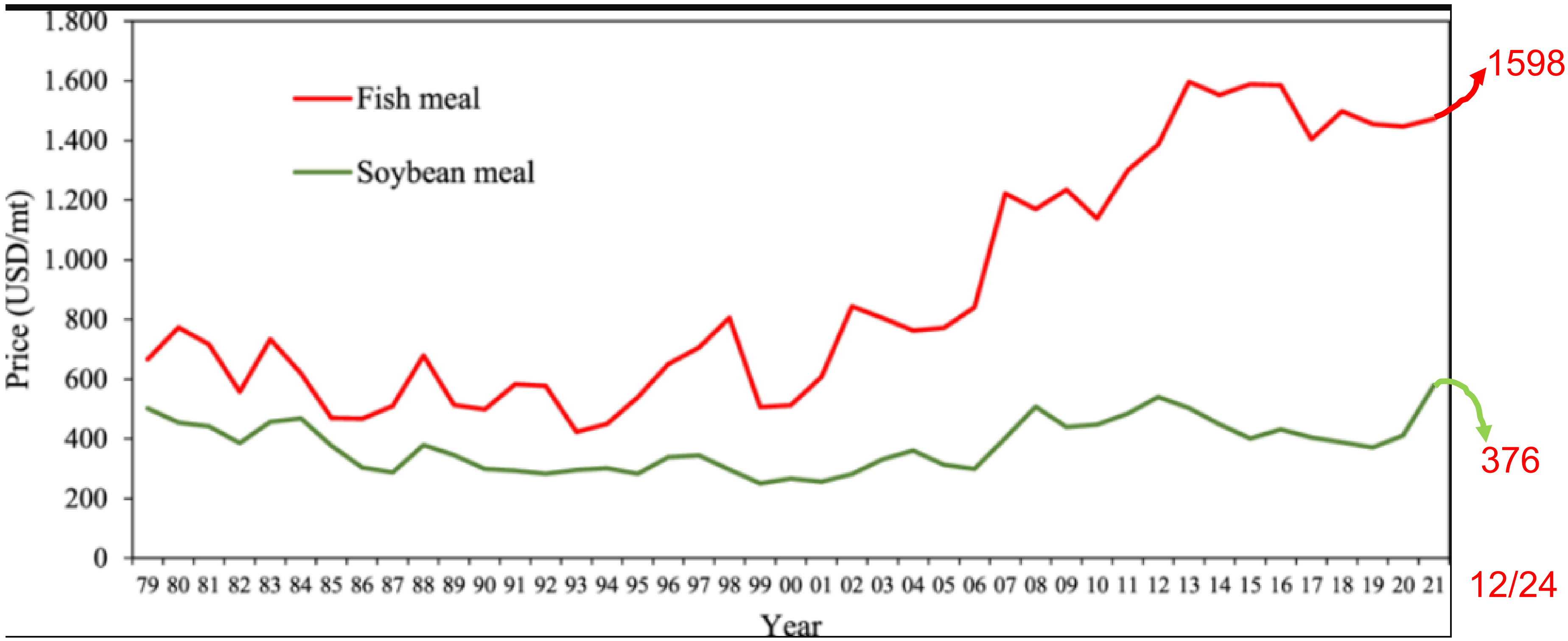
Its cost has continued to increase due to heightened demand associated with the expansion of world aquaculture.

The use of fishmeal as the primary source of dietary protein for aquaculture is not sustainable.

Alternative protein feedstuffs to replace fishmeal include soybean meal and animal byproduct feedstuffs (e.g., blood meal, feather meal, meat & bone meal, and poultry byproducts).

Gatlin DM III et al. 2007. Aquaculture Res. 38:551-579.
Hardy RW. 2010. Aquac Res 41:770-776.
Jia et al. Adv. Exp. Med. Biol. 1354:237-261.

# Prices of Fishmeal (FM) and Soybean Meal (SBM), 1979−2024




World Bank. 2024. https://www.worldbank.org/en/research/commodity-markets

| Protein or AA | Fish Meal | Blood Meal | Feather Meal | MBM | PBM | SBM |
|---|---|---|---|---|---|---|
| | | | % (as-fed basis) | | | |
| **Protein** | **63.4** | **89.6** | **82.1** | **52.0** | **64.3** | **43.6** |
| Ala | 5.07 | 7.82 | 4.18 | 4.78 | 4.91 | 1.95 |
| Arg | 4.85 | 4.91 | 5.74 | 3.67 | 4.63 | 3.18 |
| Asn | 2.92 | 4.67 | 1.67 | 2.21 | 2.73 | 2.10 |
| Asp | 4.34 | 6.20 | 2.92 | 3.07 | 4.10 | 3.14 |
| **Cys** | 0.67 | **1.92** | **4.16** | 0.49 | 1.05 | **0.70** |
| Glu | 6.01 | 6.38 | 4.81 | 4.05 | 4.89 | 4.17 |
| Gln | 3.94 | 4.32 | 2.86 | 2.81 | 3.54 | 3.80 |
| **Gly** | **6.58** | **3.86** | **8.95** | **8.67** | **9.42** | **2.30** |
| His | 1.51 | 5.57 | 0.88 | 1.19 | 1.30 | 1.13 |
| **Hyp** | **1.86** | **0.51** | **4.95** | **2.88** | **3.31** | **0.08** |
| Ile | 3.26 | 2.54 | 3.79 | 1.92 | 2.32 | 2.03 |
| **Leu** | **5.24** | **11.4** | **6.75** | 3.56 | 4.21 | **3.44** |
| **Lys** | **5.29** | **8.25** | 2.16 | **3.16** | **3.44** | **2.80** |
| **Met** | **2.02** | **1.16** | **0.75** | **1.10** | **1.39** | **0.60** |
| Phe | 2.78 | 5.83 | 3.95 | 1.85 | 2.36 | 2.21 |
| **Pro** | **4.25** | **6.29** | **11.8** | **5.86** | **6.72** | **3.05** |
| **Ser** | 2.80 | **4.49** | **8.80** | 2.08 | 2.67 | **2.12** |
| Trp | 0.70 | 1.30 | 0.80 | 0.39 | 0.49 | 0.62 |
| **Thr** | **4.11** | **3.95** | **3.97** | **2.42** | **2.85** | **1.76** |
| Tyr | 2.36 | 2.86 | 2.04 | 1.45 | 1.84 | 1.66 |
| **Val** | **3.80** | **8.21** | **5.76** | 2.23 | 2.89 | **2.09** |
| **Taurine** | **1.01** | **0.15** | 0.014 | **0.12** | **0.50** | **0.00** |
| **Total Cr** | **1.17** | 0.02 | 0.014 | **0.16** | **0.20** | **0.00** |

Cr, creatine; Hyp, 4-hydroxyproline; MBM, meat & bone meal; PBM, poultry byproduct meal; SBM, soybean meal.

Compared to fishmeal, soybean meal contain much lower amounts of some amino acids, such as glycine, 4-hydroxyproline, methionine, proline, threonine, and valine.

In addition, soybean meal lacks taurine and creatine.

Li XL et al. 2011. Amino Acids 40:1159-1168; Li P and Wu G. 2020. Amino Acids 52:523-542.

# Soybean Meal (SBM) Is a Good Protein Source but Has Some Limitations in Amino Acid Nutrition.

SBM provides adequate amounts of most, but not all, amino acids for aquatic animals, including fish, shrimp, and crabs.

SBM, like other plant-sourced animals, is deficient in glycine, proline, and 4-hydroxyproline, and lacks taurine and creatine.

Historically, glycine, proline, and 4-hydroxyproline have long been considered as nutritionally nonessential amino acids. This notion is now known to be incorrect in animal nutrition.

[Glycine, proline, 4-hydroxyproline, and taurine are functional amino acids in animals including fish, shrimp, and crabs.]

Andersen SM. 2016. Front. Biosci. 8:143-169.
Li, P. et al. 2021. Adv. Exp. Med. Biol. 1332:189-210.
Wu, G. and P. Li. 2022. Exp. Biol. Med. 247:1191-1201.

# Recirculating Aquaculture Systems at Texas A&M University

Aquacultural Research and Teaching Facility

Kleberg Center Facility

Suehs, B.A., D.M. Gatlin, III, and G. Wu. 2024. Anim. Front. 14:17-23.

# Composition of Amino Acids in the Bodies of Fish and Shrimp[a]

| AANS | HSB | LMB | WLS | AASA | HSB | LMB | WLS |
|---|---|---|---|---|---|---|---|
| | | mg/g of body weight | | | | | |
| **Arginine** | **9.80** | **9.66** | **11.4** | **Alanine** | **9.75** | **9.60** | **10.5** |
| Histidine | 3.49 | 3.47 | 3.63 | Asparagine | 5.14 | 4.95 | 7.60 |
| Isoleucine | 5.56 | 5.52 | 7.21 | Aspartate | 6.47 | 6.25 | 9.12 |
| **Leucine** | **9.76** | **9.62** | **12.1** | Cysteine | 2.01 | 1.98 | 2.81 |
| **Lysine** | **8.71** | **8.65** | **12.2** | **Glutamate** | **12.8** | **12.7** | **15.9** |
| Methionine | 4.01 | 4.02 | 3.68 | Glutamine | 8.11 | 8.06 | 9.83 |
| Phenylalanine | 5.71 | 5.63 | 8.01 | **Glycine** | **13.1** | **13.0** | **13.5** |
| Threonine | 5.73 | 5.76 | 7.11 | OH-proline | 3.03 | 3.07 | 2.15 |
| Tryptophan | 1.60 | 1.62 | 2.13 | **Proline** | **9.49** | **9.43** | **11.9** |
| Valine | 6.49 | 6.46 | 8.13 | Serine | 6.93 | 6.87 | 9.15 |
| **Taurine** | **1.10** | **1.59** | **2.19** | Tyrosine | 4.12 | 4.10 | 6.56 |

[a] Li XY et al. 2021. Adv Exp Med Biol 1285:133-168; 169-198.

AANS = amino acids that are not synthesized in animals.

AASA = amino acids that are synthesized in animals.

HSB, hybrid stripe bass; LMB, largemouth bass; Shrimp, whiteleg shrimp

## Dietary Provision of Glycine and Metabolic Needs of Juvenile Hybrid Striped Bass[a]

| Variable | Glycine |
| --- | --- |
| Glycine provision from a 60%-fishmeal diet (mg/fish) | 491 |
| Glycine required for growth and metabolic function (mg/fish) | 834 |
| Glycine needed through endogenous synthesis (mg/fish) | 343 |
| Percentage of glycine from diet to meet the need of fish (%) | 59 |
| Percentage of glycine from endogenous synthesis (%) | 41 |

[a] Suehs, B.A., D.M. Gatlin, III, and G. Wu. 2024. Anim. Front. 14:17-23. Hybrid striped bass (5.5–22.1 g) during a 4-week experimental period.

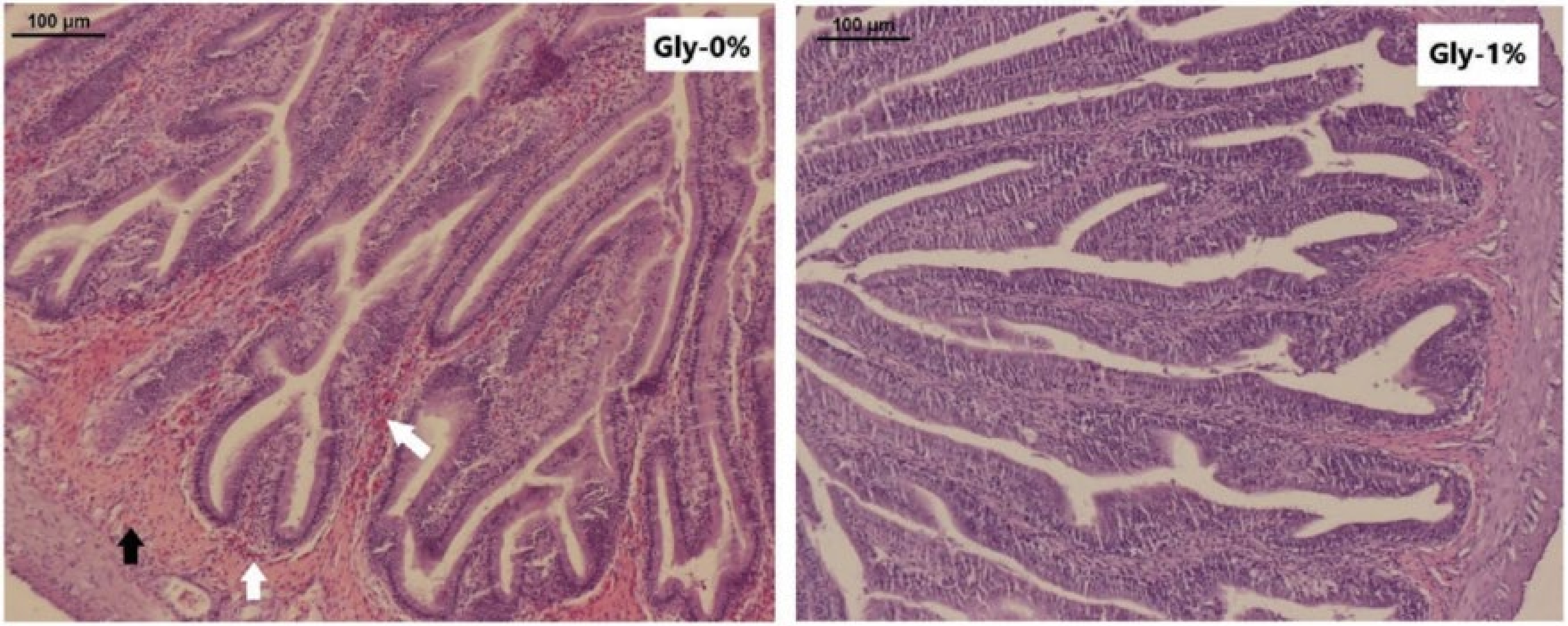
Glycine is the most abundant amino acid in the bodies of fish, shrimp, and crabs.

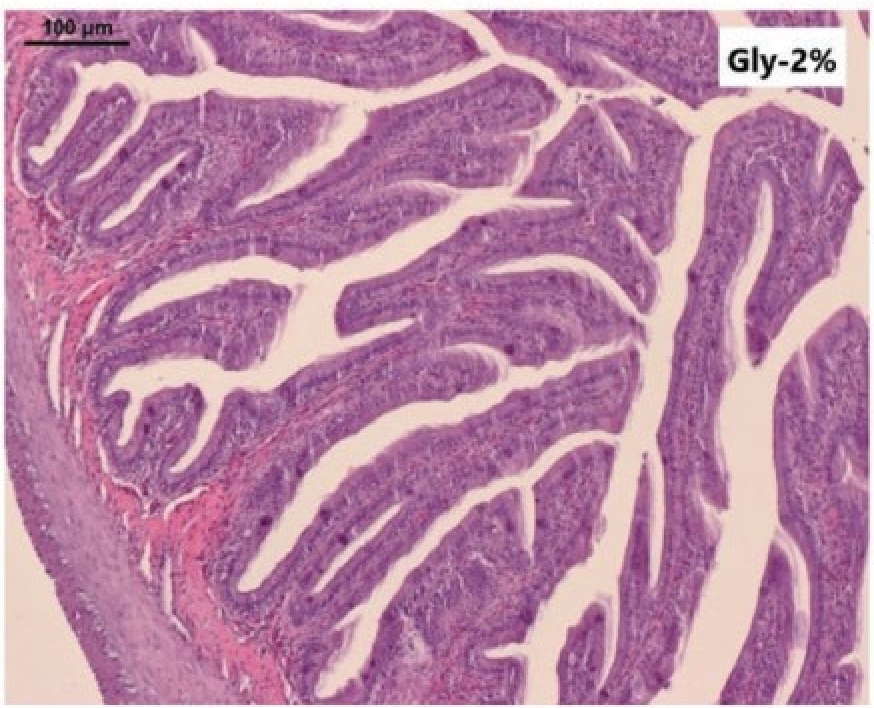
Suehs, B.A., D.M. Gatlin, III, and G. Wu. 2024. Anim. Front. 14:17-23.

# Effects of Dietary Glycine Supplementation in Fish

| Species | Feeding behavior | Suppl. level (%, DM) | Total dietary Gly (%, DM) | Response variables |
|---|---|---|---|---|
| Beluga Sturgeon | Carnivorous | 0.25–1.0% | 2.0–2.8% | ↑ Innate Immune Response<br>↑ GSH Synthesis<br>↓ Plasma Cortisol & Stress |
| Common Carp | Omnivorous | 0.5–1.0% | 2.5–3.0% | ↓ Hyperammonemia<br>↓ Stress Status<br>↓ Oxidative Stress |
| Hybrid Striped Bass | Carnivorous | 1.0–2.0% | 3.1–4.1% | ↑ Weight Gain<br>↑ Intestinal Health<br>↑ Nutrient Retention |
| Hybrid Striped Bass | Carnivorous | 1.0–2.0% | 3.2–4.2% | ↑ Creatine Synthesis<br>↑ Glutathione Synthesis |
| Largemouth Bass | Carnivorous | 2.0% | 3.74% | ↑ Weight Gain<br>↑ Protein Retentions<br>↑ Innate Immune Response |
| Nile Tilapia | Omnivorous | 0.5% | 1.94% | ↑ Weight Gain<br>↑ Anti-Oxidative Capacity |
| Rainbow Trout | Carnivorous | 1.0% | 2.7% | ↑ Protein Digestibility<br>↑ Lipid Digestibility |

Suehs, B.A., D.M. Gatlin, III, and G. Wu. 2024. Anim. Front. 14:17-23.




Histological analysis of the proximal intestine of juvenile hybrid striped bass fed glycine-supplemented diets for 8 wk.

Glycine supplementation prevented submucosal and lamina propria hemorrhages, as well as submucosal thickening.

Li XY et al. 2023. J Anim Sci 101:1-13.

# Effects of Dietary Proline (Pro) on the Survival of Pacific White Shrimp Fed Plant-Based Diets for 8 Week

| Diet[a] | Protein in diet (%) | Lipids in diet (%) | Survival[b] (%) | HSI (%) |
|---|---|---|---|---|
| Control + 0.00% Pro | 45.7 | 8.67 | 61.9 | 5.66 |
| Control + 0.36% Pro | 46.0 | 8.72 | 86.3 | 6.10 |
| Control + 0.58% Pro | 46.0 | 8.58 | 89.2 | 5.76 |
| P-value | --- | --- | <0.05 | <0.05 |

[a] The basal diet contained 2.02% proline (dry matter basis).
[b] 60 h after $NH_3$ stress. HSI, hepatosomatic index.

0.58% vs 0.0% Pro: 44% increase in survival.
0.36% vs 0.0% Pro: 8% increase in HIS.

Xie et al. 2015. Aquaculture 448:105-111.

## Effects of 4-Hydroxyproline (Hyp) on the Growth of Atlantic Salmon Fed Plant-Based Diets for 88 days[a]

| Diet | Protein in diet (%) | Lipids in diet (%) | Weight gain (g/fish) | SGR (%) |
|---|---|---|---|---|
| Control + 0.00% Hyp | 38.0 | 30.1 | 136 | 0.92 |
| Control + 0.07% Hyp | 37.7 | 30.3 | 147 | 0.97 |
| Control + 0.14% Hyp | 37.8 | 30.0 | 155 | 1.00 |
| P-value | --- | --- | <0.05 | <0.05 |

[a] Initial body weight = 110 g. SGR, specific growth rate.

0.14% vs 0.0% Hyp: 14% increase in weight gain and SGR.

Aksnes et al. 2008. Aquaculture 275:242-249.

# Single Use of As An Animal Protein Feedstuff to Replace Fishmeal in Diets for Aquatic Animals

Animal-sourced protein feedstuffs produced by the U.S. rendering industry:

- Blood meal
- Chicken by-product meal
- Chicken visceral digest
- Feather meal
- Poultry by-product meal
- Ruminant meat & bone meal
- Spray-dried egg product
- Spray-dried porcine mucosal peptone
- Spray-dried poultry plasma
- Fishmeal

These rendered products provide both high content and proper ratios of all proteinogenic amino acids, as well as taurine and creatine.

Any of these feedstuffs can be used as a single supplement to plant-based diets for aquatic animals (including fish, shrimp, and crabs) to balance amino acid content and provide all the needed functional amino acids.

Li, P. et al. 2021. Adv. Exp. Med. Biol. 1332:189-210.

# A Combination of Complementary Animal Protein Feedstuffs to Replace Fishmeal in Diets for Aquatic Animals

An example for a combination of animal-sourced protein feedstuffs can be used to further bring about complementary effects.

| | Leucine | Lysine | Histidine | Glycine | Hyp | Isoleucine | Serine |
|---|---|---|---|---|---|---|---|
| Blood meal | 11.4 | 8.25 | 5.57 | 3.86 | 0.51 | 2.54 | 4.49 |
| | (high content) | | | (relatively low content) | | | |
| Feather meal | 6.75 | 2.16 | 0.88 | 8.95 | 4.95 | 3.79 | 8.80 |
| | (relatively low content) | | | (high content) | | | |
| 50% Each | 9.08 | 5.21 | 3.23 | 6.41 | 2.73 | 3.17 | 6.65 |
| (For comparison) Soybean meal | 3.44 | 2.80 | 1.13 | 2.30 | 0.08 | 2.03 | 2.12 |

% of feedstuff, as-fed basis)

# A Combination of Complementary Animal Protein Feedstuffs

Additional example for a combination of animal-sourced protein feedstuffs can be used to further bring about complementary effects.

| | Cysteine | Tryptophan | Glycine | Hyp |
|---|---|---|---|---|
| Blood meal | 1.92 | 1.30 | 3.86 | 0.50 |
| | (high content) | | (relatively low content) | |
| Meat & Bone meal | 0.49 | 0.39 | 8.67 | 2.88 |
| | (relatively low content) | | (high content) | |
| 50% Each | 1.21 | 0.85 | 6.27 | 1.70 |
| (For comparison) | | | | |
| Soybean meal | 0.70 | 0.62 | 2.30 | 0.08 |

% of feedstuff, as-fed basis)

# A Combination of Complementary Animal Protein Feedstuffs

Additional example for a combination of animal-sourced protein feedstuffs can be used to further bring about complementary effects.

| | Histidine | Threonine | Glycine | Isoleucine |
|---|---|---|---|---|
| Blood meal | 5.57 | 3.95 | 3.86 | 2.54 |
| | (high content) | | (relatively low content) | |
| Chicken visceral digest | 0.75 | 1.99 | 8.25 | 3.84 |
| | (relatively low content) | | (high content) | |
| 50% Each | 3.16 | 2.97 | 6.06 | 3.19 |
| (For comparison)<br>Soybean meal | 1.13 | | 2.30 | |

% of feedstuff, as-fed basis)

# A Combination of Complementary Animal Protein Feedstuffs

Additional example for a combination of animal-sourced protein feedstuffs can be used to further bring in complementary effects.

| | Histidine | Lysine | Glycine | 4-Hydroxyproline |
|---|---|---|---|---|
| Spray-dried poultry plasma | 3.66 | 6.85 | 3.40 | 0.021 |
| | (high content) | | (relatively low content) | |
| Feather meal | 0.88 | 2.16 | 8.95 | 4.95 |
| | (relatively low content) | | (high content) | |
| 50% Each | 2.27 | 4.51 | 6.18 | 2.49 |
| (For comparison) Soybean meal | 1.13 | 2.80 | 2.30 | 0.09 |

% of feedstuff, as-fed basis)

# Use of Animal-Sourced Protein Feedstuffs to Replace Fishmeal in Diets for Aquatic Animals

| Feedstuff | Inclusion rate in diets |
|---|---|
| Blood meal | 8 to 20% |
| Poultry by-product meal | 20 to 30%; can replace 80% fishmeal |
| Feather meal | 15% (for salmon)<br>20 to 25% (for rainbow trout)<br>≥ 10% for other fish |
| Meat & Bone meal | 10% (for yellowtail)<br>24% (for rainbow trout, tilapia gilthead seabream); 30% golden fish |
| Spray-dried porcine plasma | 5 to 7.5% (for salmon) |

Bureau DP. 2006. Essential Rendering. pp 179-194

# Use of Rendered Products to Replace Fishmeal in Diets for Rainbow Trout

Bureau DP. 2006. Essential Rendering. pp 179-194

| Ingredients | Percent |
|---|---|
| Fish meal | 25 |
| Corn gluten meal | 12 |
| Poultry by-product meal | 12 |
| Soybean meal | 8 |
| Blood meal, spray-dried | 5 |
| Feather meal | 5 |
| Wheat | 12 |
| Vitamins and minerals | 2 |
| Dicalcium phosphate | 1 |
| DL-Methionine | 0.5 |
| Lysine HCL | 0.5 |
| Fish oil | 17 |
| Total | 100 |

# Use of Rendered Products to Replace Fishmeal in Diets for Largemouth Bass

Li XY et al. 2021.
Amino Acids 53:33-47

* Dry matter (DM) content in diet = 96%

| Ingredient [% of dry matter (DM)] | Dietary groups | | | | |
|---|---|---|---|---|---|
| | FM54 | FM30 | FM15 | FM10 | FM5 |
| Fish meal, menhaden[1] | 78.37 | 43.54 | 21.77 | 14.51 | 7.26 |
| Poultry by-product meal (PBM)[2] | – | 22.13 | 35.97 | 40.58 | 45.19 |
| Soybean meal (SBM)[3] | – | 17.50 | 28.44 | 32.08 | 35.73 |
| Poultry fat[4] | 5.96 | 2.20 | – | – | – |
| Fish oil menhaden[5] | – | 2.84 | 4.49 | 4.30 | 3.69 |
| Dextrinized starch [6] | 5.00 | 4.60 | 4.40 | 4.40 | 4.30 |
| Vitamin premix[7] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Mineral premix[8] | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Cellulose[9] | 7.53 | 3.70 | 1.23 | 0.35 | 0.00 |
| Choline chloride | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Composition (DM basis)* | | | | | |
| Crude protein (CP, %) | 54.0 | 54.0 | 54.0 | 54.0 | 54.0 |
| Crude lipids (%) | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| Phosphors (%) | 2.52 | 2.21 | 1.79 | 1.75 | 1.44 |
| Calcium (%) | 4.26 | 3.29 | 2.59 | 2.11 | 1.98 |
| Energy (kJ/g of DM) | 18.2 | 18.2 | 18.2 | 18.2 | 18.2 |

FM54, FM30, FM15, FM10, and FM5 denote that the diets contained 54, 30, 15, 10, and 5% of fishmeal CP, respectively

Growth performance of LMB fed diets with different fishmeal levels[1]

| | Body weight (BW; g/fish) | | | | |
|---|---|---|---|---|---|
| | Initial | Day 14 | Day 28 | Day 42 | Day 56 |
| FM54 | 4.93 | 12.0[a] | 18.6[a] | 25.5[a] | 35.0[a] |
| FM30 | 4.95 | 11.8[a] | 18.4[a] | 25.7[a] | 34.9[a] |
| FM15 | 4.93 | 11.3[b] | 17.8[b] | 24.8[b] | 33.4[ab] |
| FM10 | 4.94 | 11.0[b] | 17.9[b] | 24.2[c] | 32.3[b] |
| FM5 | 4.90 | 11.0[b] | 17.2[c] | 24.4[bc] | 32.2[b] |
| Pooled SEM | 0.02 | 0.10 | 0.11 | 0.15 | 0.33 |
| *P* values | | <0.001 | <0.001 | <0.001 | <0.001 |

FM54, FM30, FM15, FM10, and FM5 denote that the diets contained 54, 30, 15, 10, and 5% fishmeal CP, respectively. The total content of CP in each diet was 54%. The diets were fed to largemouth bass (LMB).

Poultry byproduct meal can replace 72% of fishmeal in diets.

Li XY et al. 2021. Amino Acids 53:33-47.

## Use of Animal-Sourced Protein Feedstuffs for Feeding Shrimp

| Feedstuff | Inclusion rate in diets |
|---|---|
| Blood meal | 3 to 5% |
| Poultry by-product meal | 30%; can replace 80 to 100% fishmeal |
| Feather meal | 33% (without Lys or Met supplement)<br>66% (with Lys and Met supplement) |
| Meat & bone meal | can replace 60% fishmeal |

Yu Y. 2006. Essential Rendering. pp 195-211

The feed composition of different shrimp feeds. (Li XY and Wu G. 2020)

| | 20 FM - 0 N | 20 FM - 5 N | 20 FM - 10 N | 15 FM - 5 N | 15 FM - 10 N |
|---|---|---|---|---|---|
| Fishmeal | 20 | 20 | 20 | 15 | 15 |
| NOVACQ™ [a] | 0 | 5 | 10 | 5 | 10 |
| Soybean meal | 10 | 10 | 10 | 10 | 10 |
| wheat flour | 15 | 15 | 15 | 15 | 15 |
| PBM | 35 | 35 | 35 | 40 | 40 |
| Soybean oil | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Soy lecithin | 1 | 1 | 1 | 1 | 1 |
| Cholesterol | 1 | 1 | 1 | 1 | 1 |
| Vitamin C | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Choline chloride | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| $K_2HPO_4$ | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 |
| $MgCl_2$ | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Astaxanthin 5% | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Premix [b] | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Cellulose | 10.37 | 5.37 | 0.37 | 5.37 | 0.37 |
| Composition (% based on dry matter) | | | | | |
| Dry matter | 94.2 | 96.6 | 95.5 | 93.7 | 95.2 |
| Crude protein | 43.0 | 43.7 | 43.9 | 43.2 | 44.0 |
| Crude lipid | 9.7 | 9.9 | 9.9 | 10.6 | 10.3 |

Poultry byproduct meal can replace 73% of fishmeal in diets for white-leg shrimp.

*(Pacific white-leg shrimp; Litopennaeus vannamei).* Initial body weight = ~ 2.6 g

# Summary

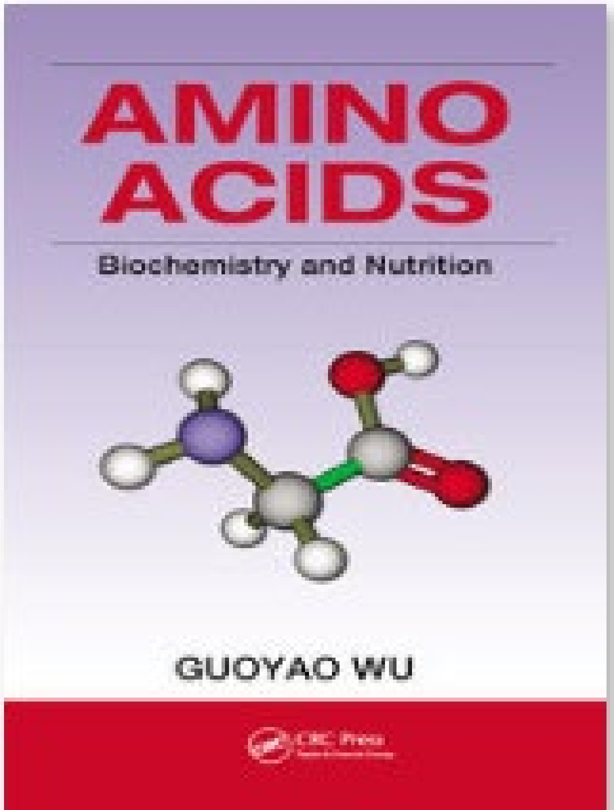
1. Animal-sourced feedstuffs provide sufficient and balanced amounts of amino acids to improve the growth, health (including intestinal health), and productivity of animals.

2. Animal-sourced feedstuffs are rich in functional amino acids, such as glycine, proline, 4-hydroxyproline, and taurine that are low or absent in plant-sourced feedstuffs.

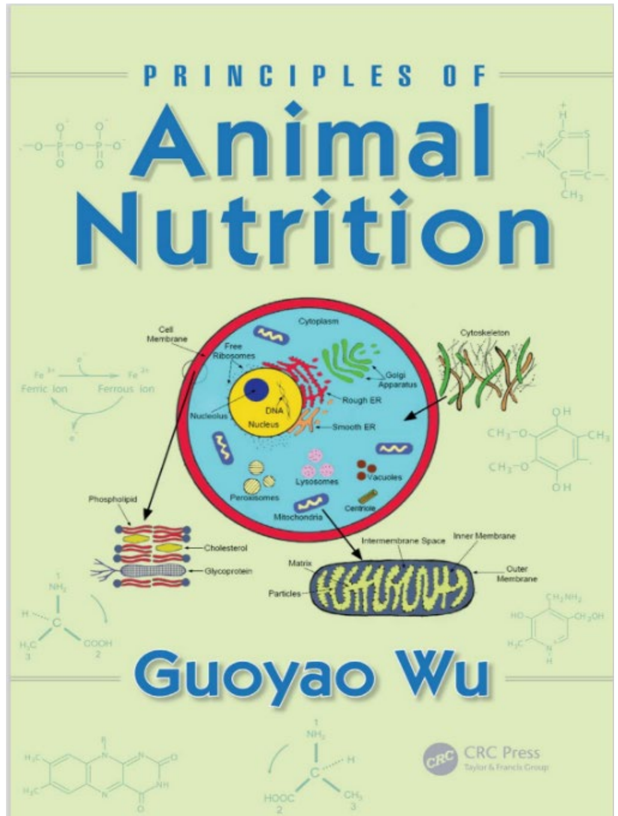
3. Animal-sourced protein feedstuffs can be used alone or in a complementary combination to achieve their effects in the nutrition of aquatic animals.

4. Animal-sourced protein feedstuffs can replace up to 80% of fishmeal in diets for aquatic animals.

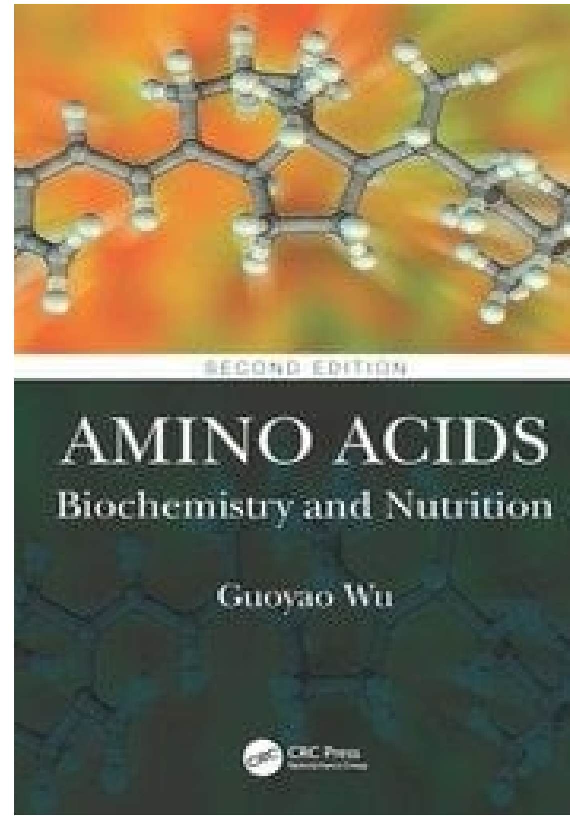
# Text/Reference Books on Animal Proteins, Amino Acids, and Animal Nutrition Published Dr. Guoyao Wu




CRC Press 2013




CRC Press 2018

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