The Effects of Fish-Based Versus Plant-Based Feeds and Solids Management on Shrimp (*Litopenaeus vannamei*) Flesh Characteristics

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National Institute of Food and Agriculture

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LExSI Systems

- Limited Exchange Super Intensive Systems
  - Little if any water exchange
  - High stocking densities
  - Dense microbial community
    - Nutrient cycling
    - Potential supplemental nutrition
    - Biofloc particles
  - Often under a greenhouse
  - Lined ponds/raceways

LExSI Shrimp Systems

- Plant-based feeds versus fish-based feeds
  - Reduced risk of contaminants
    - Mercury, dioxins, polychlorinated biphenyls (PCBs)
  - More stable/potentially reduced cost
  - Organic certification/niche marketing
  - Equivalent to fish meal in terms of production
    - Ray et al. (2010)
- Biofloc concentration management
  - Significantly improves production (Ray et al. 2010)
  - Alters the microbial community (Ray 2008)
- Unclear how these factors affect nutritional quality and sensory attributes of shrimp

Fatty Acids

- Omega-3 (n-3), highly unsaturated fatty acids (HUFA)
  - Reduced risk of heart disease, sudden cardiac death, and possibly some cancers, treatment of cardiovascular issues, improved neurological development, etc…
    - 1000's of publications (von Schacky and Harris, 2007)
  - Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and alpha linolenic acid (ALA) are each important
  - EPA and DHA = Cardiovascular benefits at 250 mg day^{-1} (Mozaffarian and Rimm, 2006)
  - American Heart Association General Recommendations (Kris-Etherton et al., 2002)
    - ALA ≈ 1500 mg day^{-1}
    - People in high risk categories may benefit from additional consumption of omega-3 fatty acids
    - Consumption of seafood is encouraged
- Omega-6 (n-6) fatty acids
  - Evidence of an inverse relationship with n-3 health benefits
  - Suggested maximum n-6:n-3 ratio of 2:1 (Simopoulos, 2002)

Experimental Design

- Two diets
  - FISHMEAL = Ziegler® Hyperintensive 35
  - PLANT = Experimental feed
    - No fishmeal, no fish oil, no binder, potential organic certification
    - Eco-friendly, cost-effective

Ingredient	Percentage
Soybean meal (expelled)	55
Corn gluten meal	12
Whole wheat	11.14
Pea meal	10
Squid meal	2
CaP - dibasic	2
Vitamin premix	1.8
DHA (Docosahexaenoic acid) - AquaGrow®	1.39
Flax seed oil	1
ARA (Arachidonic Acid) - AquaGrow®	1
Soy oil	0.8
Lecithin (soy refined)	0.5
Betaine	0.5
Trace Mineral premix	0.5
Choline cloride	0.2
Cholesterol	0.1
Stay-C 250mg/kg using 35%	0.07

Percent total composition, except where otherwise noted

	Fish-Based Feed	Plant-Based Feed
Crude Protein	35.7	36.4
Total Lipid	11.0	10.8
Ash	6.6	6.9
Moisture	9.7	8.2
Total phosphorus	1.1	0.9
Calcium	1.0	0.9
Potasium	0.7	1.2
Magnesium	0.2	0.2
Sulfur	0.5	0.4
Zinc (ppm)	121	205
Copper (ppm)	59	196
Manganese (ppm)	84	257
Iron (ppm)	166	564
Fatty Acids:	Weight % of fatty acids	
14:0	5.6	1.1
16:0	14.6	12.9
16:1n-7	3.7	0.3
17:0	0.2	0.1
18:0	2.1	4.3
C18:1n-9	9.8	19.7
C18:1n-7	2.1	1.2
C18:2n-6	16.7	42.4
C18:3n-3	2.2	11.1
C18:4n-3	1.6	0.0
C20:1n-9	8.5	0.3
C20:4n-6	0.4	1.2
C20:5n-3	5.1	0.2
C22:1n-9	0.9	0.3
C22:5n-3	0.5	0.0
C22:6n-3	4.9	2.8

ALA →

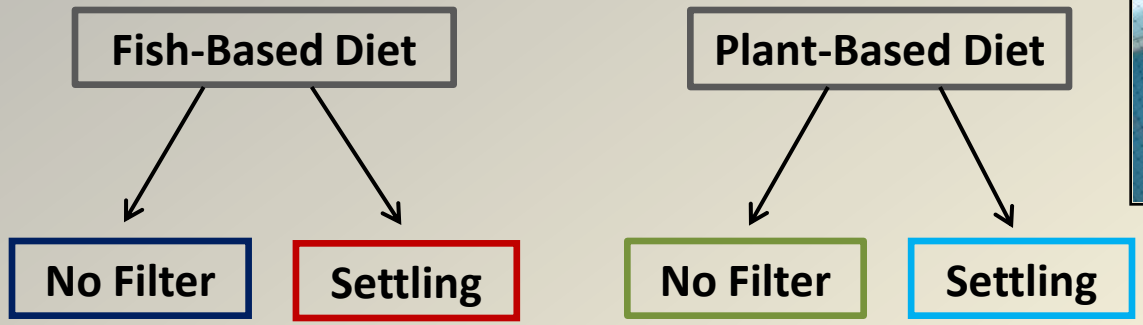
EPA →

DHA →

Experimental Design/Production Results

- Settling Systems
  - Generally maintained turbidity < 30 NTU
- 16 Outdoor, 3.5 m Diameter Tanks
  - Shrimp Stocked at 460 m^{-3}
  - Cultured for 12 weeks

- Four Unique Treatments



  - Four Randomly Assigned Replicate Tanks in Each Treatment
- Shrimp Production (Ray et al., 2010)
  - No significant differences in production between diets
  - Significantly greater production with solids removal (41% greater biomass, 40% faster growth rate)

Methods

- Analyzed Shrimp for crude protein, P, Ca, K, Mg, S, Zn, Cu, Mn, Fe, and Na
- Analyzed Shrimp Tail Flesh
  - Fatty Acid Composition
    - 100 Shrimp From Each Tank
      - (Folch et al., 1957)
    - Gas Chromatography
    - Fatty Acid Methyl Esters
  - Descriptive Sensory Analysis
    - 100 Shrimp From Each Tank
    - Boiled Shrimp Tails
    - Highly Trained Panel (n=8)
      - Trained in the Spectrum™ Method of Descriptive Analysis

http://healthyfoodblog.files.wordpress.com/2009/01/shrimp-appetizer.jpg

Sensory Attributes

Sensory Attribute	Description
Aroma	
Overall Aroma	Intensity of all the aromatics
Sea Complex/Briny Aroma	Aromatic associated with sea air, salt water, or fresh fish
Cooked Corn	Aromatic of cooked corn, canned corn, or popcorn
Sweet Aromatic	Aromatic associated with substances that also have a sweet flavor
Flavor	
Crustacean Brothy	Brothy aromatic, cooked meat note associated with shellfish
Fishy	Old fish, trimethylamine
Metallic	Chemical feeling on the tongue associated with metal coins
Earthy	Damp potting soil association
Astringent Mouthfeel	Feeling on the tongue or other mouth surfaces of drying, drawing, or puckering
Sweet	Basic taste stimulated by sugars
Sour	Basic taste stimulated by acids
Salty	Basic taste stimulated by sodium salts
Umami	Basic taste characterized by a sensation of flavor "bloom" in the mouth
Appearance/Texture	
Shape (visual)	Degree to which the sample is intact (no broken tails, shells, or bodies)
Springiness (hand)	Degree to which the sample returns to original shape after partial compression with the thumb and forefinger
Hardness (first bite)	Force required to bite completely through the sample with the front teeth
Moisture Release (first bite)	Amount of moisture released from the sample on the first bite
Moisture Release (mastication)	Amount of moisture released from the sample at 5 to 7 chews
Cohesiveness of Mass (mastication)	Degree to which the sample holds together in a mass at 5 to 7 chews
Graininess/Grittiness (mastication)	Degree to which small, hard particles are perceived during mastication
Fibrous/Stringy (mastication)	Degree to which individual fibers are perceptible and separate from each other during mastication
Mouthcoating (residual)	Amount of moisture or fat left on the mouth surfaces after swallow

- Flavor and aroma scored on a 0-15 point universal intensity scale
  - Most Shrimp attributes typically fall in the lower (0-5) part of this scale
- Appearance and texture scored on a 0-15 point product-specific scale

Nutritional Results

	Treatment			
	Fishmeal	Fishmeal Settled	Plant	Plant Settled
Crude Protein	72.3	73.3	72.0	72.8
Total Lipid	1.2^{ax}	1.1^{ax}	1.1^{bx}	1.2^{bx}
Total Phosphorus	1.1^{a}	1.1^{a}	1.0^{b}	1.0^{b}
Calcium	2.6	2.6	2.5	2.6
Potassium	1.1^{ax}	1.2^{bx}	1.2^{ax}	1.2^{bx}
Magnesium	0.3	0.3	0.3	0.2
Sulfur	0.8	0.8	0.8	0.8
Zinc (ppm)	62.2^{a}	62.1^{a}	69.1^{b}	63.6^{b}
Copper (ppm)	113.9	106.5	120.7	115.1
Manganese (ppm)	4.1^{a}	3.1^{a}	6.4^{b}	6.2^{b}
Iron (ppm)	22.7	33.5	41.0	29.4
Sodium (ppm)	8860	9773	9121	8492

*Percent total composition, except where indicated otherwise. Data within rows with different letters are significantly different (P≤ 0.05).

- Total Lipid
  - ↑ Fish (P = 0.001)
  - ↑ Plant x Settling (P = 0.002)
- Phosphorus
  - ↑ Fish (P = 0.001)
- Potassium
  - ↑ Settling (P = 0.013)
  - ↑ Fish x Settling (P = 0.038)
- Zinc
  - ↑ Plant (P = 0.005)
- Manganese
  - ↑ Plant (P = 0.005)

Fatty Acids Results

- Many Differences in Fatty Acid Composition Between Both Diet and Settling Level ($P \leq 0.05$)
- Alpha-Linolenic (ALA)
  - ↑ Plant ($P = 0.000$)
  - ↑ Settling ($P = 0.008$)
  - Diet x Settling ($P = 0.045$)
- Eicosapentaenoic (EPA)
  - ↑ Fish ($P = 0.000$)
  - Diet x Settling ($P = 0.044$)
- Docosahexaenoic (DHA)
  - ↑ Fish ($P = 0.000$)
  - Diet x Settling ($P = 0.011$)
- EPA + DHA
  - ↑ Fish ($P = 0.000$)
- n-6:n-3
  - ↑ Plant ($P = 0.000$)

	Treatment			
	Fishmeal	Fishmeal Settled	Plant	Plant Settled
Fatty Acids:		mg 100 g^{-1}		
14:0	5.3^{a}	5.1^{a}	0.9^{b}	0.8^{b}
16:0	148.6^{a}	148.2^{a}	120.1^{b}	125.5^{b}
16:1n-7	8.6^{a}	8.5^{a}	1.6^{b}	1.4^{b}
17:0	5.8^{ax}	5.1^{bx}	5.1^{cx}	4.9^{dx}
18:0	54.0^{ax}	54.9^{bx}	78.1^{cx}	84.6^{dx}
C18:1n-9	76.5^{ax}	75.2^{ax}	78.1^{bx}	83.5^{bx}
C18:1n-7	22.1^{ax}	20.7^{ax}	11.3^{bx}	11.4^{bx}
C18:2n-6	89.3^{a}	89.4^{a}	157.8^{b}	171.6^{b}
C18:3n-3	5.2^{ax}	5.7^{bx}	22.9^{cx}	25.7^{dx}
C18:4n-3	n.t.	n.t.	n.t.	n.t.
C20:1n-9	28.5^{a}	28.0^{a}	3.4^{b}	3.6^{b}
C20:4n-6	16.7^{ax}	14.0^{bx}	44.7^{cx}	44.7^{dx}
C20:5n-3	109.5^{ax}	114.1^{ax}	39.9^{bx}	38.2^{bx}
C22:1n-9	2.9	2.9	3.1	2.8
C22:5n-3	3.8^{a}	3.6^{a}	1.4^{b}	1.3^{b}
C22:6n-3	94.0^{ax}	90.7^{ax}	78.5^{bx}	82.1^{bx}
EPA + DHA	203.5^{a}	204.8^{a}	118.4^{b}	120.4^{b}
n-6:n-3	0.5^{a}	0.5^{a}	1.5^{b}	1.6^{b}

Data within rows with different letters are significantly different ($P \leq 0.05$).
n.t. = not tested

Human Health Implications of Fatty Acid Concentrations

- EPA + DHA (250 mg day^{-1})
  - One 4 oz. (113 g) serving
    - Fish-fed shrimp = 93% daily recommendation
    - Plant-fed shrimp = 54% daily recommendation
- ALA (1500 mg day^{-1})
  - One 4 oz. (113 g) serving
    - Fish-fed shrimp = 1% daily recommendation
    - Plant-fed shrimp = 3% daily recommendation
- n-6:n-3 Ratio Recommendations (below 2:1)
    - Fish-fed shrimp = 0.5:1
    - Plant-fed shrimp = 1.6:1

Sensory Analysis Results

	Main Effects				Significant Interactive Effects	
	Fish Meal	Plant	Settling	No Settling	Diet x Settling by Diet	Diet x Settling by Settling
Aroma						
Overall Aroma	5.4	5.3	5.3	5.5	Fish Meal	No Settling
Sea Complex/Briny Aroma	3.4	3.1	3.6	3.1	Fish Meal	Settling
Cooked Corn	2.4	2.0	2.0	2.4	Fish Meal	Settling and No Settling
Sweet Aromatic	2.5	2.4	2.7[a]	2.5[b]	N.D.	N.D
Flavor						
Fishy	N.D	N.D.	N.D.	N.D.	N.D.	N.D.
Crustacean Brothy	3.8	3.5	3.4	3.5	N.D.	N.D.
Metallic	0.5	0.5	0.5	0.4	N.D.	N.D.
Earthy	1.1	1.1	1.2	1.0	Fish Meal	Settling
Astringent Mouthfeel	1.6	1.6	1.6	1.5	N.D.	N.D
Sweet	3.2	2.8	2.9	3.2	Fish Meal	Settling and No Settling
Sour	N.D	N.D.	N.D.	N.D.	N.D.	N.D.
Salty	1.3	1.3	1.3	1.3	N.D.	N.D.
Umami	3.1	3.2	3.1	3.0	N.D.	N.D.
Appearance/Texture						
Shape (visual)	14.9	14.9	14.9	15.0	N.D.	N.D.
Springiness (hand)	14.6	14.7	14.7	14.6	N.D.	N.D.
Hardness (first bite)	9.9	9.4	9.8	9.9	Fish Meal	No Settling
Moisture Release (first bite)	3.1[a]	3.7[b]	3.4	3.3	N.D.	N.D.
Moisture Release (mastication)	5.9[a]	6.7[b]	6.3	6.0	N.D.	N.D.
Cohesiveness of Mass (masticati	6.0	6.2	6.1	6.2	N.D.	N.D.
Graininess/Grittiness (mastication	N.D	N.D.	N.D.	N.D.	N.D.	N.D.
Fibrous/Stringy (mastication)	2.8[a]	3.2[b]	3.0	3.0	N.D.	N.D.
Mouthcoating (residual)	3.8	3.6	3.8	3.7	N.D.	N.D.

Data within rows in each section with different letters are significantly different ($P \leq 0.05$). N.D. = none detected

Summary

- General nutritional profiles affected by both diet and solids management
- Total lipid increased with fish diet, and also settling
- Fatty acids
  - Profiles affected by both diet and solids management
  - EPA and DHA
    - More concentrated in fish-fed shrimp
    - Reasonable concentration in plant-fed shrimp
  - ALA
    - More concentrated in plant-fed shrimp
  - n-6:n-3 Ratio
    - Below 2:1 in shrimp fed both diets

Summary

- No significant differences between shrimp fed the two diets with respect to any of the 13 aroma or flavor attributes
- Plant-fed shrimp
  - ↑ moisture
  - ↑ fibrousness
- Shrimp cultured with solids management
  - ↑ sweet aroma
- Multiple interactive effects of diet and solids management

Conclusions

- Both Diet and System Management
  - Can Significantly Affect Biochemical Composition and Sensory Attributes of Shrimp in Biofloc Systems.
- Important Consumer Health Components
  - Comparable between shrimp fed the two diets
  - Need to improve fatty acid profile of plant-fed shrimp
- Sensory Attributes
  - Comparable between diets
  - Need to perform a consumer preference study
- Need to Improve Sustainability While Maintaining or Enhancing Product Quality

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Thank You

- Clemson University's Agricultural Services Laboratory
  - = Crude Protein, Ash, Moisture, P, Ca, K, Mg, S, Zn, Cu, Mn, Fe, and Na Analyses
- NOAA's Center for Coastal Environmental Health and Biomolecular Research
  - Fatty Acid Analyses
- North Carolina State University's Department of Food, Bioprocessing, and Nutrition Services
  - Descriptive Sensory Analyses
- Maggie Holbrook Broadwater, Kathy Moore, Joe Wade, and the Staff of the Waddell Mariculture Center
- Funding: US Marine Shrimp Farming Program, USDA Integrated Organic Program