USSEC
2nd Asian Aquaculture Feed Formulation Database Workshop

Day 2:

Educational Modules

AAFFD
Asian Aquaculture Feed Formulation Database

Agenda

0900-0915 Introduction and Outline of Aquaculture Formulation Approach

0915-1015 Introduction to Formulation with Bestmix:

- Ingredients selection
- Nutritional specifications selection
- Least-cost formulation

1015-1030 Introduction to Feed Formulation Exercises

1045-1145 Feed Formulation Exercise: Formulating for a species

1145-1245 Educational Module #1: Ingredient Composition and Nutritive Value

- Adjusting the composition of ingredients on Bestmix
- Development of equations for predicting parameters
- Variability in the nutritive value of ingredients: Nutritional principles

1345-1445 Educational Module #2 Nutritional Specifications

- Nutritional specifications – How they are developed, adjusted, updated
- Meeting essential fatty acids and minor lipids requirements
- Effectively meeting phosphorus requirement

1445-1530 Feed Formulation Exercise (continued)

1545-1645 Presentation of feed formulations

1645-1715 Wrap-up, certificate presentation and group picture

Educational Module #1: Ingredient Composition and Nutritive Value (1h)

- Adjusting the composition of ingredients on Bestmix

- Development of equations for predicting parameters

- Variability in the nutritive value of ingredients: Nutritional principles

Educational Module #2 Nutritional Specifications (1h)

Nutritional specifications – How they are developed, adjusted, updated

Meeting essential fatty acids and minor lipids requirements

Effectively meeting phosphorus requirement

Educational Module #3: Dietary Energy: Definitions and Requirements (30 min)

- Energy Partitioning Scheme

- Dietary Energy
  - Gross energy
  - Digestible energy
  - Metabolizable energy

- Bioenergetics Model
  - Energy Requirement Estimations
  - Theoretical feed requirement and feed conversion ratio

Educational Module #1: Ingredient Composition and Nutritive Value (1h)

- Adjusting the composition of ingredients on Bestmix

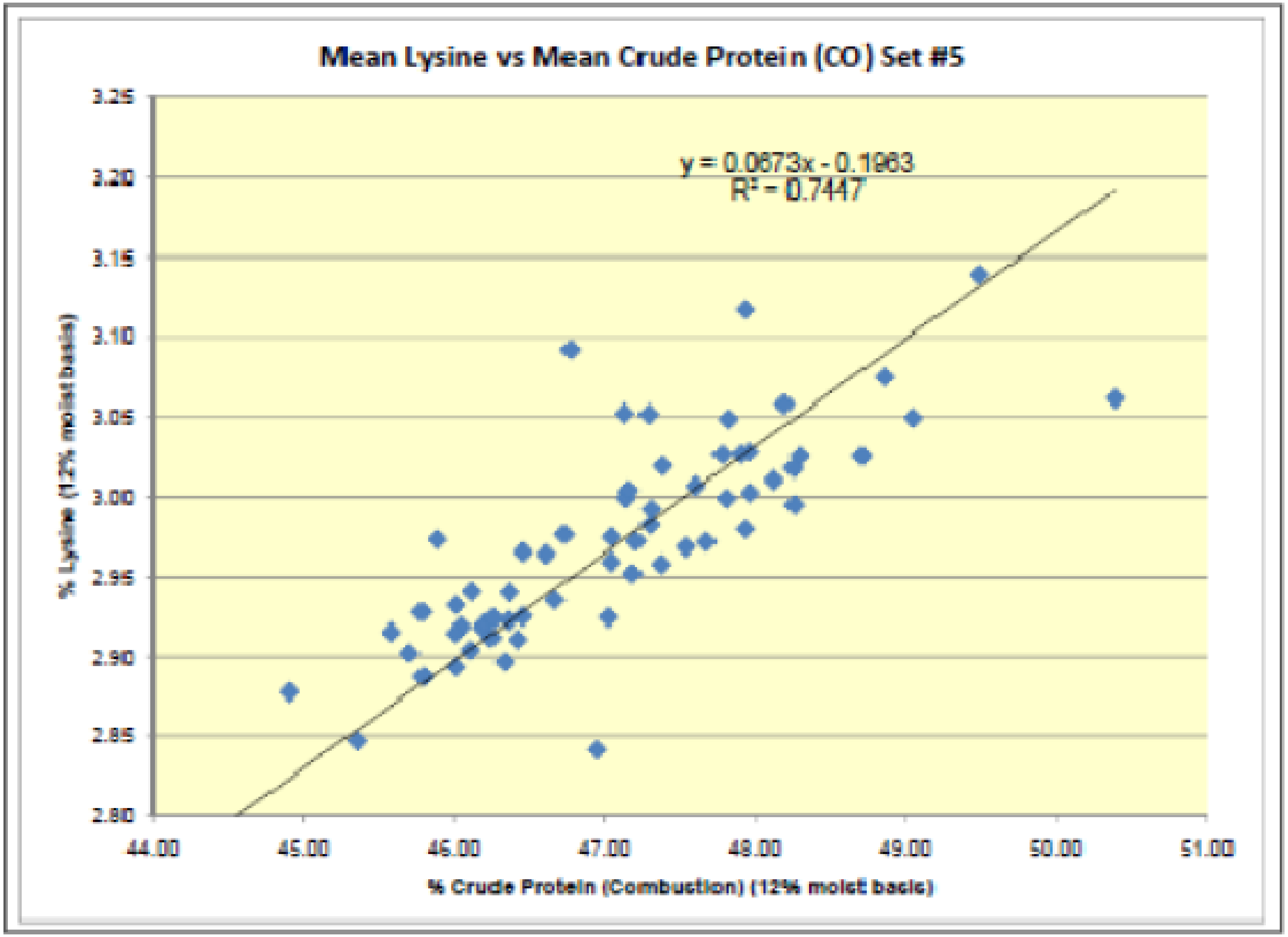
- Development of equations for predicting parameters

- Variability in the nutritive value of ingredients: Nutritional principles

Adjusting the Composition of Ingredients

- Adjusting the composition of ingredients in AAFFD and Bestmix
  - Done on the basis of coefficients that relate amino acid, fatty acid, and mineral (Ca, P) compositions to protein, lipid or ash
  - Coefficients are specific per ingredients or ingredient types
  - Example of equation in BestMix:
    - If Nutrients.Amino acid coefficients.Arg Coeff <>0 Then Nutrients.Amino acids.Arginine = Round (Nutrients.Proximate analysis.Crude Protein *Nutrients.Amino acid coefficients.Arg Coeff /100,2) End If

Variability of Lysine Concentration in Relation to Crude Protein Content of US Soybean Meal Samples



Data courtesy of Paul Smolen and United Soybean Board

Gross Energy

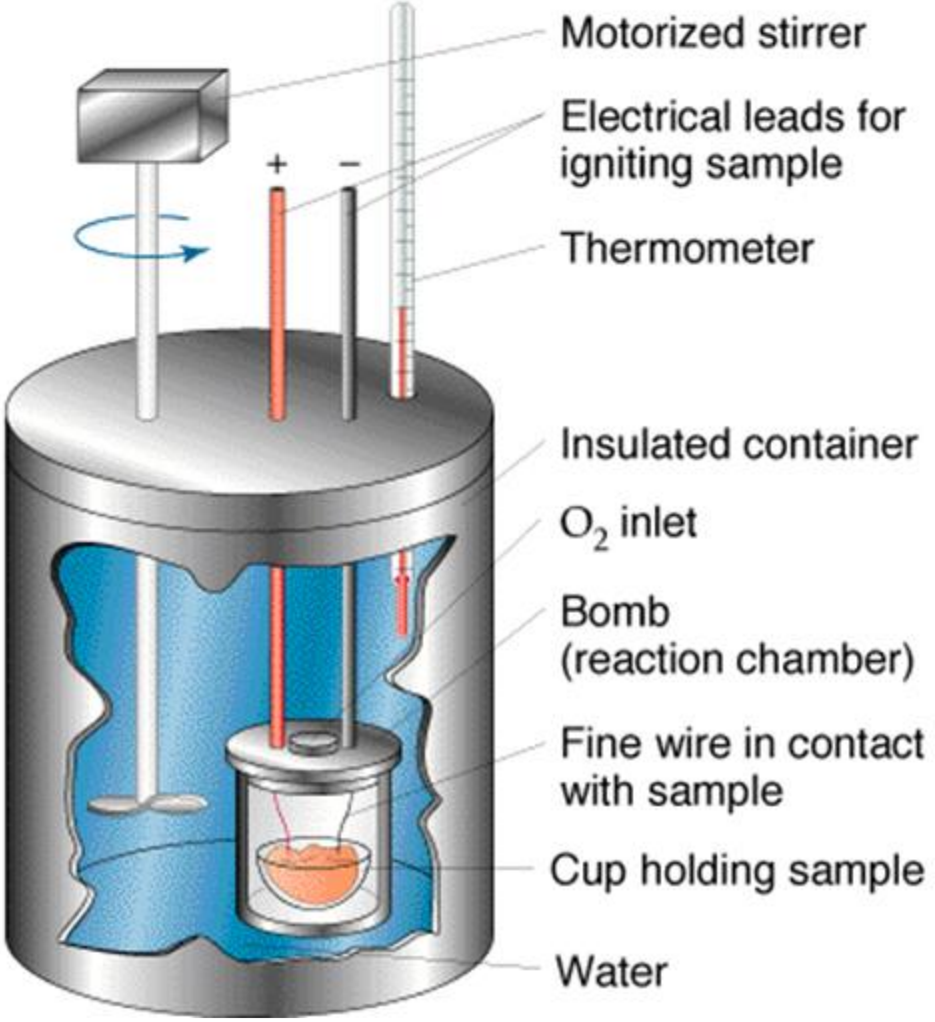
Gross energy (GE) is the commonly used term for enthalpy (ΔH) of combustion in nutrition. However, as opposed to enthalpy, GE is generally represented by a + sign. GE content of a substance is usually measured by its combustion in a heavily walled metal container (bomb) under an atmosphere of compressed oxygen. The method is referred to as bomb calorimetry.

The GE content of an ingredient or a compounded diet depends upon its chemical composition.

The mean values of GE of carbohydrates, proteins and lipids are 17.2, 23.6 and 39.5 kJ/g, respectively (Blaxter, 1989).

Minerals (ash) have no GE because these components are not combustible.

Bomb Calorimeter



Gross Energy (MJ/kg) =

Crude Protein (kg/kg) x 23.6 MJ/kg
+
Lipids (kg/kg) x 39 MJ/kg
+
Total Carbohydrate (kg/kg) x 17 MJ/kg

Gross Energy (MJ/kg) = 0.32 * 23.6 + 0.06 * 39 + 0.4 * 17
For a 32% CP, 6% fat and 40% total CHO feed

Gross energy (MJ/kg)*1000 / 4.184 = Gross energy (kcal/kg)

Digestible Energy (MJ/kg) =

$$\text{Gross energy (MJ/kg)} \times ADC_{\text{Gross Energy}}$$

Species specific
Carnivorous vs. omnivorous vs. carp vs. shrimp?

<u>or</u>

$$\text{Crude Protein (kg/kg)} \times 23.6 \text{ MJ/kg} \times ADC_{\text{Crude Protein}}$$

+

$$\text{Lipids (kg/kg)} \times 39 \text{ MJ/kg} \times ADC_{\text{Lipids}}$$

+

$$\text{Total Carbohydrate (kg/kg)} \times 17 \text{ MJ/kg} \times ADC_{\text{Total CHO}}$$

Species specific
Carnivorous vs. omnivorous vs. carp vs. shrimp?

Digestible Energy (MJ/kg) =

Crude Protein (kg/kg) x 23.6 MJ/kg x $ADC_{\text{Crude Protein}}$

ADC crude protein: 0.85 to 0.9

+

Lipids (kg/kg) x 39 MJ/kg x ADC_{Lipids}

ADC Lipids = 0.85-0.95

+

Total Carbohydrate (kg/kg) x 17 MJ/kg x $ADC_{\text{Total CHO}}$

ADC total CHO = 0.4 to 0.7
(depends on fiber level, heat processing, species)

Digestible Energy (MJ/kg) (Starch +sugars) =

Crude Protein (kg/kg) x 23.6 MJ/kg x $ADC_{\text{Crude Protein}}$

+

Lipids (kg/kg) x 39 MJ/kg x ADC_{Lipids}

+

Starch+ Sugars (kg/kg) x 17 MJ/kg x $ADC_{\text{Total Starch+Sugars}}$

Species specific
Carnivorous vs. omnivorous vs. carp vs. shrimp?

Digestible Energy (MJ/kg) =

Crude Protein (kg/kg) x 23.6 MJ/kg x $ADC_{\text{Crude Protein}}$

ADC crude protein: 0.85 to 0.9

+

Lipids (kg/kg) x 39 MJ/kg x ADC_{Lipids}

ADC Lipids = 0.85-0.95

+

Total Starch + Sugars (kg/kg) x 17 MJ/kg x $ADC_{\text{Total starch+sugars}}$

ADC total starch+sugars = 0.6 to 0.95
(depends on heat processing, species)

Equations in AAFFD and BestMix

- 'Energy calculations
- Nutrients.Energy Aqua.Gross Energy -MJ = Round (23.6*Nutrients.Proximate analysis.Crude Protein /100+ 39*Nutrients.Proximate analysis.Crude Lipids /100 + 17*Nutrients.Proximate analysis.Total CHO /100 ,1)
- Nutrients.Energy Aqua.Gross energy -Kcal = Round (Nutrients.Energy Aqua.Gross Energy -MJ * 238.85,0)
- Nutrients.Energy Aqua.DE Carp = Round ((23.6*Nutrients.Proximate analysis.Crude Protein /100*Nutrients.App Diges Coeff Prox Aqua.ADC DM -fish /100 + 39*Nutrients.Proximate analysis.Crude Lipids /100*Nutrients.App Diges Coeff Prox Aqua.ADC CP -fish /100 + 17*Nutrients.Proximate analysis.Total CHO /100*Nutrients.App Diges Coeff Prox Aqua.ADC GE - fish /100)* 238.85 ,0)
- Nutrients.Energy Aqua.DE Fish Carni = Round ((23.6*Nutrients.Proximate analysis.Crude Protein /100*Nutrients.App Diges Coeff Prox Aqua.ADC DM -fish /100 + 39*Nutrients.Proximate analysis.Crude Lipids /100*Nutrients.App Diges Coeff Prox Aqua.ADC CP -fish /100 + 17*Nutrients.Proximate analysis.Total CHO /100*Nutrients.App Diges Coeff Prox Aqua.ADC GE - fish /100)* 238.85 ,0)
- Nutrients.Energy Aqua.DE Fish Omni = Round ((23.6*Nutrients.Proximate analysis.Crude Protein /100*Nutrients.App Diges Coeff Prox Aqua.ADC DM -fish /100 + 39*Nutrients.Proximate analysis.Crude Lipids /100*Nutrients.App Diges Coeff Prox Aqua.ADC CP -fish /100 + 17*Nutrients.Proximate analysis.Total CHO /100*Nutrients.App Diges Coeff Prox Aqua.ADC GE - fish /100)* 238.85 ,0)
- Nutrients.Energy Aqua.DE Shrimp = Round ((23.6*Nutrients.Proximate analysis.Crude Protein /100*Nutrients.App Diges Coeff Prox Aqua.ADC DM -fish /100 + 39*Nutrients.Proximate analysis.Crude Lipids /100*Nutrients.App Diges Coeff Prox Aqua.ADC CP -fish /100 + 17*Nutrients.Proximate analysis.Total CHO /100*Nutrients.App Diges Coeff Prox Aqua.ADC GE - fish /100)* 238.85 ,0)

Variability in the Nutritive Value of Ingredients: Nutritional Principles

- Most variability in nutritive value is associated with chemical damage/ degradation of proteins and lipids in the feed ingredients
- Damage can occur due to heat treatment, chemical reaction, oxidative rancidity and microbial action
- Some natural variability exists and mainly related to variability in raw material composition and seasonal variability, affecting nutrient levels (fatty acid, amino acids, minerals) and levels of anti-nutritional factors and contaminants
- Differences between species are probably minor, except for starch digestibility and fermentation of soluble fiber components and ability to use starch and sugars,

Digestibility – Direct method (Total Collection Method)

Requires:

Very accurate estimate of feed consumption (e.g. over 24-72h)

Total collection of fecal material produced (e.g. over 24-72h)

	Feed g/fish	Feces g/fish	Digestibility	
Dry matter	100	25	$\frac{100-25}{100}$	75%
Protein	40	4	$\frac{40-4}{40}$	90%
Lipid	20	1	$\frac{20-1}{20}$	95%

Digestibility – Indirect method

Requires:

- Use of digestion indicator (marker) = 100% indigestible
- Collection of representative samples fecal material produced

Apparent Digestibility Coefficient (ADC) = 1- (F/D x Di/Fi)

	Feed %	Feces %	Digestibility	**%**
Dry matter	95	95	1-(95/95 x 1/4)	**75**
Protein	40	8	1-(8/40x 1/4)	**95**
Lipid	20	6	1-(6/20 x 1/4)	**92.5**
Marker	1	4	1-(4/1 x 1/4)	**0**

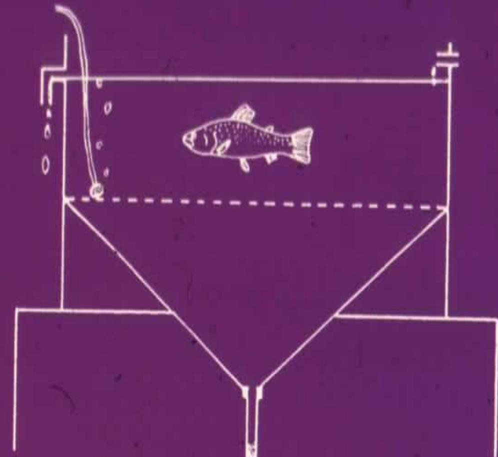
Measuring Digestibility in Fish

Several Methods:

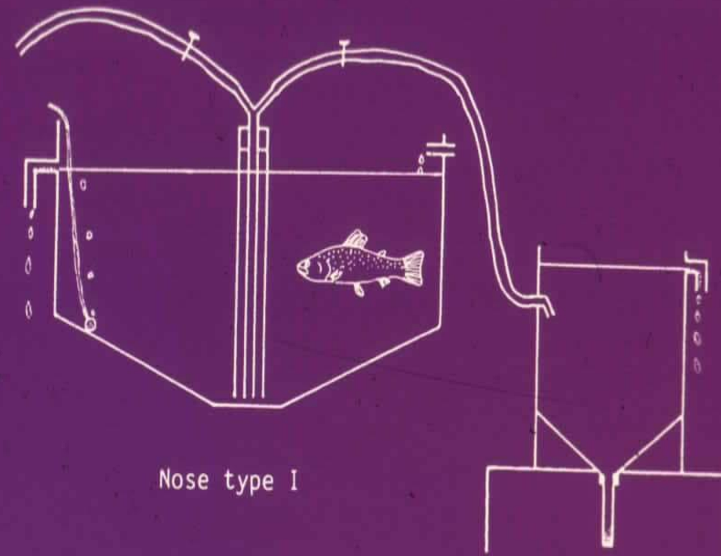
Stripping, dissection, siphoning

Three passive collection methods believed to be more reliable:

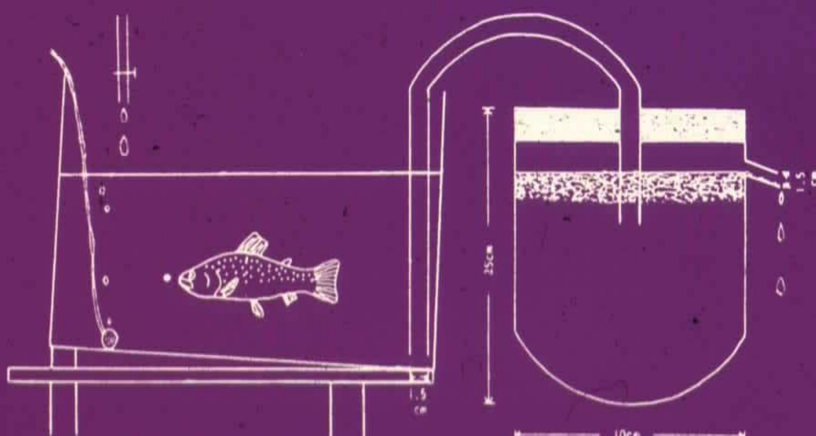
TUF Column (Japan)
St.-Pee System (France)
Guelph System (Canada)



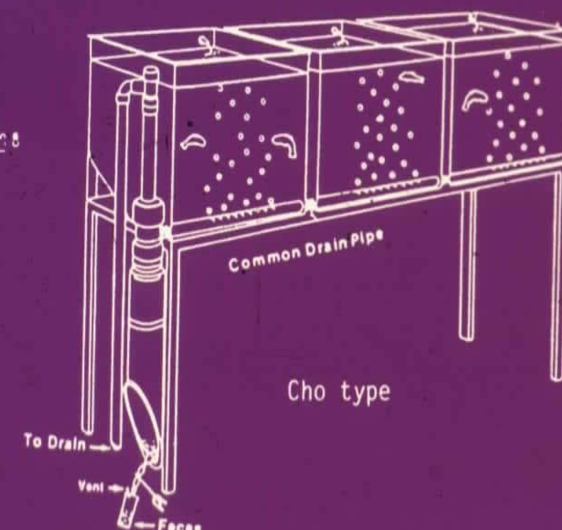
Nose type II



Nose type I



Ogino type II

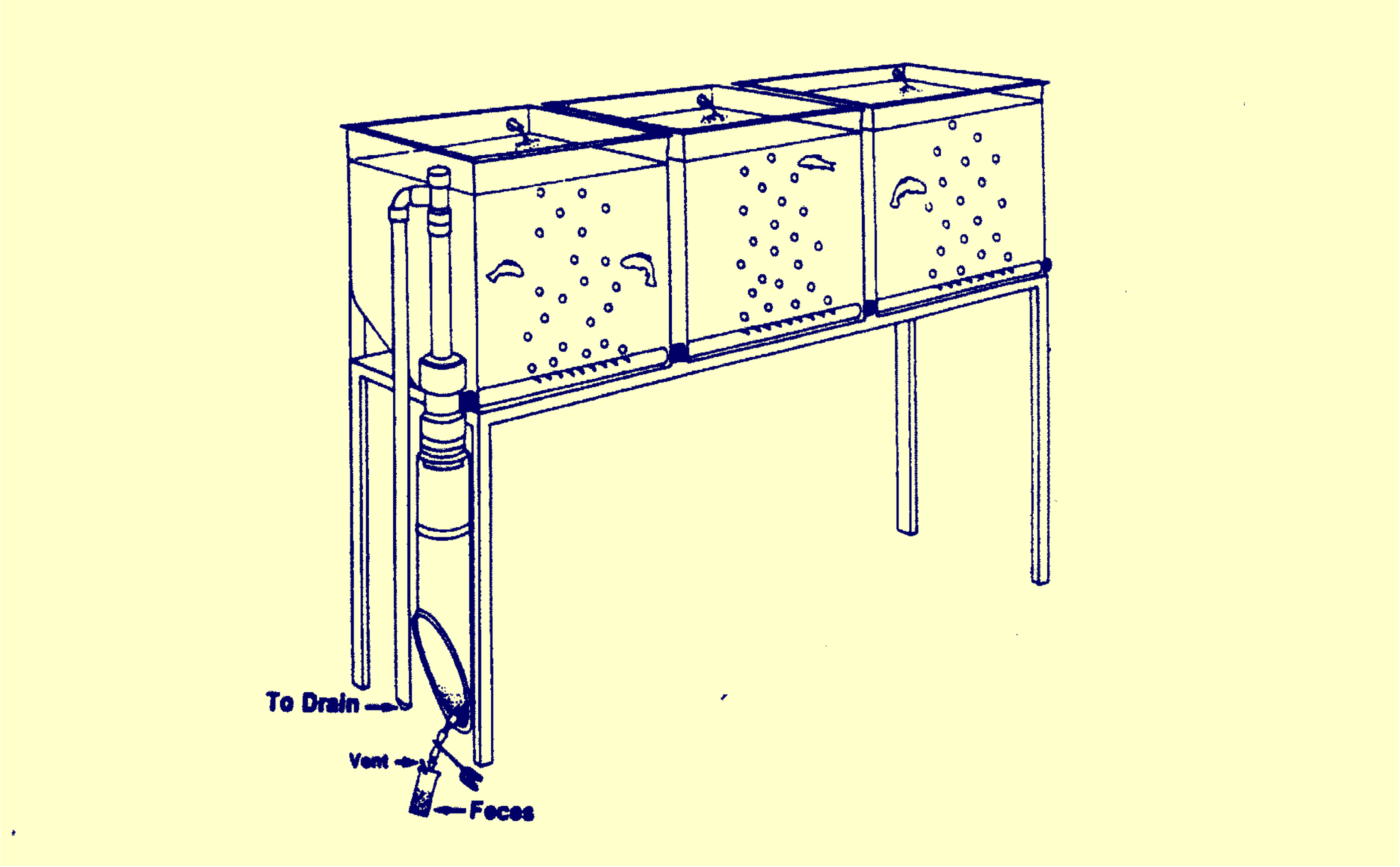


Cho type

St-Pée System (INRA, St-Pée-sur-Nivelle, France)

Choubert, Luquet, and de la Noue (1979)

Guelph System (Cho et al., 1982)



The Guelph System


'90 5 20


'90 8 2

Digestibility of Single Ingredients

Most ingredients cannot be fed alone

- Acceptance (palatability)
- Pelletability
- Nutritional quality

Test diet

- 70% Reference diet
- 30% Test ingredient

Reference Diet

Ingredient	%
Fish meal	30
Corn gluten meal	13
Soybean meal	17
Wheat middlings	27
Vitamin premix	1
Mineral premix	1
Fish oil	10
Digestion indicator	1
	100

Equation - Digestibility

$$ADC_{ingr} = ADC_{test} + ((1-s)D_{ref}/sD_{ingr})\,(ADC_{test} - ADC_{ref})$$

ADC_{ingr}=	Apparent digestibility coefficient test diet
ADC_{ref}=	Apparent digestibility coefficient reference diet
D_{ref}=	Nutrient content of reference diet
D_{ingr}=	Nutrient content of ingredient
s =	Level of incorporation of ingredient in test diet (e.g. 30%)

Ingredients	Apparent digestibility coefficients (%)			
	Dry Matter	Crude Protein	Lipid	Energy
Alfalfa meal	39	87	71	43
Blood meal				
ring-dried	87	85	-	86
spray-dried	91	96	-	92
flame-dried	55	16	-	50
Brewer's dried yeast	76	91	-	77
Corn yellow	23	95	-	39
Corn gluten feed	23	92		29
Corn gluten meal	80	96	-	83
Corn distiller dried soluble	46	85	71	51
Feather meal	77	77	-	77
Fish meal, herring	85	92	97	91
Meat and bone meal	70	85	-	80
Poultry by-products meal	76	89	-	82
Rapeseed meal	35	77	-	45
Soybean, full-fat, cook.	78	96	94	85
Soybean meal, dehulled	74	96	-	75
Wheat middlings	35	92	-	46
Whey, dehydrated	97	96	-	94
Fish protein concentrate	90	95	-	94
Soy protein concentrate	77	97	-	84

Feather Meal

	ADC	
Guelph System	Protein	Energy
Cho et al. (1982)	58%	70%
Sugiura et al. (1998)	82-84%	N/A
Bureau (1999)	81-87%	76-80%
Stripping	HCl hydrolyzed feather meal	
Pfeffer et al. (1995)	83%	81%

Poultry By-Products Meal

Guelph System	ADC	
	Protein	Energy
Cho et al. (1982)	68%	71%
Hajen et al. (1993)	74-85%	65-72%
Sugiura et al. (1998)	96%	N/A
Bureau et al. (1999)	87-91%	77-92%

ISSUES (in order of importance)

1. Aquatic System – Fecal Collection System

2. Experimental Design – Experimental Dietary Design
    1. Focus on individual ingredient
    2. Focus on complete feed

3. Chemical Analyses
    1. Digestion indicator analysis
    2. Proximate, energy and chemical analysis

4. Digestibility Equations – Mathematical & statistical issues

5. Factors
    1. Batch variability for ingredients
    2. Environmental factors
    3. Species and lifestages differences

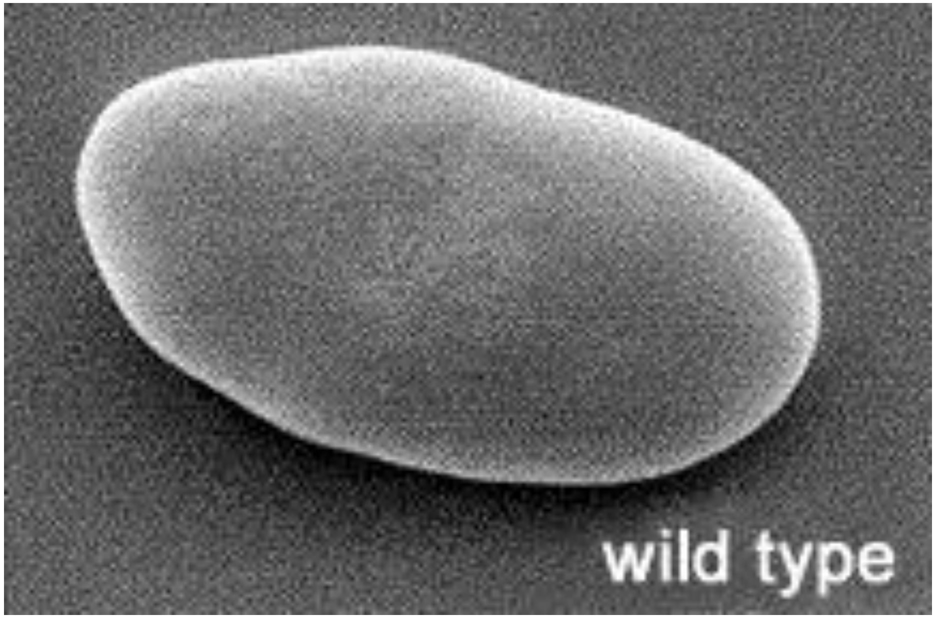
Factors Affecting Digestibility of Nutrients?

Processing / Chemical Damage

Digestibility of Starches from Various Botanical Origins

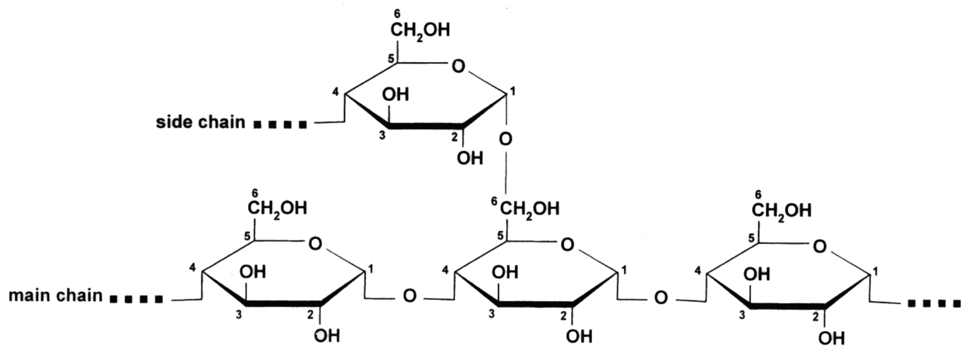
Starch type (at 30% of diet)	ADC starch (%)
Corn, raw	33
Corn, raw (65% amylose)	19
Corn, "Waxy", raw (99% amylopectin)	54
Corn, extruded	96
Corn, gelatinized	96
Wheat	54
Rice	39
Manioc	16
Potato	3

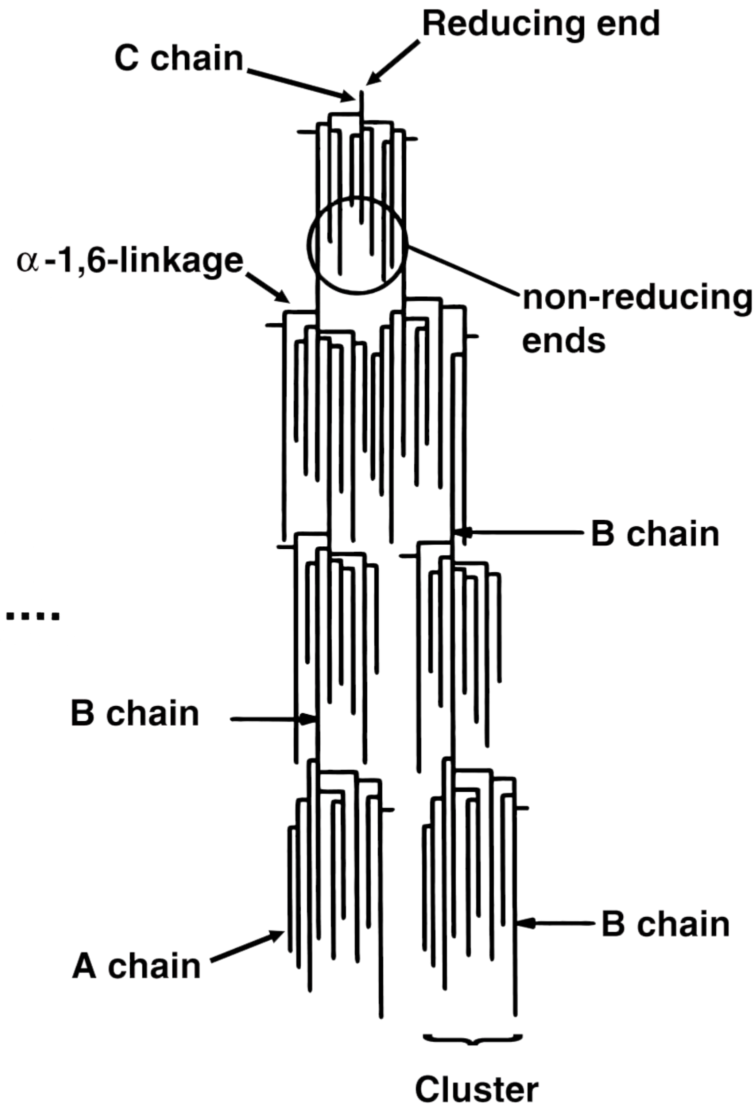
Starch Granule from a Pea Seed



http://www.jic.bbsrc.ac.uk/staff/cliff-hedley/Starch.htm

Structure of Starch





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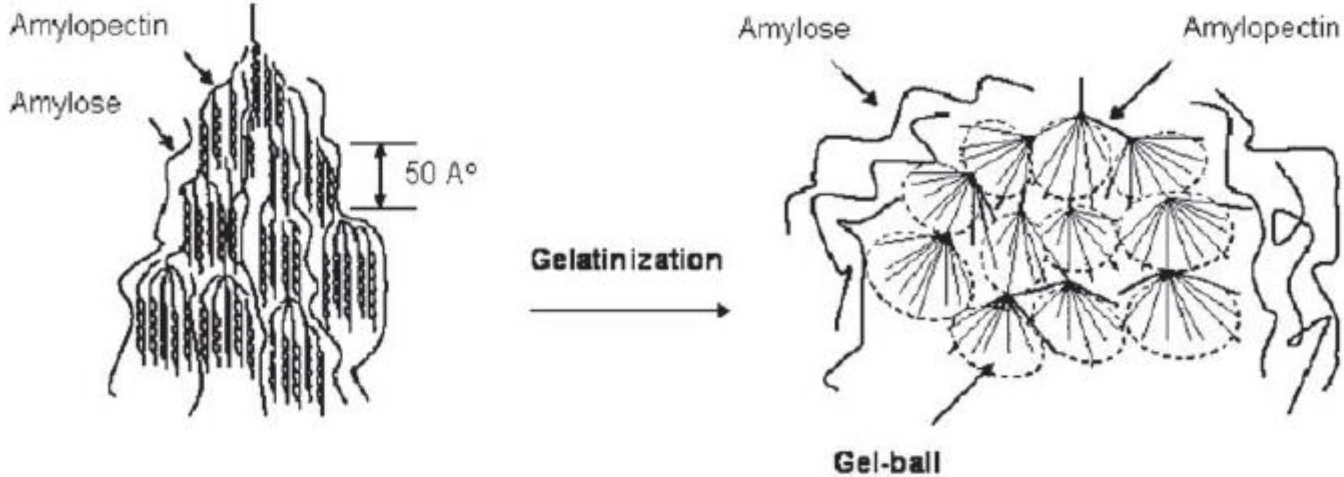


Fig. 5. Schematic representation of microstructure and phase transition of starch during gelatinization.

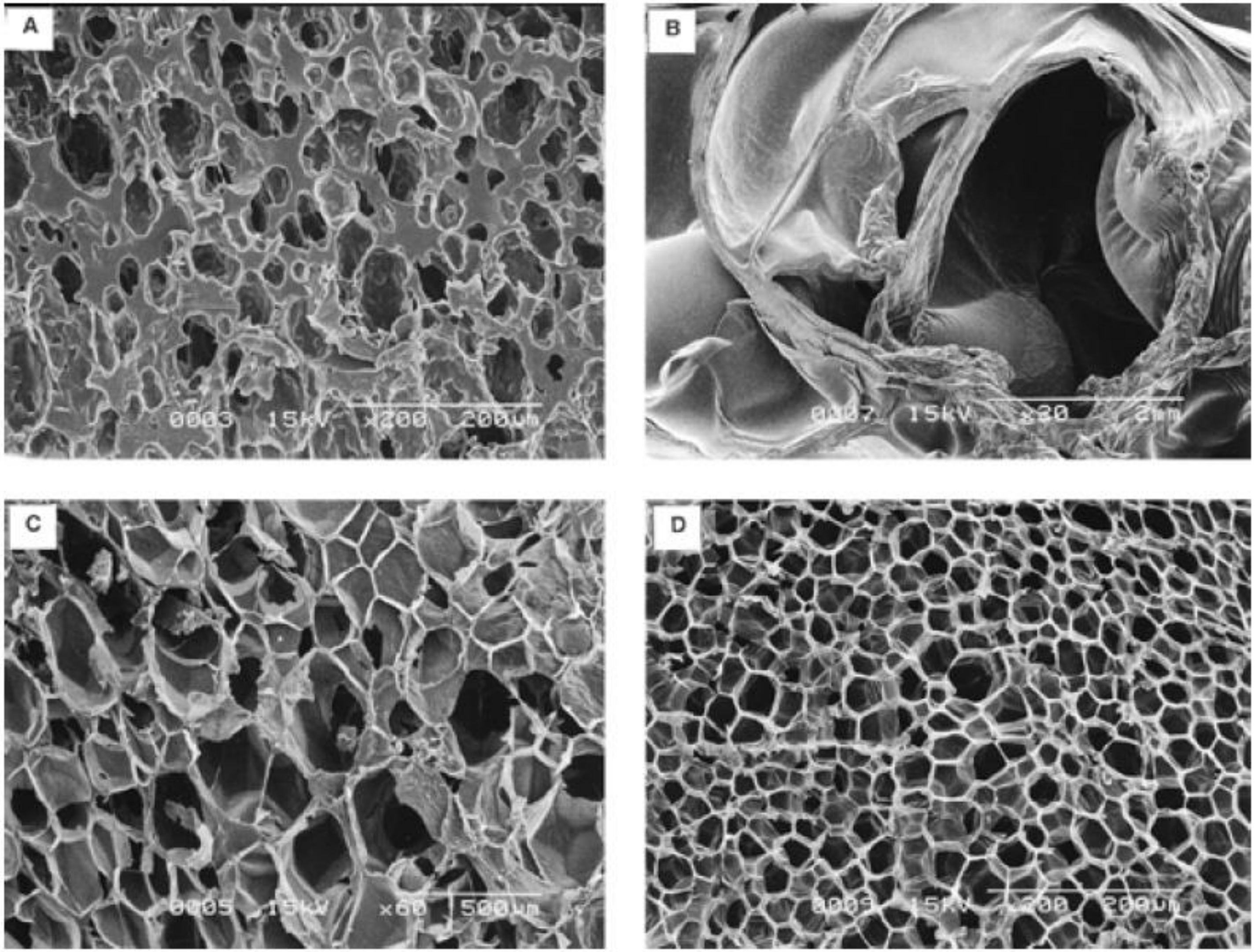


Fig. 3. Scanning electron micrographs of cross-sections of microwave-puffed products at different temperatures and water feeding rates: **A,** 70°C and 42 g/min (×200); **B,** 110°C and 42 g/min (×20); **C,** 90°C and 63 g/min (×200); **D,** commercial popcorn (×200).

Blood Meal

Guelph System	ADC	
	Protein	Energy
Spray-dried	96-99%	92-99%
Ring-dried	85-88%	86-88%
Steam-tube dried	84%	79%
Rotoplate dried	82%	82%

↑

Different drying technique

Bureau et al. (1999)

Differences between Species?

Blood Meal

Guelph System	ADC	
	Protein	Energy
Spray-dried	96-99%	92-99%
Ring-dried	85-88%	86-88%
Steam-tube dried	84%	79%
Rotoplate dried	82%	82%

↑ Different drying technique

Bureau et al. (1999)

Feather Meal

75-85% Crude Protein

Rich in:
- Arginine (5.8%)
- Cystine (3.8%)
- Threonine (3.9%)

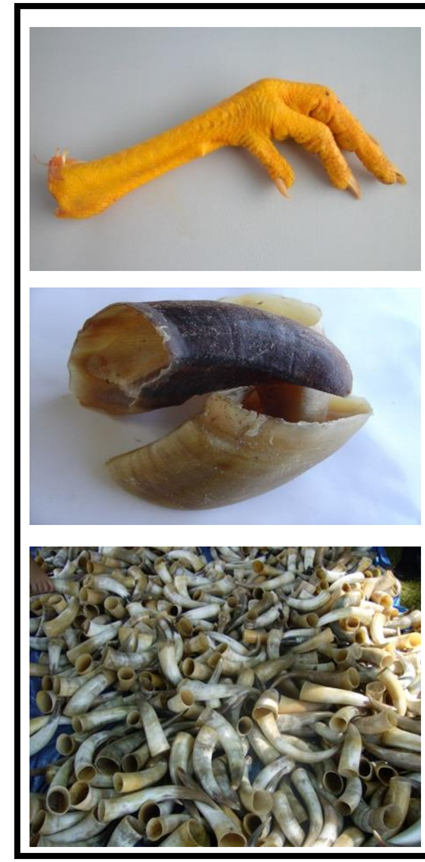
Poor in:
- Lysine: (1.8%)
- Histidine: (0.7%)
- Tryptophan: (0.55%)

High variability in nutritional value!!!

Great Variability in Digestibility of Feather Meals from Various Origins by Rainbow Trout

Author	ADC		
	DM	CP	GE
		(%)	
Cho et al. (1982)	75	58	70
Cho and Kaushik (1990)	81	77	77
Bureau et al. (1999)	79	81	76
Bureau et al. (1999)	80	81	80
Bureau et al. (1999)	82	81	83
Bureau et al. (1999)	84	87	80
Cheng et al. (2004)	80	77	77
Gaylord et al. (2008)	-	87	88

Variability of raw materials



Variability processing equipment

Batch Pressure Cooker

Continuous Pressure Cooker

Flash Dryer

Disc Dryer

Ring Dryer

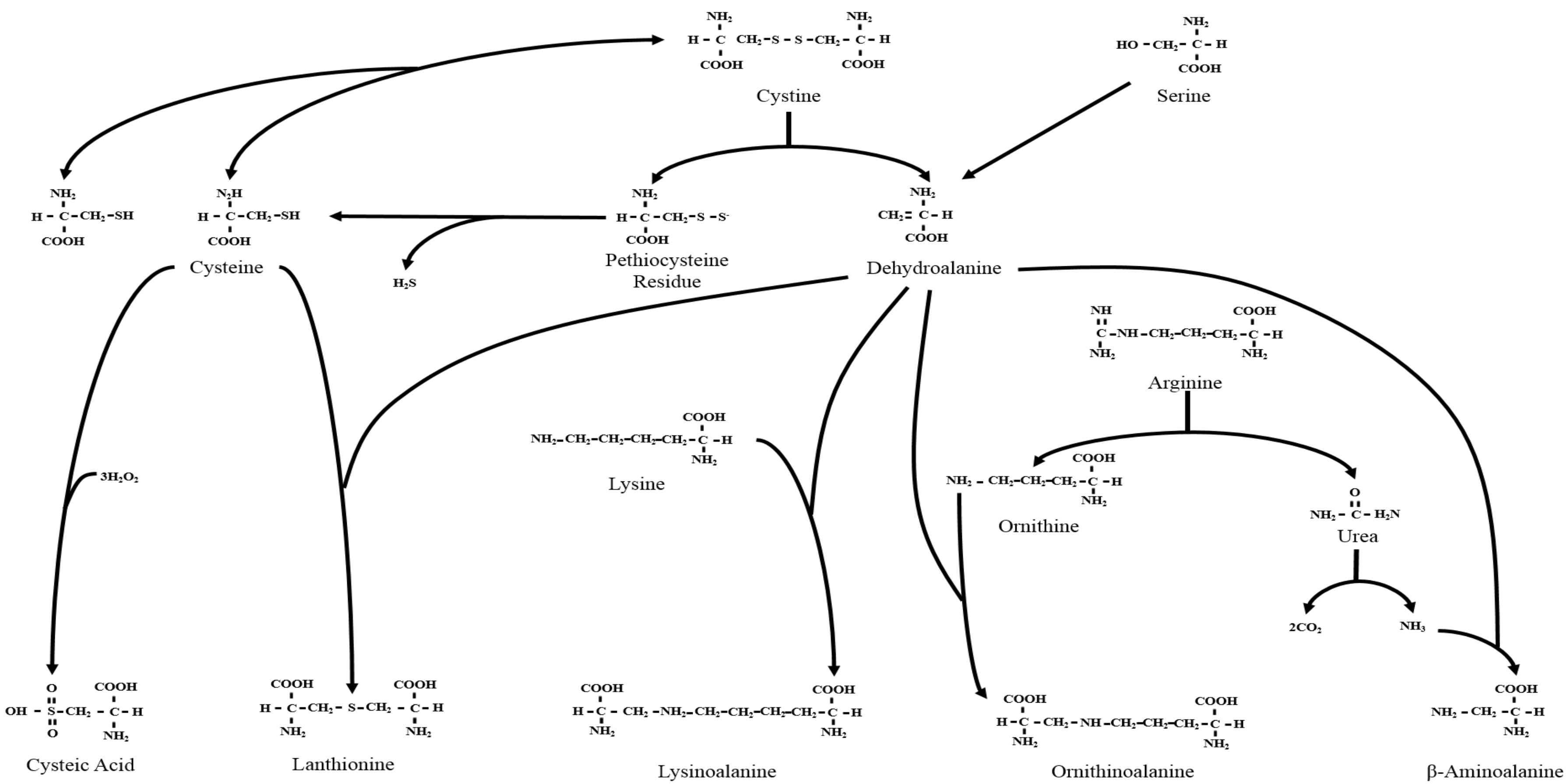
Ring dryer with full manifold for vital wheat gluten

Variability of the processing conditions affects available amino acid content and level of cross-linked amino acid of no nutritive value.

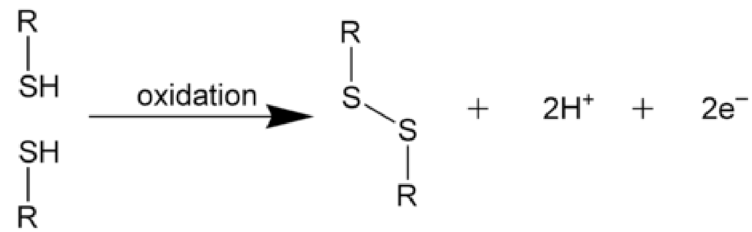
	Pressure (kPa)				
Amino acids	207	310	414	517	SEM
Methionine	0.43	0.37	0.39	0.31	0.02*
Cystine	3.99	2.44	2.21	1.48	0.24**
Lysine	1.37	1.08	1.02	0.93	0.08**
Threonine	3.54	3.16	3.22	2.97	0.06**
Arginine	5.46	4.99	5.31	5.00	0.13
Valine	5.98	5.70	5.92	5.48	0.11*
Isoleucine	4.07	3.88	4.07	3.80	0.05*
Leucine	6.62	6.28	6.60	6.13	0.10*
Aspartate	4.20	3.08	3.25	2.95	0.19**
Glutamate	7.82	6.66	6.86	6.34	0.21**
Serine	9.30	8.37	8.73	8.05	0.17**
Lanthionine	0.33	0.72	0.90	0.96	0.03**
TA Cys equivalent[1]	4.53	3.16	3.05	2.29	0.26**
TME	3.51	2.97	3.03	2.95	0.11*

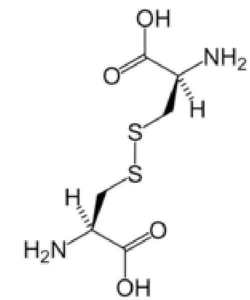
Moritz and Latshaw (2001)

Formation of Cross-Linked Amino Acids



Disulfide Bonds





Cys-Cys
(Cystine)

Very stable (heat) & indigestible

Certain natural proteins, such as keratins and lysozymes, contain many disulfide bonds

Raw feather and hair (>90% keratins) Apparent digestibility coefficient = 0%
Feather treated with heat + pressure Apparent digestibility coefficient > 70%
(Steam hydrolyzed, pressure cooked)
Feather treated with keratinase Apparent digestibility coefficient > 70%
(enzyme-treated)

Moist heat + pressure break disulfide bonds

Overheated proteins (dried at high temperature) = creation of disulfide bonds

Flame-dried (drum) blood meal Apparent digestibility coefficient = 16%
Spray-dried blood meal Apparent digestibility coefficient = 99%

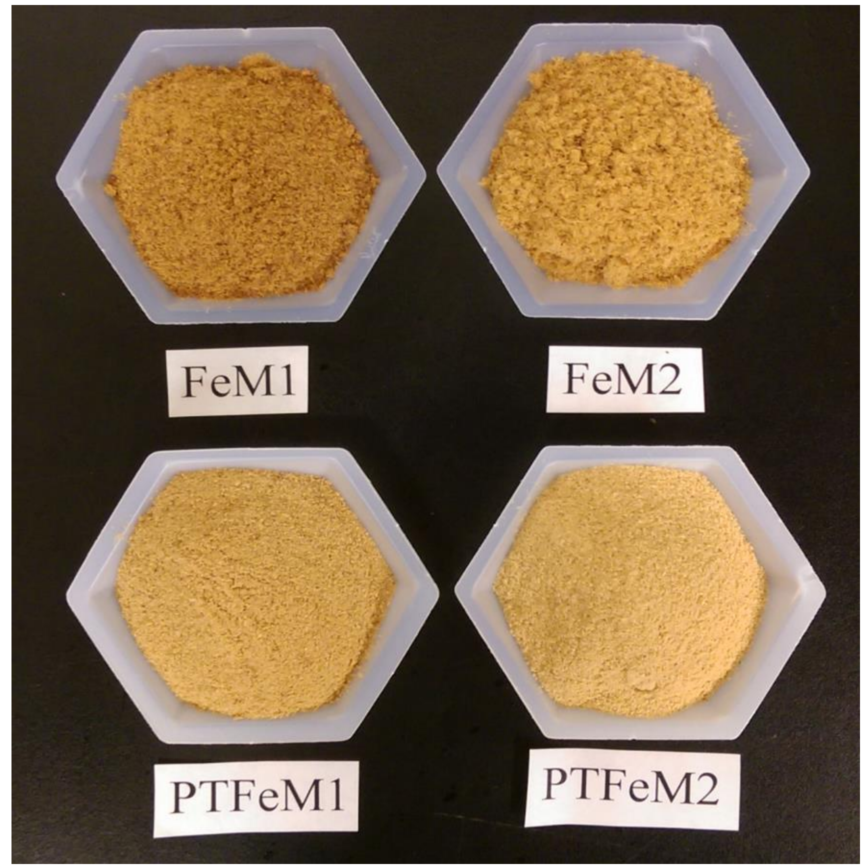
Slope-Ratio assay to assess the bioavailability of PTFEMs

Processing of two feather meals

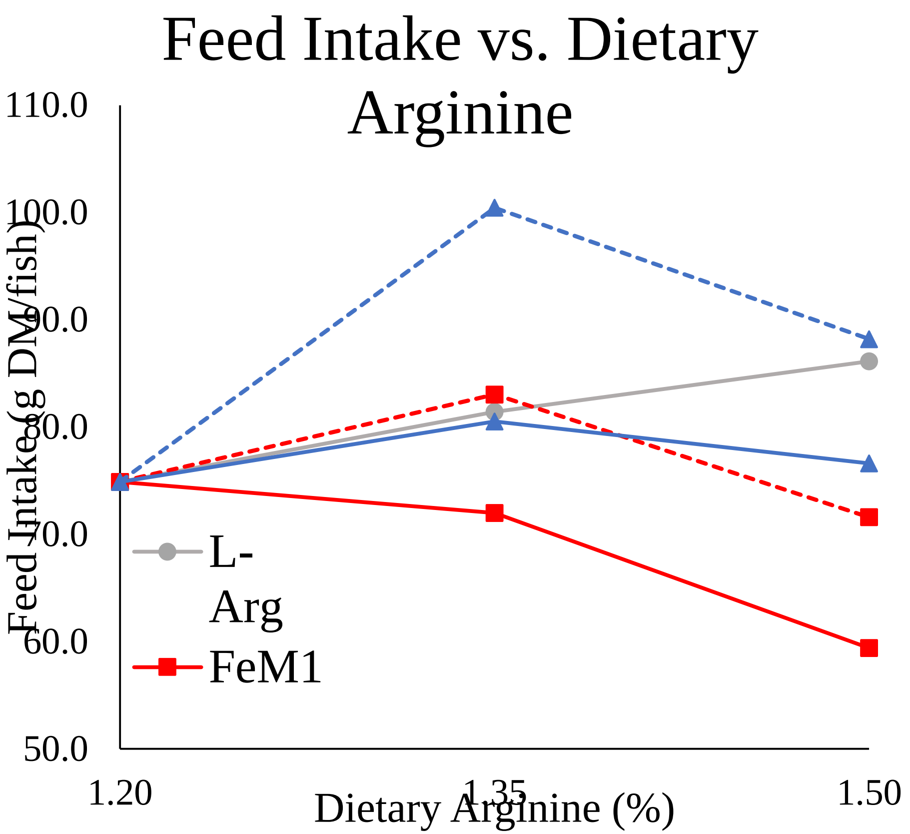
- 2% sodium sulfite
- 0.05% bacterial enzyme
- 2:1 water:FeM ratio
- 24h incubation

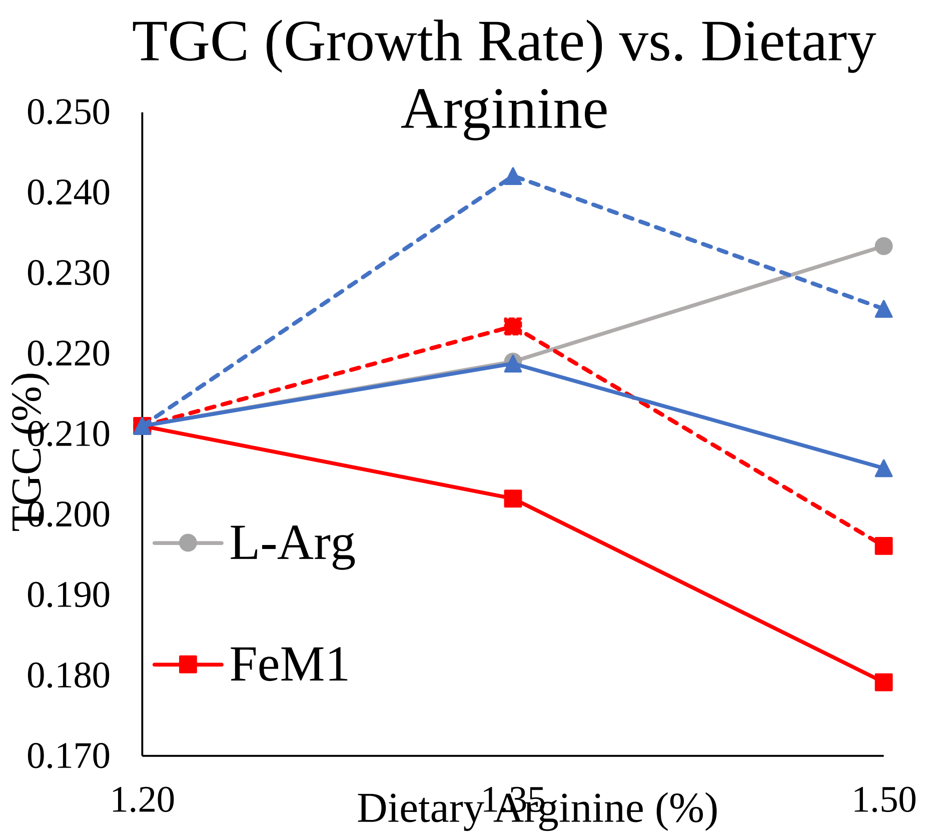
Slope-ratio assay carried out using the protocol of Poppi et al 2010.

- 12 diets
- 1 basal diet deficient in arginine (1.2%)
- 10 diets were formulated to contain 1.35% or 1.5% arginine by adding increasing amounts of L-Arg, FeMs, or PTFeMs
- 1 Control diet with fish meal (20%)

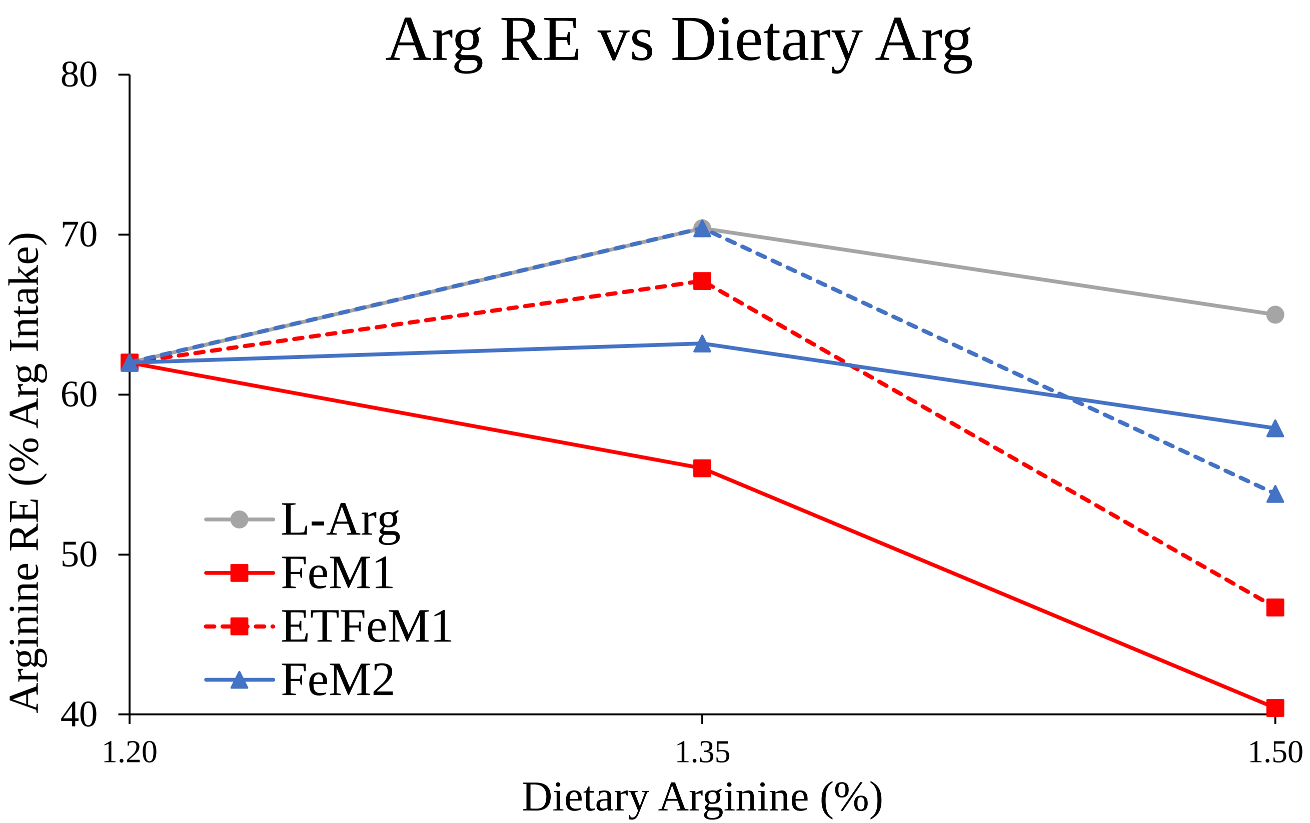


Results of slope-ratio assay

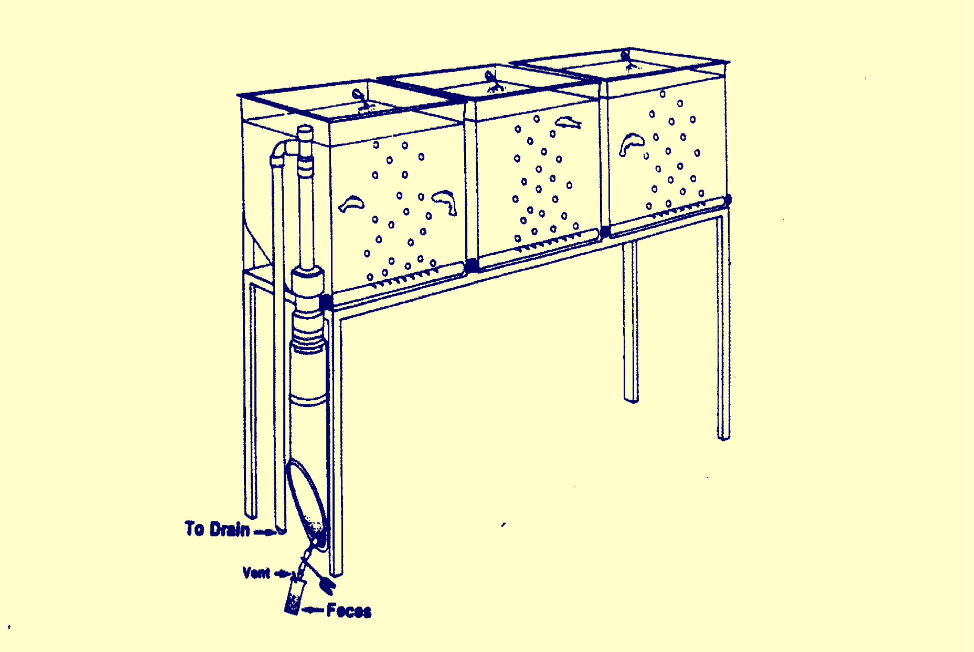




Results of slope-ratio assay



Assessing the apparent digestibility coefficient of the 12 diets

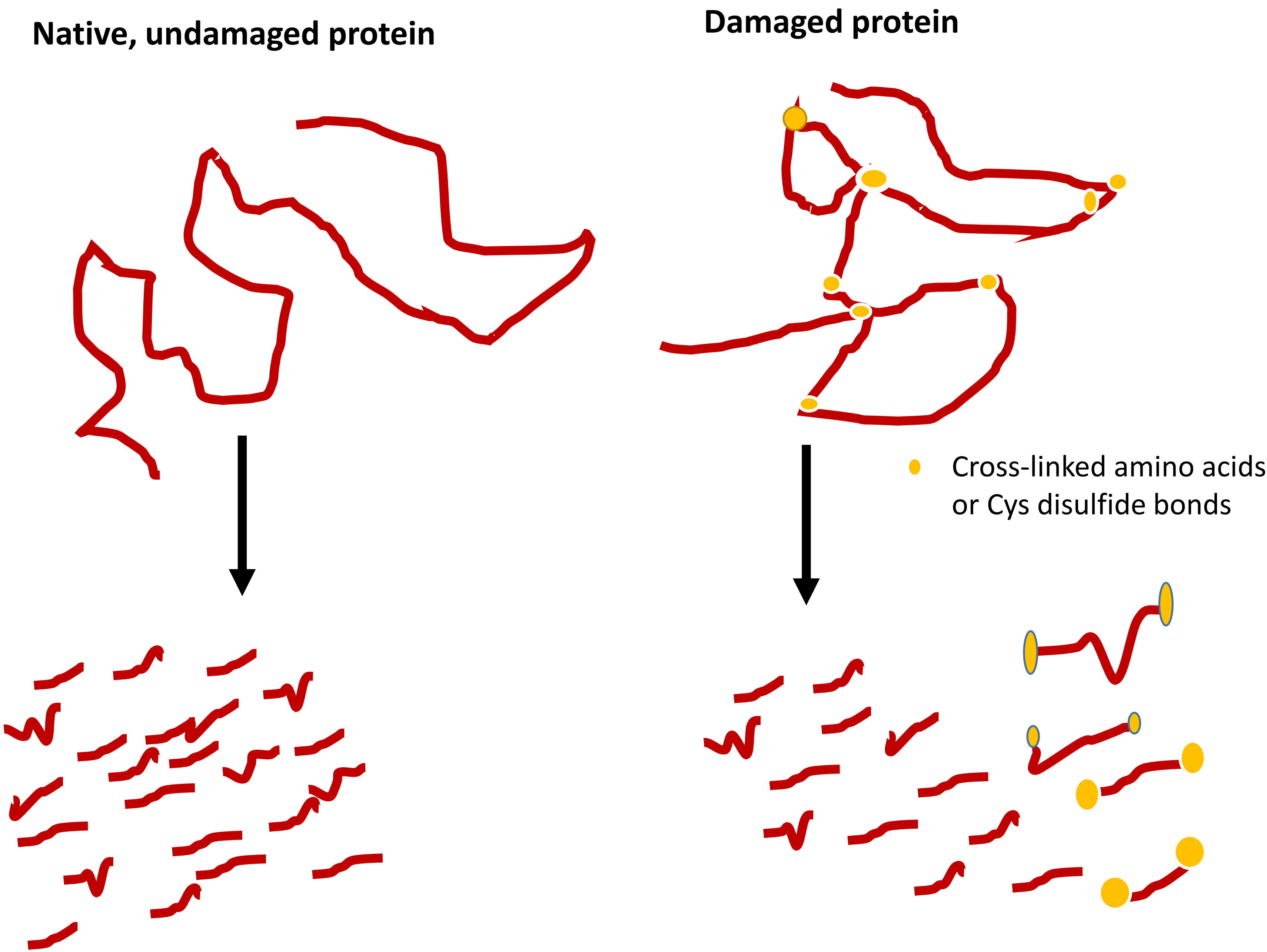


$$ADC_{ingr} = ADC_{test} + ((1\text{-}s)D_{ref}/sD_{ingr})\ (ADC_{test} - ADC_{ref})$$

Results of Digestibility Trial

ADC of nutrients, gross energy and arginine

	Source	DM %	CP %	GE %	Arg %
1.2% Arginine					
Diet 1	-	77.3	93.9	81.6	94.3
1.35% Arginine					
Diet 2	L-Arg	77.3	93.7	81.7	95.1
Diet 4	FeM1	74.1	91.4	77.0	90.5
Diet 6	PTFeM1	78.5	94.6	82.1	94.8
Diet 8	FeM2	74.4	90.8	78.5	87.1
Diet 10	PTFeM2	78.8	94.6	82.7	93.3
1.5% Arginine					
Diet 3	L-Arg	78.3	94.2	82.4	95.3
Diet 5	FeM1	74.4	89.6	77.9	83.7
Diet 7	PTFeM1	74.8	92.0	78.2	91.7
Diet 9	FeM2	75.2	88.2	78.5	80.9
Diet 11	PTFeM2	76.6	93.5	80.6	94.3
Diet 12	FM	69.1	86.9	75.4	85.2


Native, undamaged protein
Damaged protein
Cross-linked amino acids
or Cys disulfide bonds

Educational Module #2 Nutritional Specifications (1h)

Nutritional specifications – How they are developed, adjusted, updated

Meeting essential fatty acids and minor lipids requirements

Effectively meeting phosphorus requirement

Nutritional Specifications

- Nutritional specifications are guidelines. The are defined carefully, reviewed occasionally, and generally quite strictly followed by feed formulators to ensure consistency of nutritional quality of feeds

- Nutrient restrictions are “practical” values taking into account :
    - Requirements of the animal
    - Production objectives
        - Ex: Minimizing cost of formula while obtaining maximum performance
    - Uncertainties
        - Ex: Uncertainties around estimate of nutritional composition, nutritional requirements or potential losses of nutrients requiring use of certain safety margin

Ingredient Restrictions

- Generally driven by practical considerations and “gaps” in knowledge

- Considerations:

  - Effect on processing (handling limitations, effect on pellet quality, etc.)
  - Chemical and/or nutritional characteristics not easily or not adequately addressed through the current nutritional specifications
  - Logistical, risk management and market issues (limited availability, contamination, variability, final product characteristics, customer concerns, export regulations, etc.)

- In general, the more we characterize the animals and the ingredients, the less important the ingredient specifications. However, some logistical considerations still always play a role

Specifications are sometime highly related / redundant but the formulation program can't deal with this

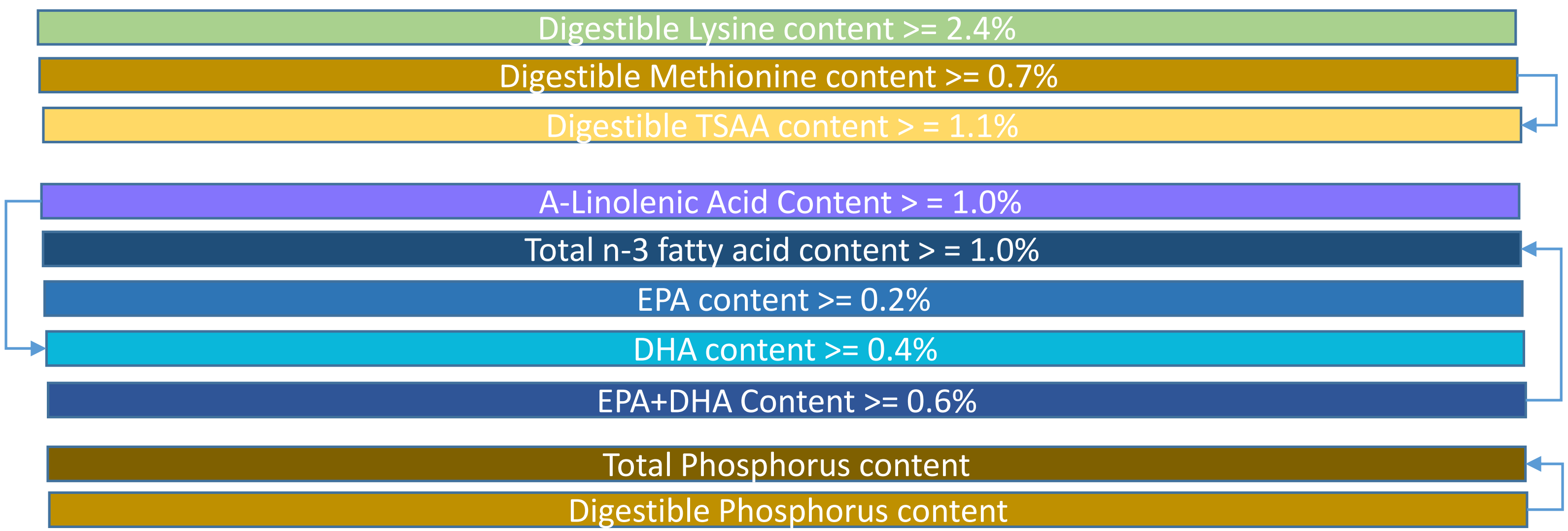
Least Cost Feed Formulation = Linear Programming

Program solving a series of linear (additive) equations to achieve a certain objective (i.e. minimize cost)

Solving dozens of independent equations until all equations are "true"

No real linkage / feedback loop between equations

Some nutritional specifications are interrelated but the program doesn't know this.



Adequately and Cost-Effectively Meeting Requirements

Key Strategies:

1- Determining nutrient requirements across life stages

Effective approach:
- Fine characterization of nutrient requirements
- Research trials / review of literature
- Use of nutritional models

2- Cost-effectively meeting nutrient requirements

Effective approach:
- Fine chemical characterization of ingredients
- Digestibility trials, *in vitro* lab analysis
- Use nutritional models (digestible nutrients)
- Use additives and processing techniques

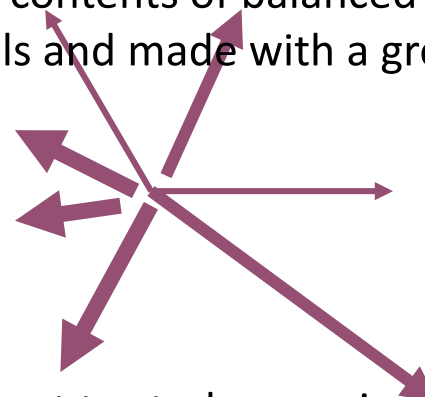
3- Verifying if predictions correspond to commercial reality

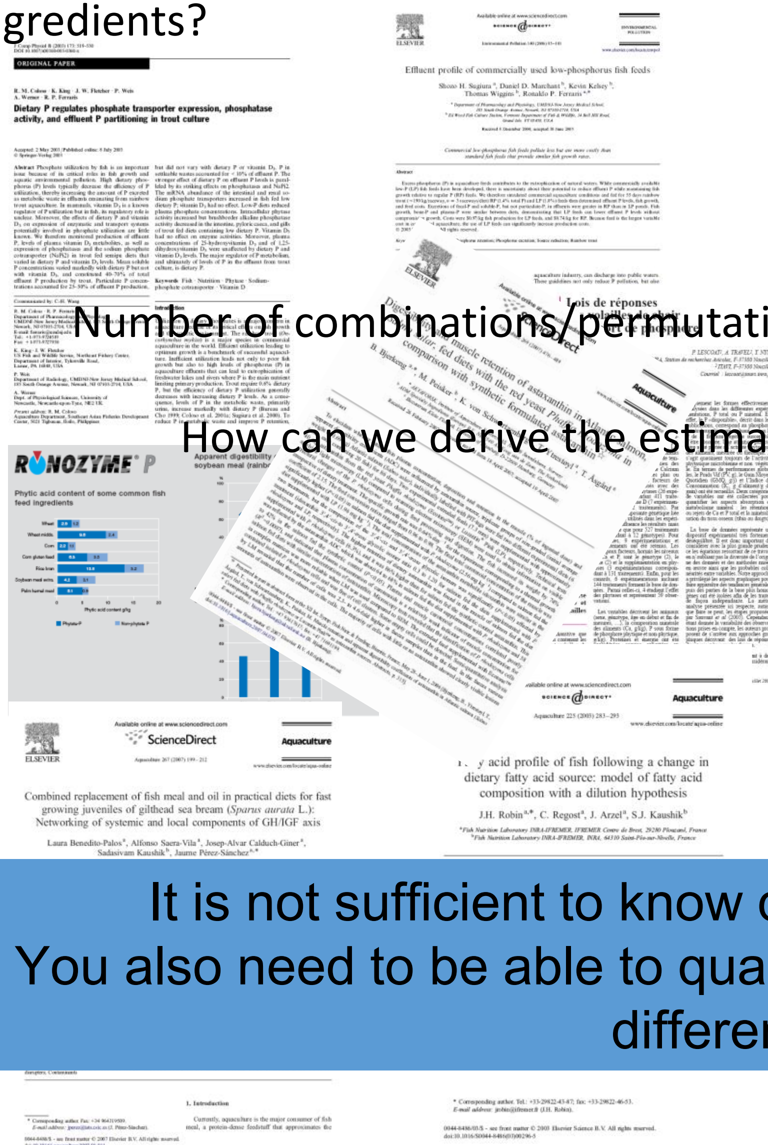
Effective approach:
- Benchmarking / production modeling
- Investment in Research & Development (R&D)
- Never be satisfied with status quo

EFFECTIVELY MEETING PHOSPHORUS REQUIREMENT

Challenge:

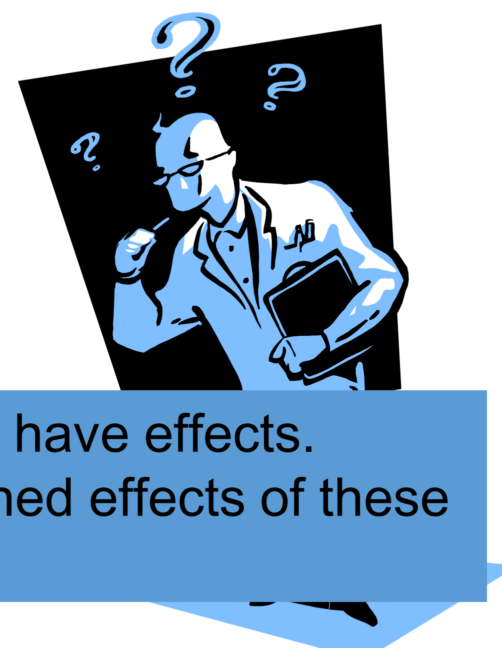
Predicting digestible nutrient (e.g. lipids, phosphorus) contents of balanced feeds formulated to widely different digestible nutrient levels and made with a great variety of ingredients?





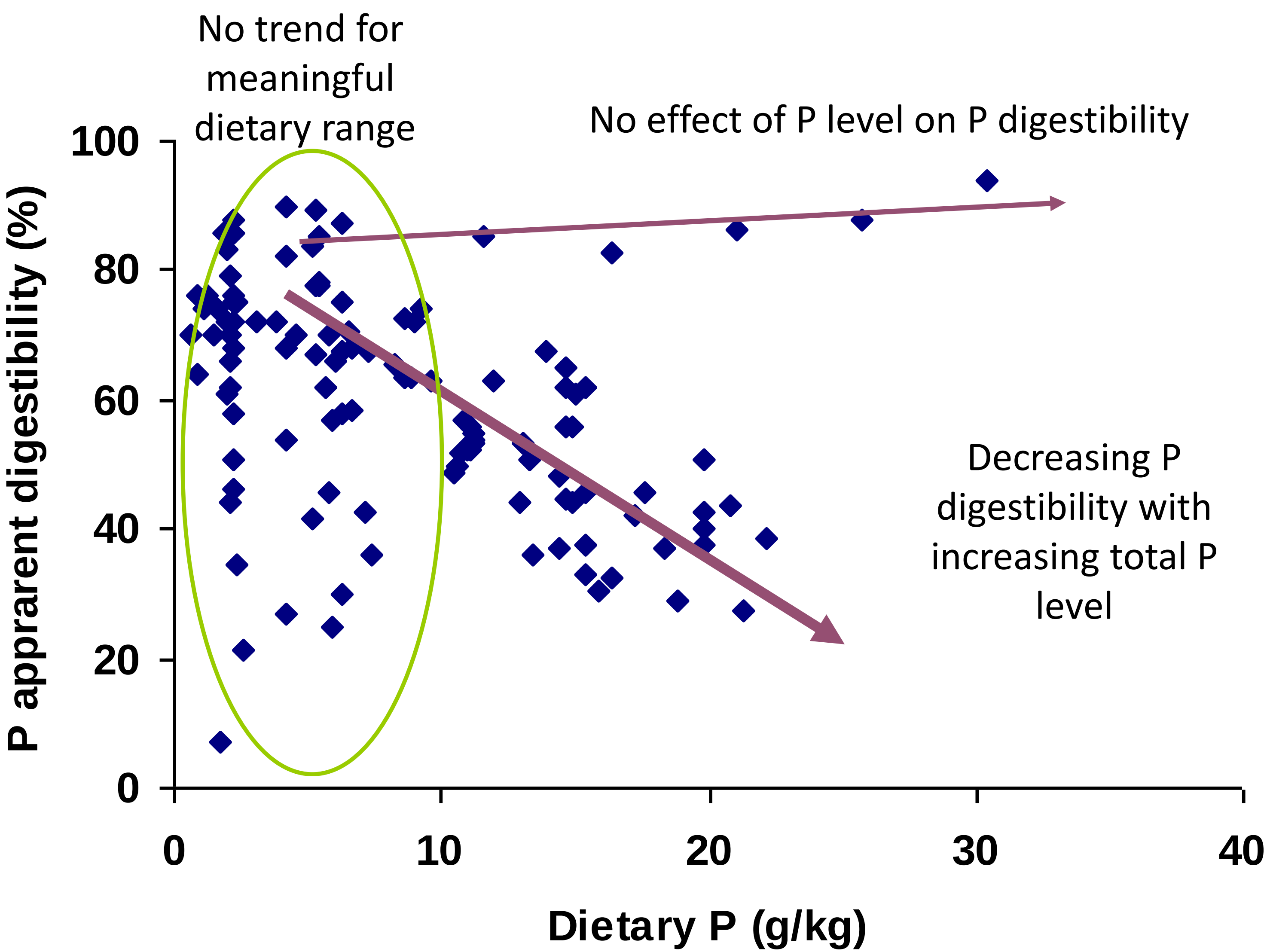
Number of combinations/permutations too great to study experimentally.

How can we derive the estimates we need from the literature?



It is not sufficient to know different factors have effects.
You also need to be able to quantify the combined effects of these different factors

Example: Dietary Phosphorus Digestibility



Dataset: 137 treatments from 22 studies with rainbow trout

The answer is organizing the information at hand in a sensible way!

Modelling can be a very effective way of achieving this.

Before

After

P Content of Common Fish Feed Ingredients

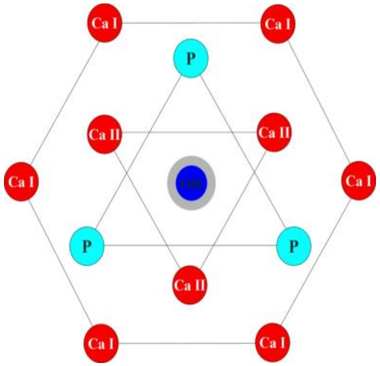
Ingredients	P content (%)
Fish meal	1.08 – 4.19
Meat and bone meal	2.49 – 7.08
Poultry by-product meal	1.65 – 3.45
Blood meal	0.08 – 1.71
Feather meal	0.54 – 1.26
Corn gluten meal	0.44 – 0.55
Soybean meal	0.64 – 0.85
Wheat middling	0.97 – 1.17

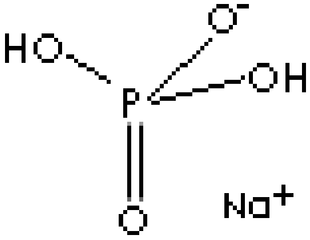
Summarized from various sources in literature

P Forms Present in Feed

1. Inorganic P

- Bone P: hydroxyapatite $Ca_{10}(OH)_2(PO_4)_6$
- Pi supplement:
  - Monobasic: NaH_2PO_4, $Ca(H_2PO_4)_2$
  - Dibasic: $CaHPO_4$

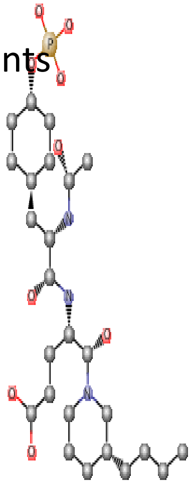




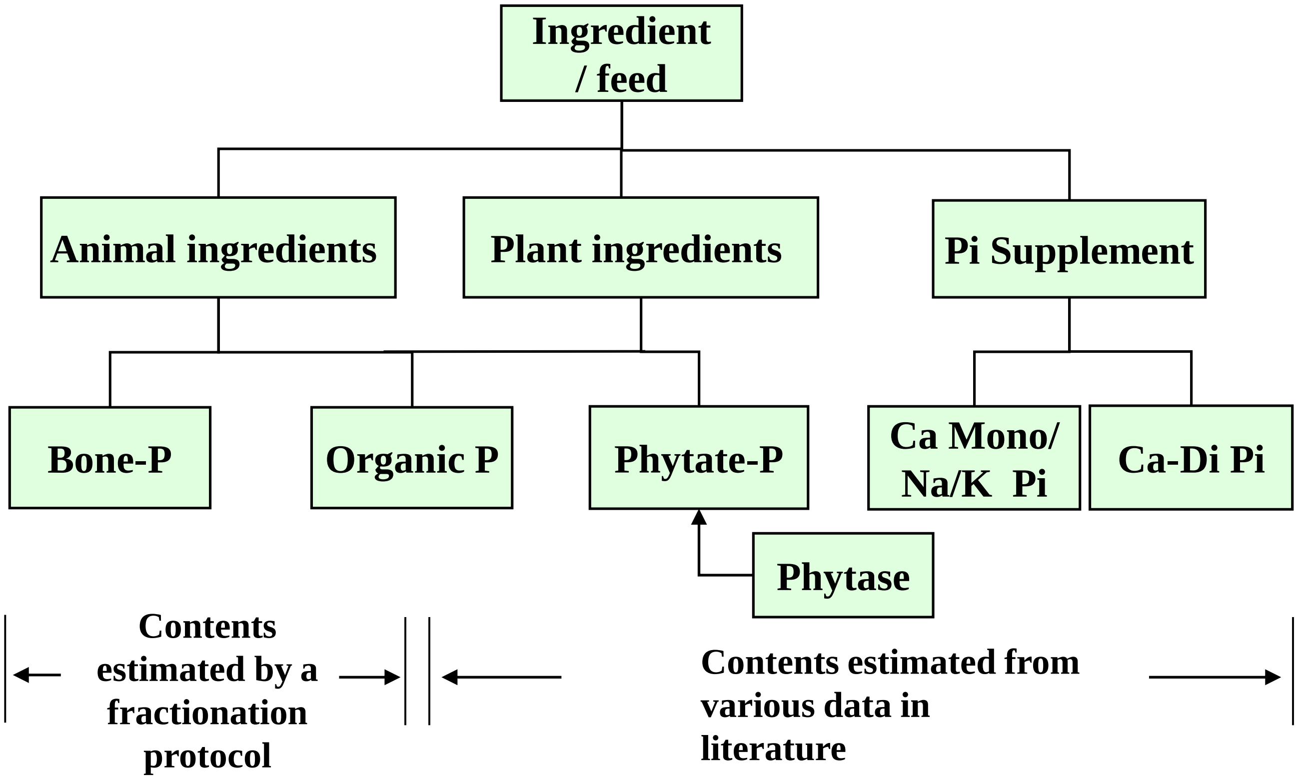
P Forms Present in Feed

2. Organic P

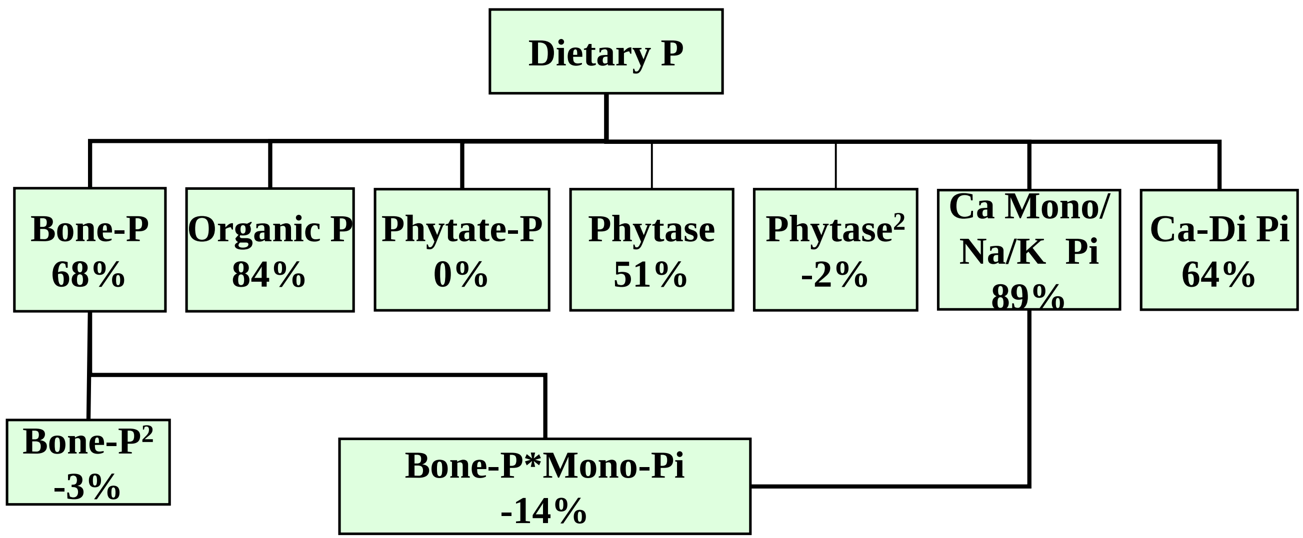
- Phospholipids, e.g. phosphatidyl choline
- Phosphoproteins, e.g. casein
- Phosphosugars, e.g. Glucose-6-P
- Phytate: account for 60 – 80% of total P in plant ingredients



Classification and Content of P Compounds



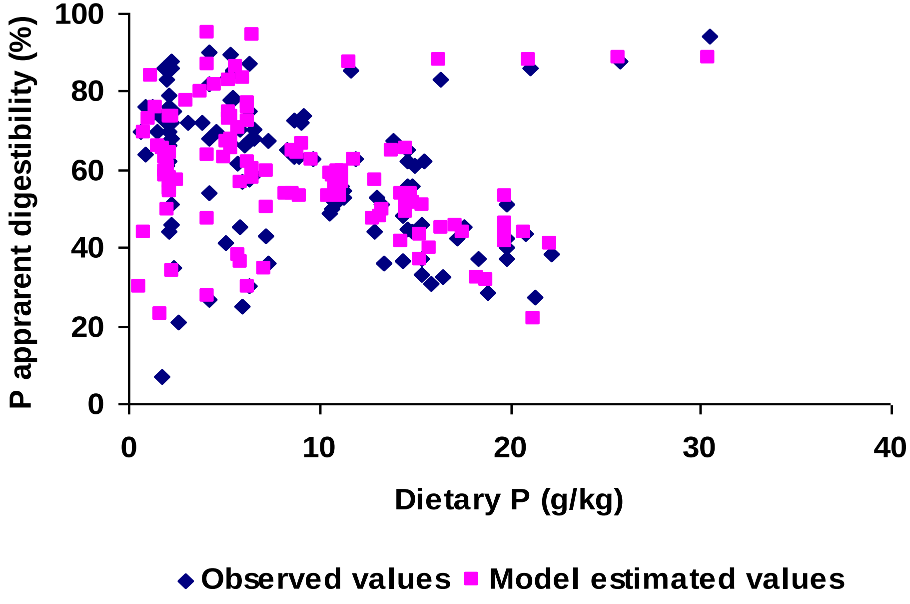
Results: Parameter Estimates From Multiple Regression



Hua and Bureau (2006)

P Digestibility Model

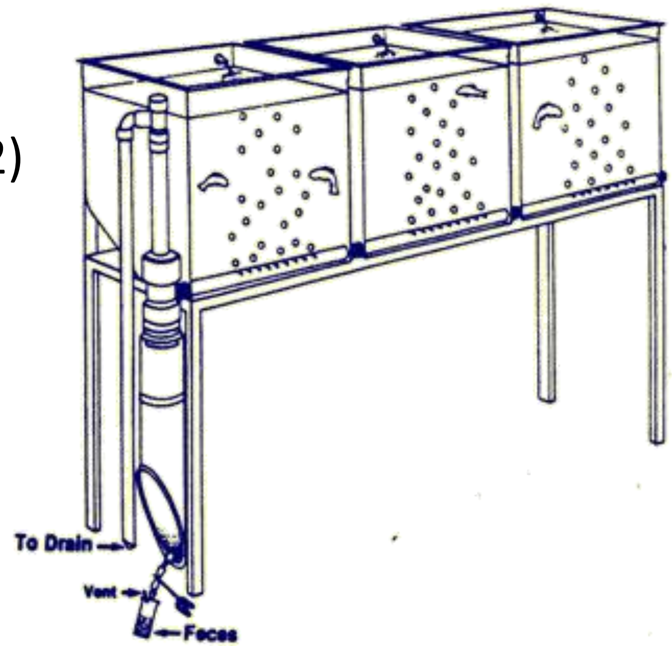
- The model explained 96% of the variance of the data and well described the observations of the dataset



Hua and Bureau (2006)

Experimental Validation by Digestibility Trial

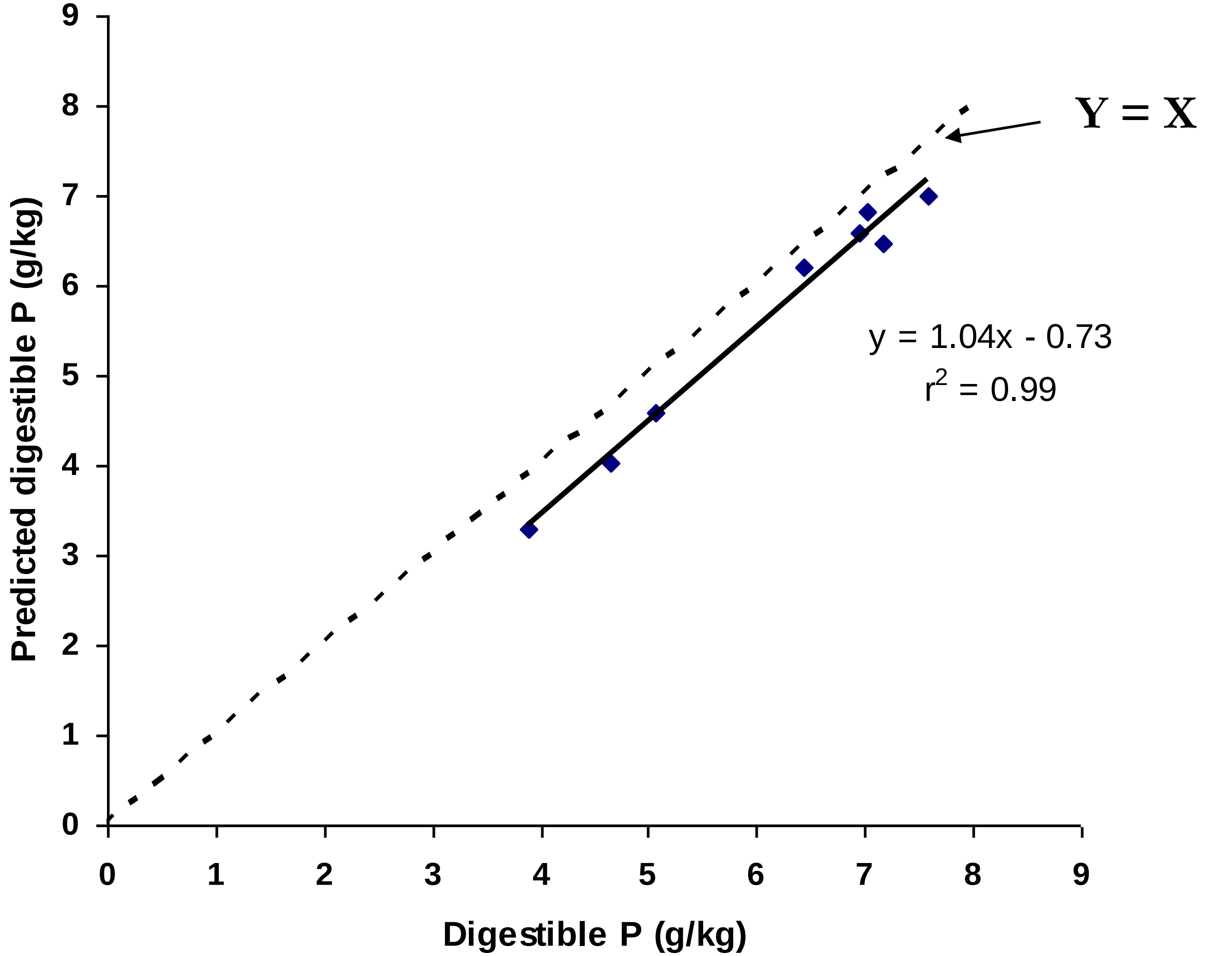
- Digestibility trial conducted with the Guelph system using the protocol of Cho et al. (1982)



- Reference diet:
  - Fish meal/corn gluten meal-based diet
- Test diets:
  - 2 fish meals (high vs. low ash)
  - 1 meat and bone meal
  - 2 poultry by-products meals (high vs. low ash)
  - 2 soy protein concentrates (regular vs. dephytinized)

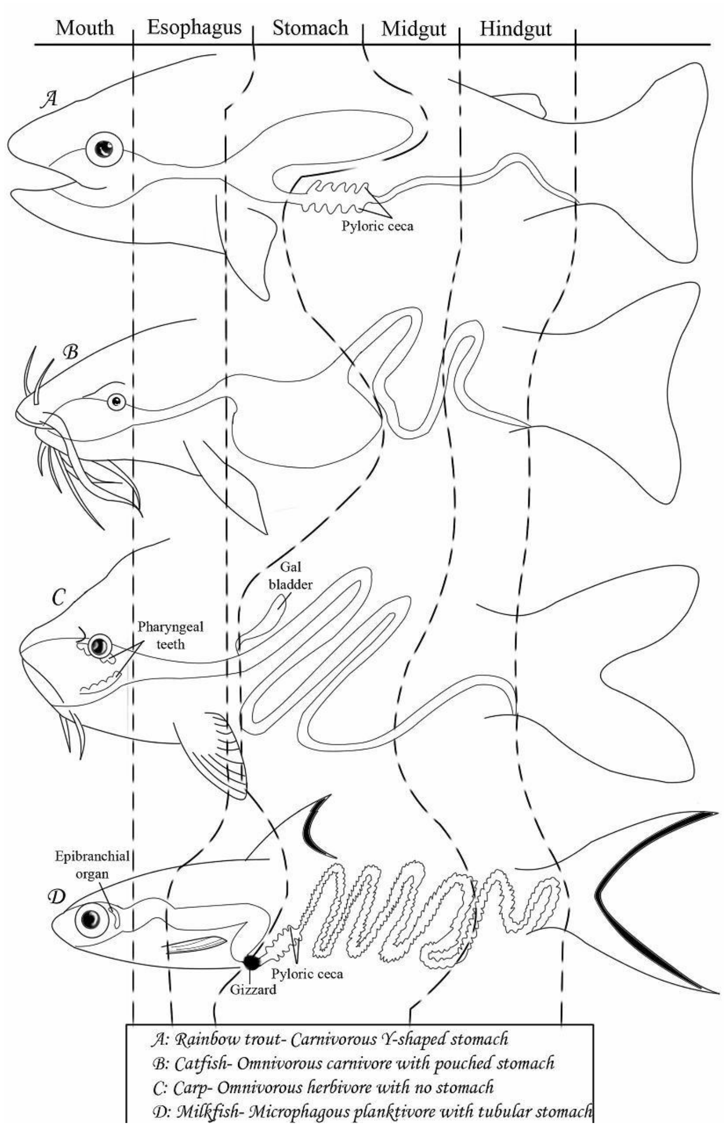
Hua and Bureau (2006)

Results of Experimental Validation



Hua and Bureau (2006)

Differences between fish species in terms of mineral digestibility?



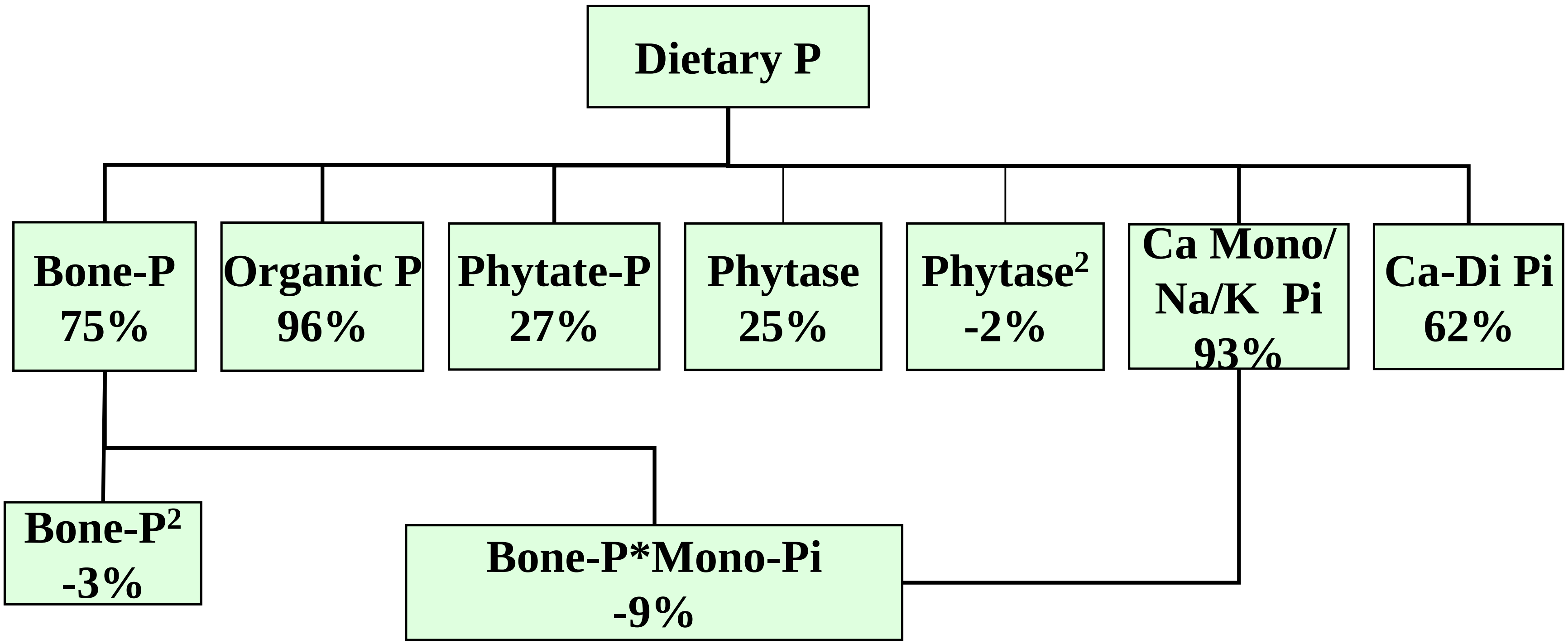
Short GI tract

Effect of absence of true stomach?

Effect of very long and/or very acid GI tract?

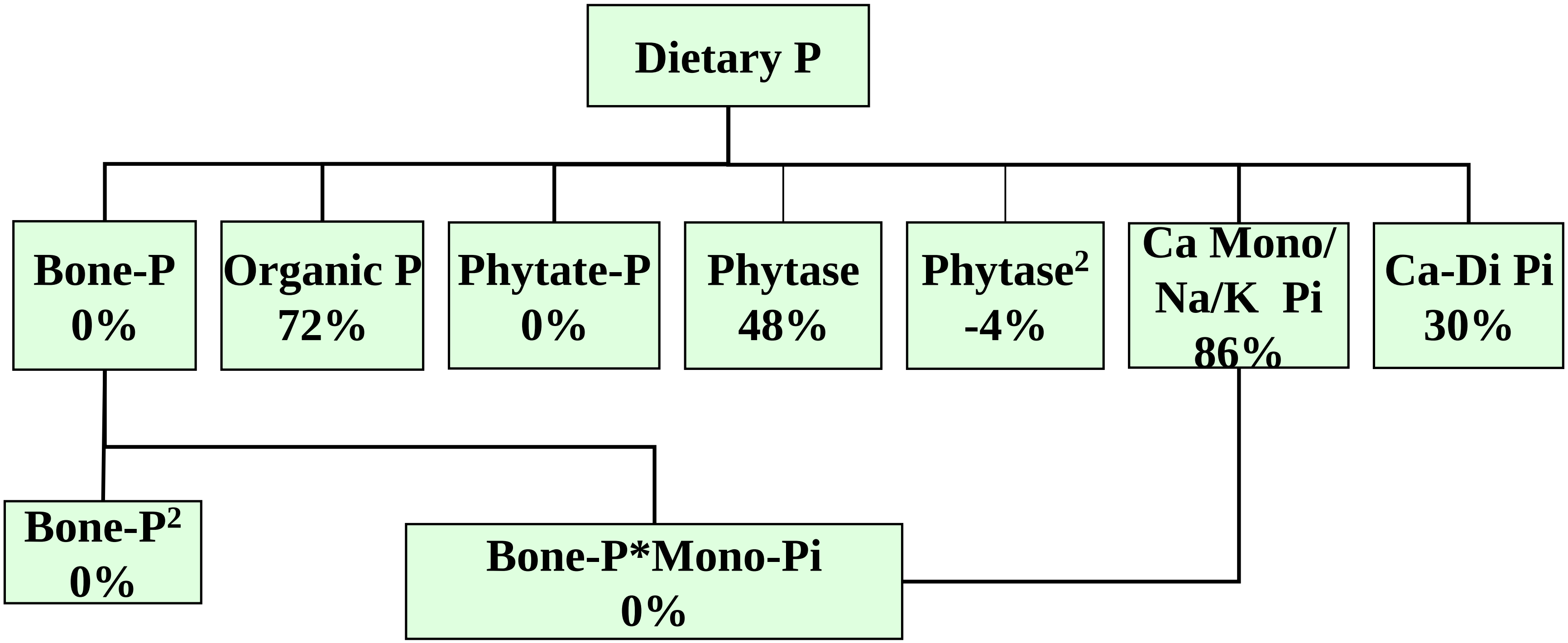
FNRL

P Digestibility Model for Tilapia



$$
\begin{aligned}
\text{Digestible P} = {} & 0.75 \text{ bone–P} \\
& + 0.27 \text{ phytate–P} \\
& + 0.95 \text{ organic P} \\
& + 0.93 \text{ Ca monobasic /Na/ K Pi supplement} \\
& + 0.62 \text{ Ca dibasic Pi supplement} \\
& + 0.25 \text{ phytase/phytate} \\
& - 0.02 \text{ (phytase/phytate)}^2 \\
& - 0.03 \text{ (bone–P)}^2 \\
& - 0.09 \text{ bone–P} \\
& \times \text{*Ca monobasic /Na/ K Pi supplement}
\end{aligned}
$$

P Digestibility Model for Common carp



$$
\begin{aligned}
\text{Digestible P} = {} & 0 \text{ bone} - \text{P} + 0 \text{ phytate} - \text{P} + 0.72 \text{ organic P} \\
& + 0.86 \text{ Ca monobasic /Na/ K Pi supplement} \\
& + 0.30 \text{ Ca dibasic Pi supplement} \\
& + 0.48 \text{ phytase/phytate} - 0.04 (\text{phytase/phytate})^2
\end{aligned}
$$

Forms of Dietary P and Estimation of Digestible P

www.asianaquafeeddatabase.com/feed.html?v=1.2

				Forms of Phosphorus						Estimates of Digestible P			
Calcium(%)	Phosphorus(%)	Ca Coeff(% Ash)	P coeff(% Ash)	Phytate P(%)	Bone P(%)	Cellular P(%)	Monobasic P(%)	Dibasic P(%)	Tribasic P(%)	Dig P Carni(%)	Dig P Omni(%)	Dig P Carp(%)	Dig P Shrimp(%)
2.00	1.90	20	19	0.00	1.16	0.74	0.00	0.00	1.16	1.32	1.38	0.65	0.97
2.38	2.70	15	17	0.00	1.95	0.75	0.00	0.00	1.95	1.80	1.91	0.70	1.22
9.04	5.66	30	19	0.00	4.84	0.82	0.00	0.00	4.84	3.60	3.85	0.90	2.14
5.88	3.05	25	13	0.00	2.28	0.76	0.00	0.00	2.28	2.01	2.13	0.72	1.33
4.20	2.85	22	15	0.00	2.09	0.76	0.00	0.00	2.09	1.89	2.00	0.71	1.26
4.34	2.40	36	20	0.00	1.65	0.75	0.00	0.00	1.65	1.62	1.71	0.68	1.12
4.50	3.00	26	17	0.00	2.24	0.76	0.00	0.00	2.24	1.98	2.10	0.72	1.31

Equations in AAFFD and BestMix

- 'Digestible Phosphorus calculation, Aqua
- Nutrients.Minerals.Dig P Carni = Nutrients.Minerals.Bone P * 68/100 +Nutrients.Minerals.Cellular P * 84/100 + Nutrients.Minerals.Monobasic P * 89/100 + Nutrients.Minerals.Dibasic P * 64/100

- Nutrients.Minerals.Dig P Omni = Nutrients.Minerals.Cellular P * 72/100 + Nutrients.Minerals.Monobasic P * 86/100 + Nutrients.Minerals.Dibasic P * 30/100

- Nutrients.Minerals.Dig P Carp = Nutrients.Minerals.Bone P * 75/100 +Nutrients.Minerals.Cellular P * 95/100 + Nutrients.Minerals.Monobasic P * 90/100 + Nutrients.Minerals.Dibasic P * 62/100

- Nutrients.Minerals.Dig P Shrimp = Nutrients.Minerals.Bone P * 70/100 +Nutrients.Minerals.Cellular P * 85/100 + Nutrients.Minerals.Monobasic P * 85/100 + Nutrients.Minerals.Dibasic P * 60/100

Educational Module #2 Nutritional Specifications (1h)

Nutritional specifications – How they are developed, adjusted, updated

Meeting essential fatty acids and minor lipids requirements

Effectively meeting phosphorus requirement

Outstanding Issue – Independent recommendations that are interrelated

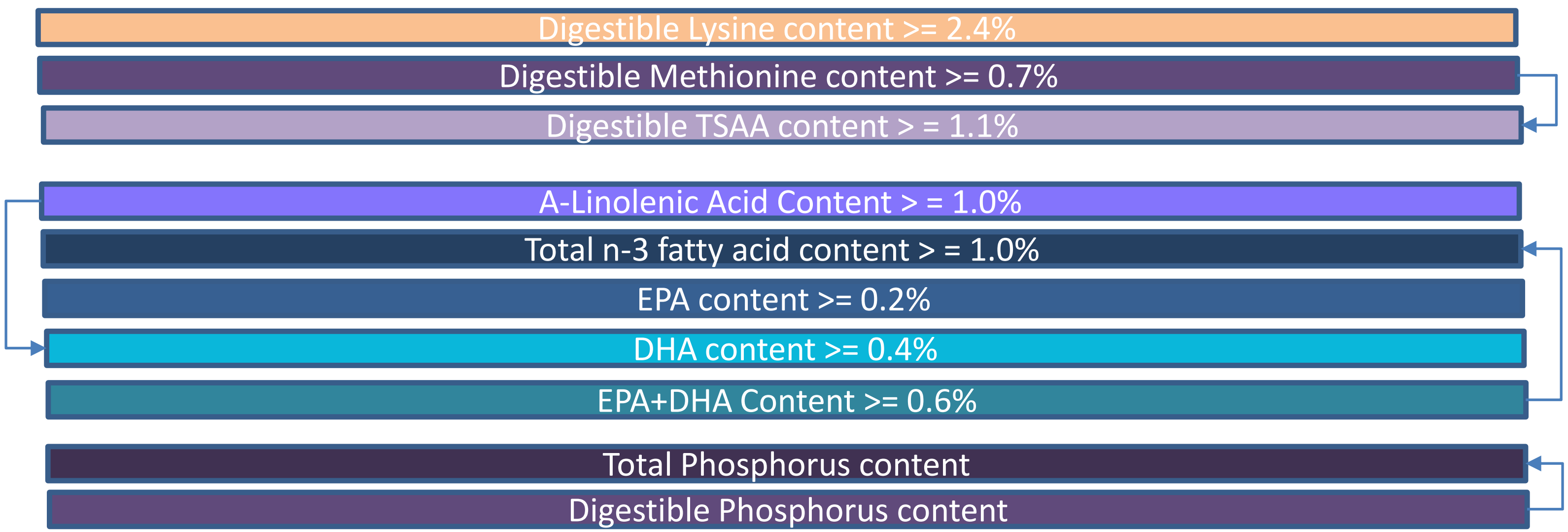
Least Cost Feed Formulation = Linear Programming

Program solving a series of linear (additive) equations to achieve a certain objective (i.e. minimize cost)

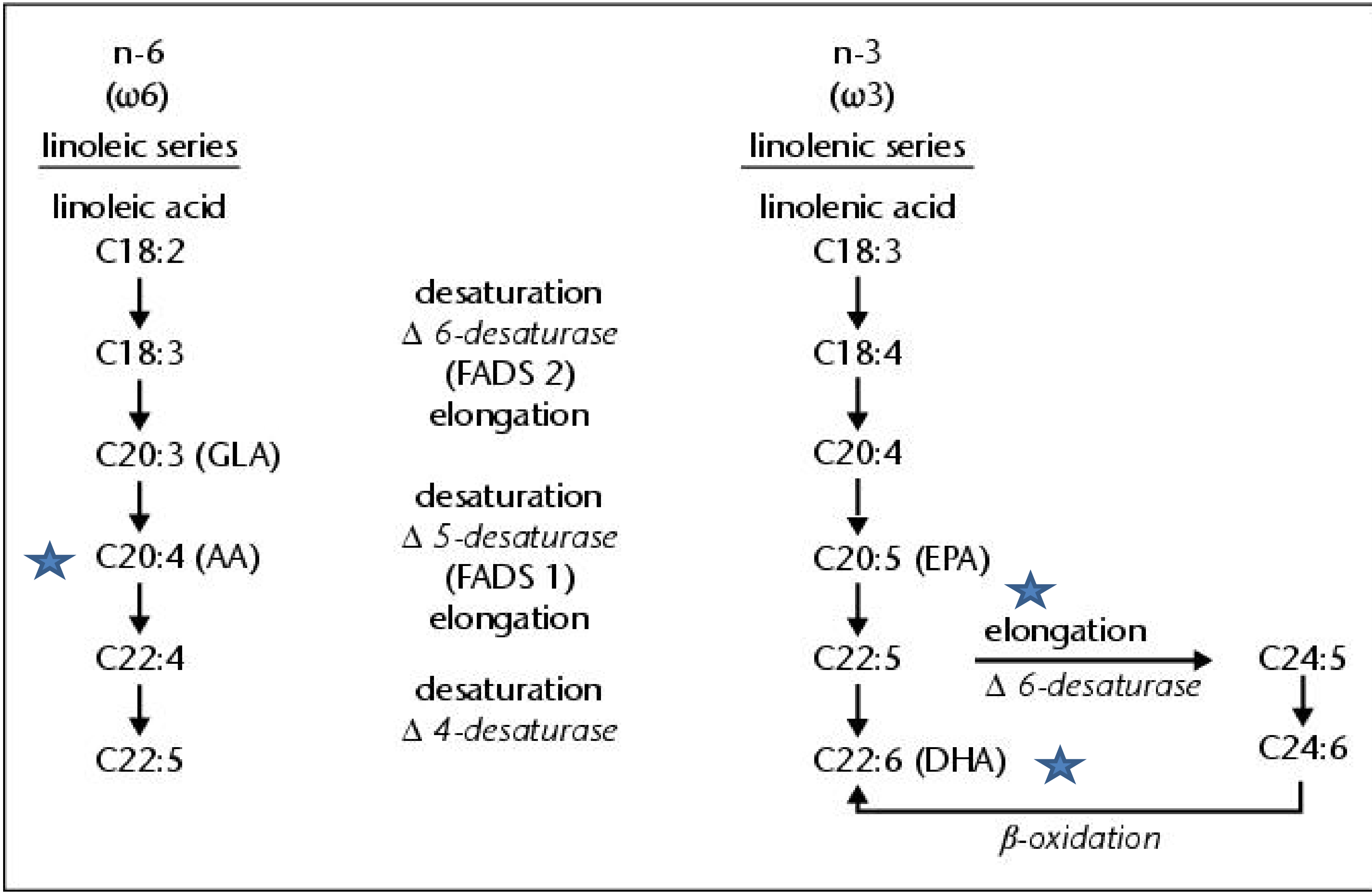
Solving dozens of independent equations until all equations are “true”

No real linkage / feedback loop between equations

Some nutritional specifications are interrelated but the program doesn’t know this.



Elongation and Desaturation of Polyunsaturated Fatty Acids



Determining What Species Needs What and How Much?

- A little more complicated than for other nutrients
  - Synthesis / bioconversion plays an important role but efficiency of conversion depends on species and life stages
    - ALA (18:3 n-3) = precursor of 20:5 n-3 and 22:6 n-3
    - LA (18:2 n-6) = precursor of 20:4 n-6
  - Substitution issues = "physically" and metabolically one fatty acid can partly replace another one
    - Deficiency is thus not always very overtly seen
  - Metabolic needs can be very small (ng) and body reserve large (mg or g)

TABLE 6-1 Reported Quantitative Essential Fatty Acid (EFA) Requirements of Juvenile and Subadult Freshwater and Diadromous Species of Finfish[a]

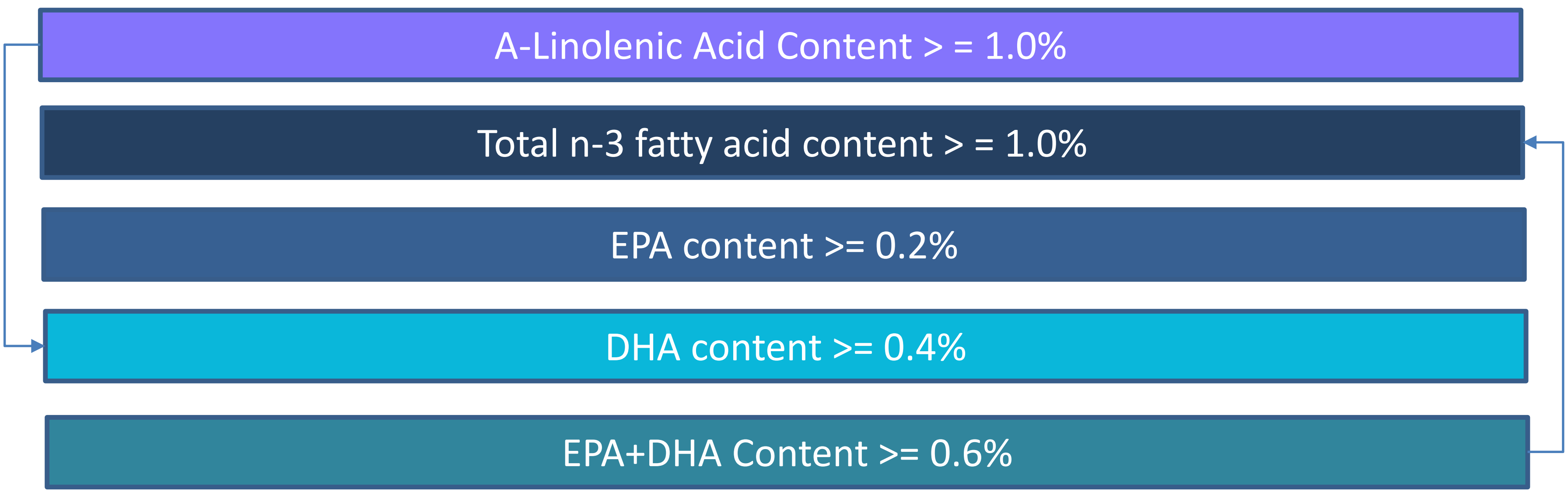
Species	Scientific Name	EFA	Requirement (% Dry Diet)	Reference
Arctic charr	*Salvelinus alpinus*	18:3n-3	1.0–2.0	Yang et al. (1994)
Atlantic salmon	*Salmo salar*	18:3n-3	1.0	Ruyter et al. (2000a)
		n-3 LC-PUFA	0.5–1.0	Ruyter et al. (2000b)
Ayu	*Plecoglossus altivelus*	18:3n-3 or EPA	1.0	Kanazawa et al. (1982)
Channel catfish	*Ictalurus punctatus*	18:3n-3	1.0–2.0	Satoh et al. (1989)
Cherry salmon	*Oncorhynchus masou*	18:3n-3 or n-3 LC-PUFA	1.0	Thongrod et al. (1990)
Chum salmon	*Oncorhynchus keta*	18:2n-6 and 18:3n-3	1.0 of each	Takeuchi et al. (1979)
Coho salmon	*Oncorhynchus kisutch*	18:2n-6 and 18:3n-3	1.0 of each	Yu and Sinnhuber (1979)
Common carp	*Cyprinus carpio*	18:2n-6	1.0	Takeuchi and Watanabe (1977)
		18:3n-3	0.5–1.0	Takeuchi and Watanabe (1977)
Grass carp	*Ctenopharyngodon idella*	18:2n-6	1.0	Takeuchi et al. (1991)
		18:3n-3	0.5	Takeuchi et al. (1991)
Japanese eel	*Anguilla japonicus*	18:2n-6 and 18:3n-3	0.5 of each	Takeuchi et al. (1980)
Milkfish	*Chanos chanos*	18:2n-6 and 18:3n-3	0.5 of each	Bautista and de la Cruz (1988)
Rainbow trout	*Oncorhynchus mykiss*	18:3n-3	0.7–1.0	Castell et al. (1972)
		n-3 LC-PUFA	0.4–0.5	Takeuchi and Watanabe (1976)
Sheatfish	*Silurus glanis*	18:3n-3	1.0	Borgut et al. (1998)
Striped bass	*Morone chrysop* × *Morone saxatilis*	n-3 LC-PUFA	1.0	Gatlin et al. (1994)
Tilapia	*Tilapia zilli*	18:2n-6	1.0	Kanazawa et al. (1980)
	Oreochromis nilotica	18:2n-6	0.5	Takeuchi et al. (1983)
	Oreochromis niloticus × *Oreochromis aureus*	n-3 required	?	Chou and Shiau (1999)
Whitefish	*Coregonus laveratus*	18:3n-3	> 1.0	Thongrod et al. (1989)
		n-3 LC-PUFA	0.5–1.0	Watanabe et al. (1989)

[a]Based on Tocher (2010).

TABLE 6-3 Reported Quantitative Essential Fatty Acid (EFA) Requirements of Juvenile and Subadult Marine Species of Finfish[a]

Species	Scientific Name	EFA	Requirement (% Dry Diet)	Reference
European sea bass	*Dicentrarchus labrax*	n-3 LC-PUFA	1.0	Coutteau et al. (1996a)
Gilthead sea bream	*Sparus aurata*	n-3 LC-PUFA	0.9 (DHA:EPA = 1)	Kalegeropoulos et al. (1992)
		n-3 LC-PUFA	1.9 (DHA:EPA = 0.5)	Ibeas et al. (1994)
		DHA:EPA	0.5	Ibeas et al. (1997)
Grouper	*Epinephelus malabaricus*	n-3 LC-PUFA, DHA > EPA	1.0	Wu et al. (2002)
Japanese flounder	*Paralicthys olivaceus*	n-3 LC-PUFA	1.4	Takeuchi (1997)
Korean rockfish	*Sebastes schlegeli*	n-3 LC-PUFA	0.9	Lee et al. (1993)
		EPA or DHA	1.0	Lee et al. (1994)
Red drum	*Sciaenops ocellatus*	n-3 LC-PUFA	0.5–1.0	Lochman and Gatlin (1993)
		EPA + DHA	0.3–0.6	Lochman and Gatlin (1993)
Red sea bream	*Pagrus major*	n-3 LC-PUFA or EPA	0.5	Yone (1978)
		EPA	1	Takeuchi et al. (1990)
		DHA	0.5	Takeuchi et al. (1990)
Silver bream	*Rhabdosargus sarba*	n-3 LC-PUFA	1.3	Leu et al. (1994)
Starry flounder	*Paralichthys stellatus*	n-3 LC-PUFA	0.9	Lee et al. (2003)
Striped bass	*Morone chrysop × Morone saxatilis*	n-3 LC-PUFA	1.0	Gatlin et al. (1994)
Striped jack	*Pseudocaranx dentex*	DHA	1.7	Takeuchi et al. (1992c)
Turbot	*Psetta maxima*	n-3 LC-PUFA	0.8	Gatesoupe et al. (1977)
		ARA	~0.3	Castell et al. (1994)
Yellowtail flounder	*Pleuronectes ferrugineus*	n-3 LC-PUFA	2.5	Whalen et al. (1999)
Yellowtail/Kingfish	*Seriola* spp.	n-3 LC-PUFA	2.0–2.4	Deshimaru et al. (1982)

[a]Based on Tocher (2010).


A-Linolenic Acid Content > = 1.0%
Total n-3 fatty acid content > = 1.0%
EPA content >= 0.2%
DHA content >= 0.4%
EPA+DHA Content >= 0.6%

Evidence that for some species DHA is the essential fatty acid and that EPA doesn't have to same efficacy.

Table 1
Requirement of docosahexaenoic acid (DHA) and its efficacy in comparison to eicosabentaenoic acid (EPA) for larval marine fish fed on enriched *Artemia*

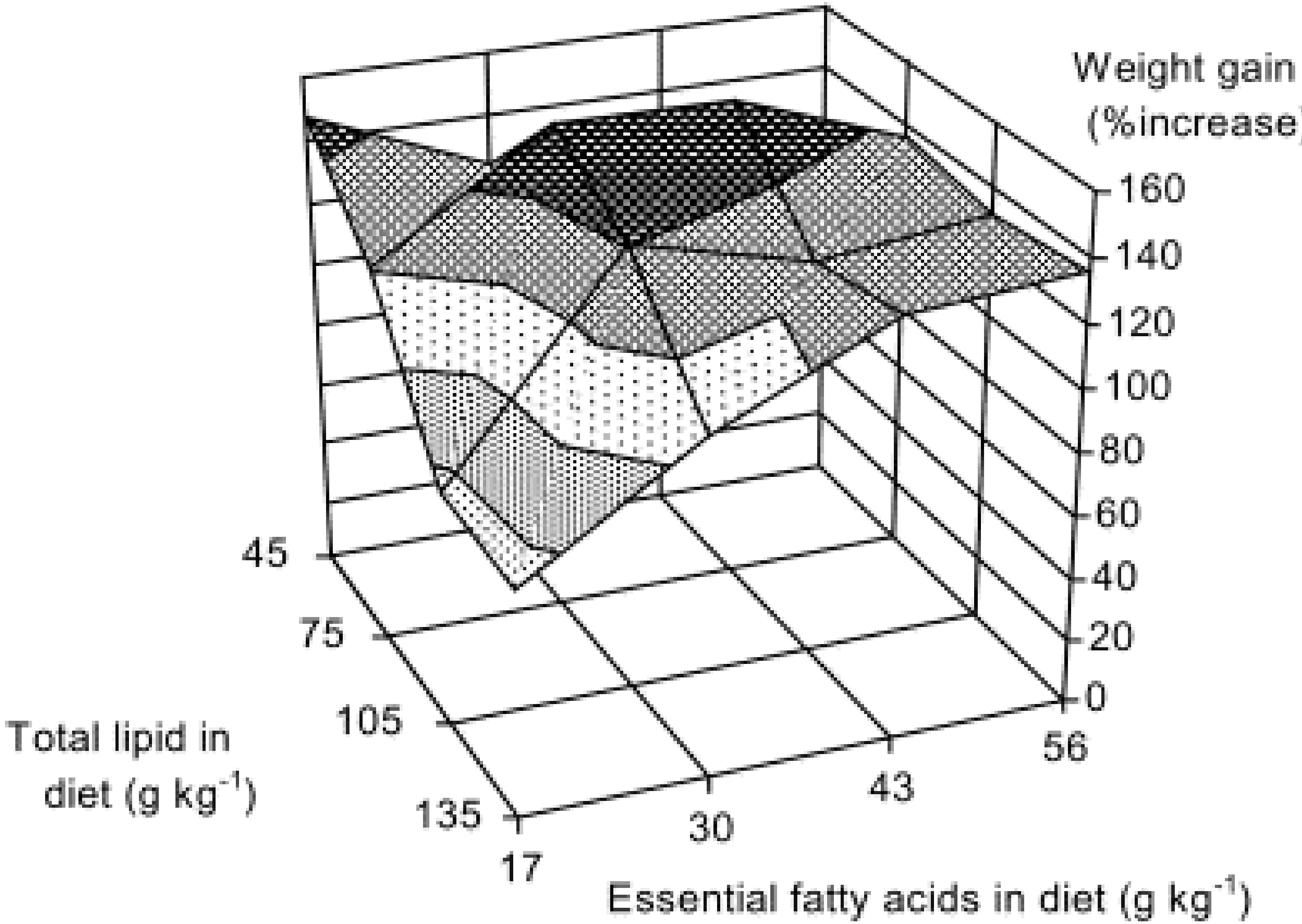
Species	Requirement of DHA (%)	Relative efficacy		
		Growth	Survival rate	Vitality test[a]
Japanese flounder	1.0–1.6	EPA = DHA	EPA = DHA	EPA $\leqq$ DHA[b]
Red sea bream	1.0–1.6	EPA = DHA	EPA = DHA	EPA < DHA
Cod	1.6–2.1	EPA $\leqq$ DHA	EPA $\leqq$ DHA	EPA < DHA
Striped jack	1.6–2.2	EPA $\leqq$ DHA	EPA < DHA	EPA < DHA
Yellowtail	1.4–2.6	EPA < DHA	EPA < DHA	EPA < DHA

[a] Survival at the 24th h after fish were held in air for 30–60 s by a scoop net and moved to a culture tank.
[b] Salinity tolerance test (65‰ for 120 min) was employed for flounder.

This is a lot more informative and accurate than "fish oil replacement value"

Takeuchi (2001)

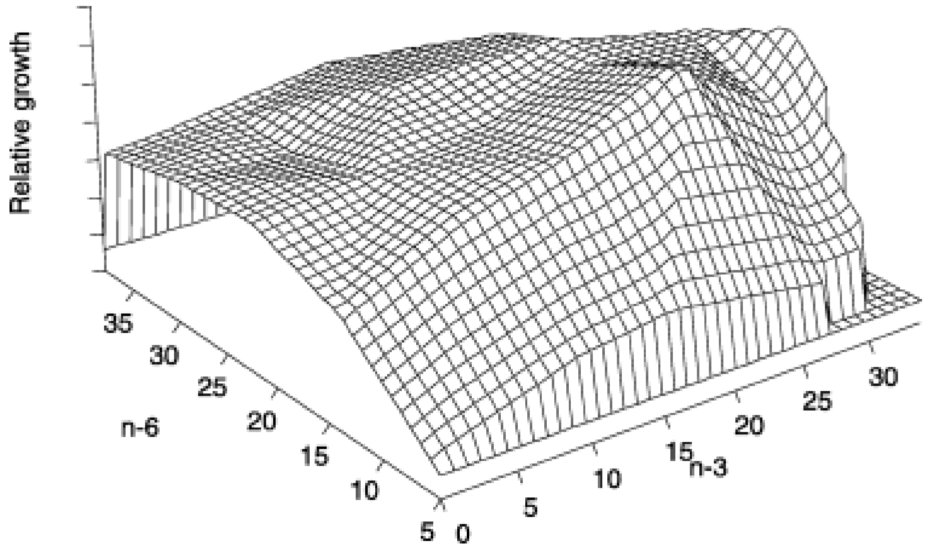
Combined Response of Shrimp to Dietary Lipid and Essential Fatty Acid Contents



B. D. Glencross, D. M. Smith, M. R. Thomas and K. C. Williams. 2002. Optimising the essential fatty acids in the diet for weight gain of the prawn, *Penaeus monodon. Aquaculture 204, 85-99.*

GLENCROSS, D.M. SMITH, M.R. THOMAS & K.C. WILLIAMS. 2002.
The effect of dietary n-3 and n-6 fatty acid balance on the growth of the prawn *Penaeus monodon* B. Aquaculture Nutrition 8, 43

Dietary n-3 and n-6 fatty acid balance



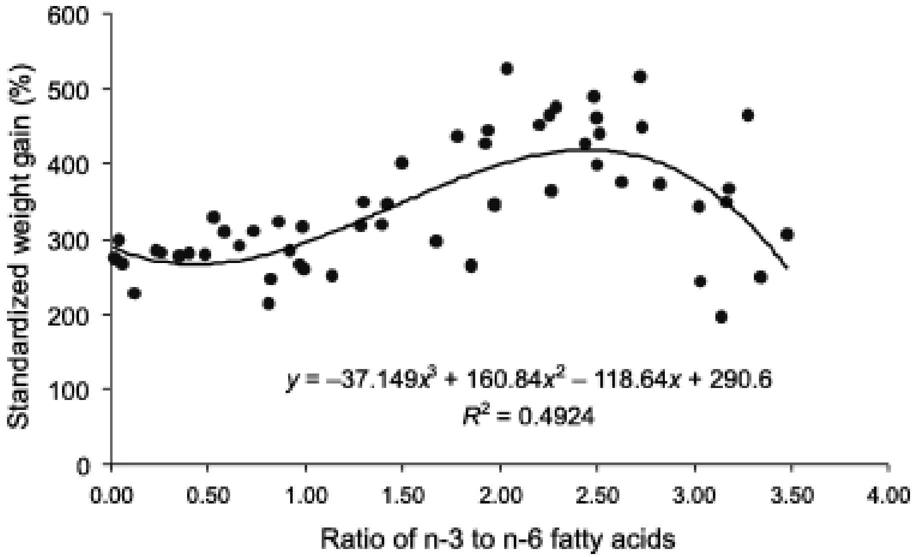
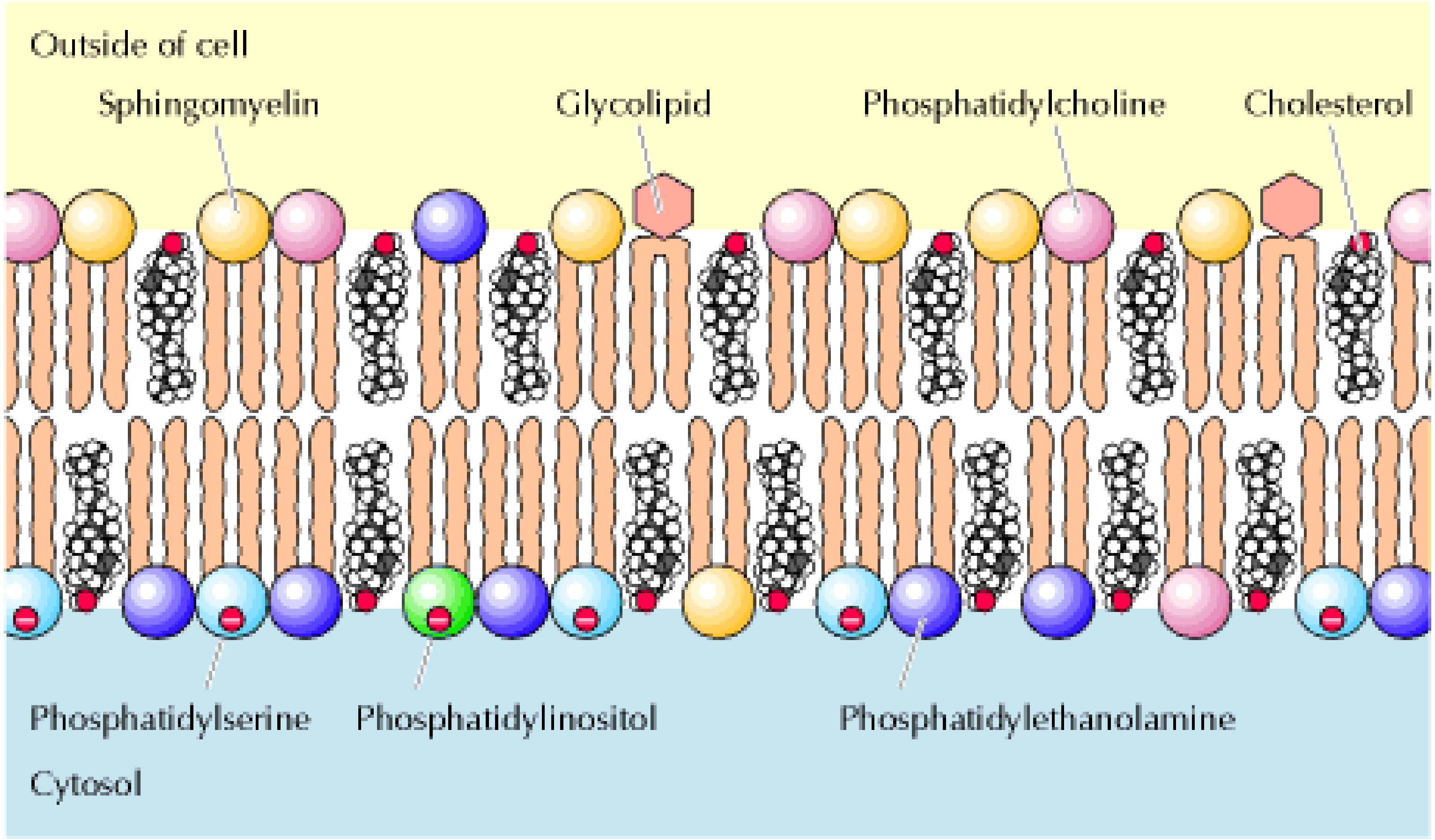


TABLE 6-5 Reported Phospholipid Requirements in Juvenile and Larval Shrimp Species

Species	Requirement	Reference
Tiger shrimp (*Penaeus monodon [juvenile]*)	1.0–1.5%	Paibulkichakui et al. (1998)
P. monodon	80% pure soybean PC	Chen (1993)
Marine shrimp (*Penaeus penicillatus*)	80% pure soybean PC	Chen and Jenn (1991)
Pacific white shrimp (*Litopenaeus vannamei*)	1.5% PC (from soybean) 6.5% deoiled soybean lecithin	Coutteau et al. (1996b)
Kuruma prawn (*Marsupenaeus japonicus [juvenile]*)	1.0% (PC + PE)	Kanazawa et al. (1979c)
M. japonicus (juvenile)	3.0% soybean (lecithin) PE and PI	Teshima et al. (1986a,b)
M. japonicus (larvae)	3.0% soybean lecithin	Kanazawa (1983)
M. japonicus (larvae)	0.5 to 1.0% (PC and PI)	Kanazawa et al. (1985)
Banana shrimp (*Fenneropenaeus merguiensis*)	2.5% pure soybean lecithin	Thongrod and Boonyaratpalin (1998)

TABLE 6-6 Reported Quantitative and Qualitative Phospholipid Requirements of Finfish[a]

Species	Developmental Stage	Phospholipid Supplement[b] and Levels Studied[c]	Optimal Requirement and Criteria Used[d]	Feeding Period	Reference
Atlantic salmon (*Salmo salar*)	Juvenile (180 mg)	0, 2, 4, 6, and 8% SL/CPL	6% (G)	14 weeks	Poston (1991)
	Juvenile (180 mg)	0 and 4% SL	4% (G)	16 weeks	Poston (1990b)
	Juvenile (1.0 g)	0 and 4% SL	4% (G)	12 weeks	Poston (1990b)
	Juvenile (1.7 g)	0 and 4% SL	4% (G)	12 weeks	Poston (1990b)
	Juvenile (7.5 g)	0 and 4% SL	0% (no requirement)	12 weeks	Poston (1990b)
Ayu (*Plecoglossus altivelus*)	Larvae	0 and 3% SL or EL	3% (G,S,M)	20 days	Kanazawa et al. (1981)
	Larvae	0, 1, 3, and 5% SL	3% (M), 5% (G,S)	50 days	Kanazawa et al. (1983a)
	Larvae	0 and 3% EL or BPL	3% (G,S,M)	50 days	Kanazawa et al. (1983a)
	Juvenile	0 and 3% SL or BPL	3% (G)	33 days	Kanazawa et al. (1981)
	Juvenile	0, 1, 3, and 5% EL	3% (G)	33 days	Kanazawa et al. (1981)
Common carp (*Cyprinus carpio*)	Larvae	0 and 2% EL	2% (G,S)	25 days	Geurden et al. (1995a)
	Larvae	0 and 2% PL	2% (G,S)	21 days	Geurden et al. (1995a)
	Larvae	0 and 2% SPC, SPI, or EL	2% (G,S,M except EL)	25 days	Geurden et al. (1997a)
European sea bass (*Dicentrarchus labrax*)	Larvae	3, 6, 9, and 12% SL	12% (G,S,M)	40 days	Cahu et al. (2003)
	Juvenile	0 and 3% SL	3% (G)	40 days	Geurden et al. (1995b)
	Juvenile	0 and 2% EPC or SPC	2% (G)	40 days	Geurden et al. (1995b)
Gilthead sea bream (*Sparus aurata*)	Larvae	9, 11, and 15% SL	> 9% (G,S)	23 days	Seiliez et al. (2006)
Japanese flounder (*Paralichthys olivaceus*)	Larvae	0, 3, 5, and 7% SL	7% (G,S)	30 days	Kanazawa (1993)
	Juvenile	0, 3, 5, and 7% SL	7% (G)	30 days	Kanazawa (1993)



Source: Cooper, G.M. 2000.The Cell: A Molecular Approach. 2nd Ed. Sinaeur Associate Inc., Sunderland, Mass. http://www.ncbi.nlm.nih.gov/books/bv.fcgi?rid=cooper

TABLE 6-7 Reported Cholesterol/Sterol Requirements of Shrimp and Other Crustaceans

Species	Requirement	Reference
Cholesterol alone		
Pacific white shrimp (*Litopenaeus vannamei*)	0.35%	Gong et al. (2000)
Kuruma prawn (*Marsupenaeus japonicus*)	0.50%	Kanazawa et al. (1971)
M. japonicus (larval)	1.00%	Teshima et al. (1983)
M. japonicus	0.20%	Shudo et al. (1971)
M. japonicus	2.00%	Deshimaru and Kuroki (1974)
American lobster (*Homarus americanus*)	0.50%	Kean et al. (1985)
H. americanus	0.50%	Castell et al. (1975)
Signal crayfish (*Pacifastacus leniusculus*)	0.40%	D'Abramo et al. (1985b)
Cholesterol + phospholipid		
L. vannamei	0.14% (1.5% deoiled soybean lecithin)	Gong et al. (2000)
L. vannamei	0.13% (3.0% deoiled soybean lecithin)	Gong et al. (2000)
H. americanus	(8% soybean lecithin)	D'Abramo et al. (1985a)

Take Home Message

Freshwater fish:

Require either n-3 or n-6 fatty acids
(probably all fish require both types)
Elongate & desaturate shorter chain fatty acids but requirement= 5 to 10x

Marine fish :

Generally require n-3 fatty acids and small amount of n-6 fatty acids
Very limited ability to elongate (and desaturate) shorter chain fatty acids
Basically require EPA, DHA and AA (20:4 n-6)

Marine crustaceans :

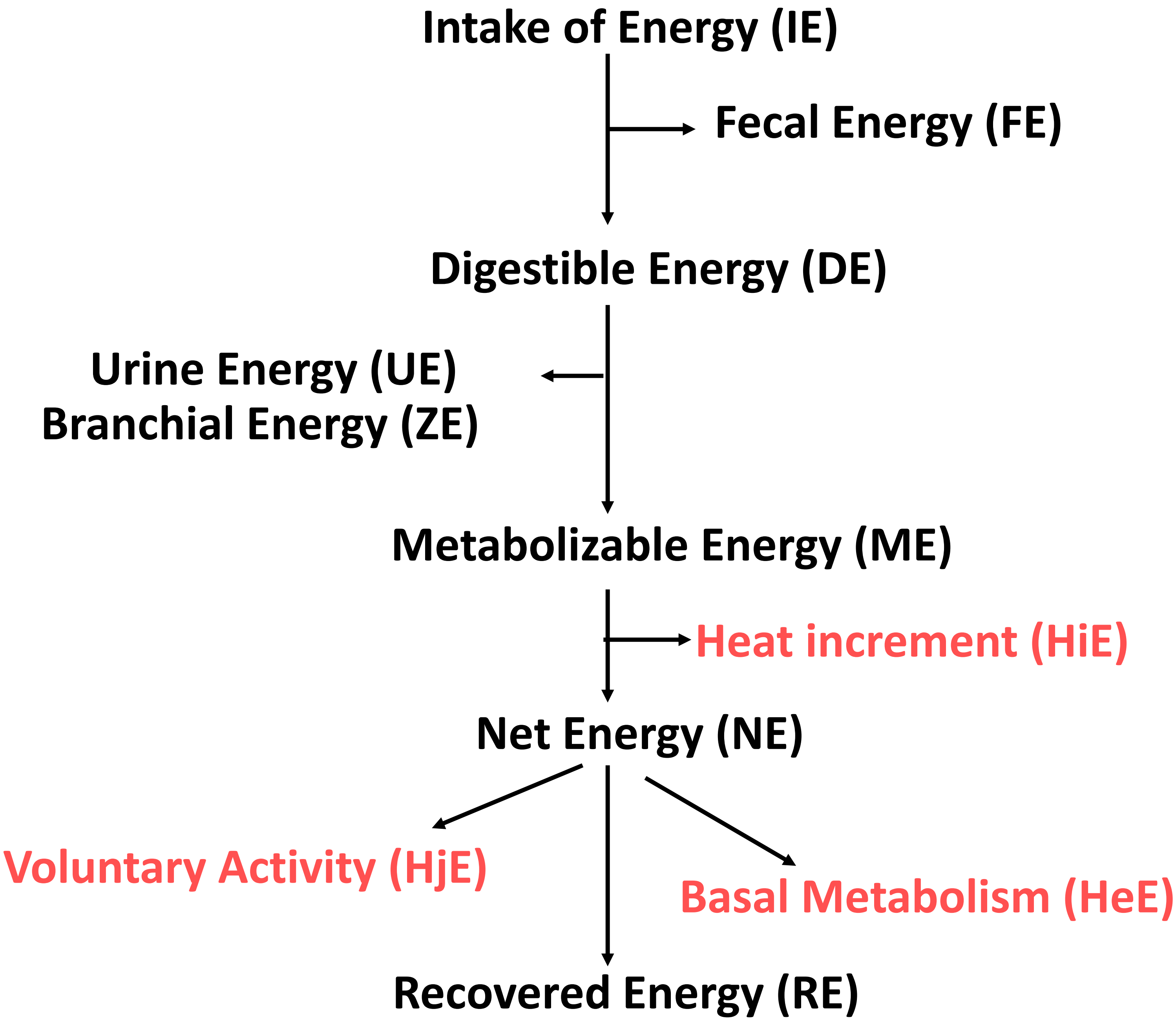
Generally require n-3 fatty acids and small amount of n-6 fatty acids
Very limited ability to elongate (and desaturate) shorter chain fatty acids
Basically require EPA, DHA and AA (20:4 n-6)
Require phospholipids
Require cholesterol (or sterols)

Educational Module #3: Dietary Energy: Definitions and Requirements (30 min)

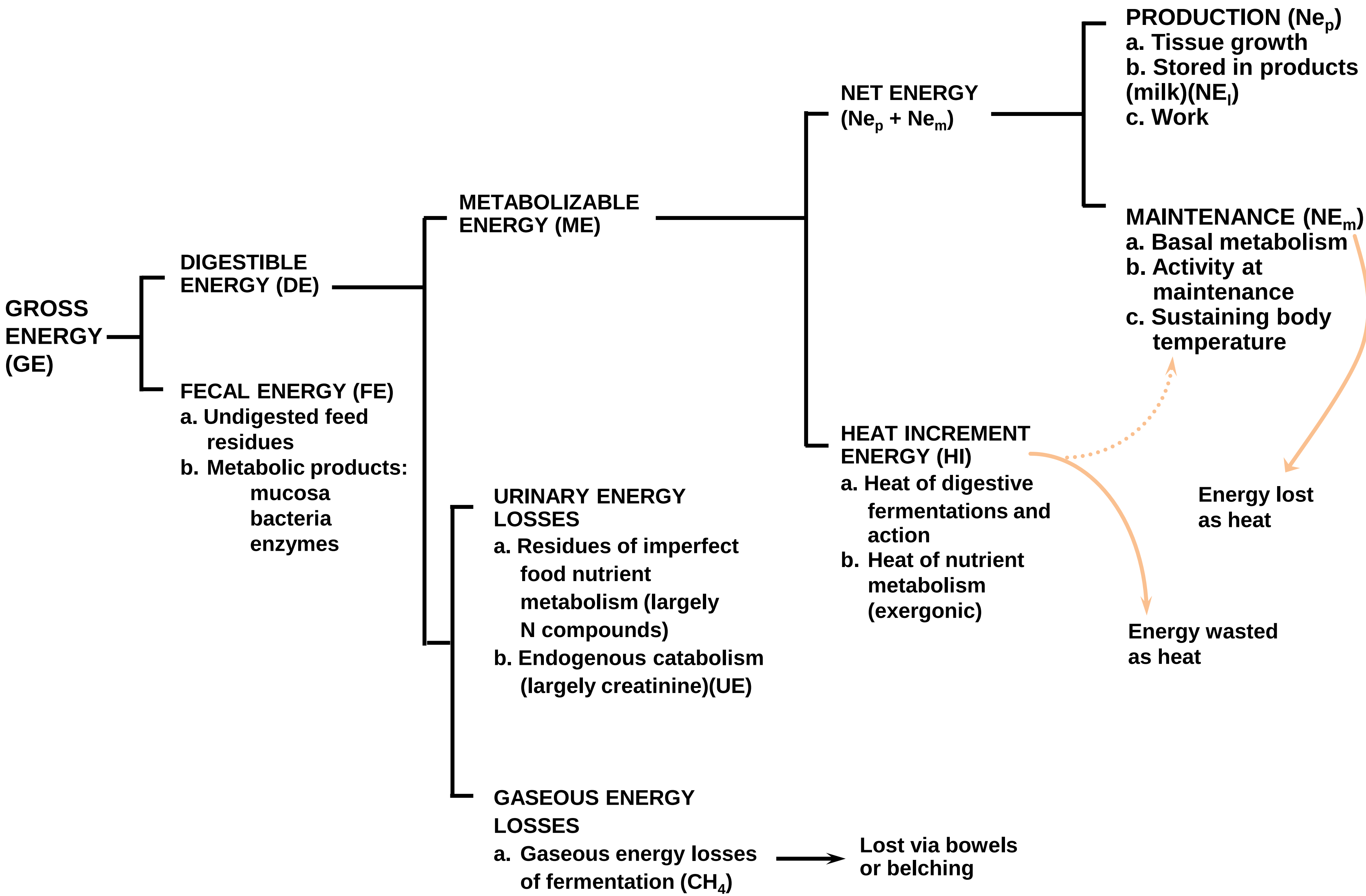
- Energy Partitioning Scheme

- Dietary Energy
  - Gross energy
  - Digestible energy
  - Metabolizable energy

- Bioenergetics Model
  - Energy Requirement Estimations
  - Theoretical feed requirement and feed conversion ratio


Intake of Energy (IE)
Fecal Energy (FE)
Digestible Energy (DE)
Urine Energy (UE)
Branchial Energy (ZE)
Metabolizable Energy (ME)
Heat increment (HiE)
Net Energy (NE)
Voluntary Activity (HjE)
Basal Metabolism (HeE)
Recovered Energy (RE)

Partitioning of Feed Energy



Growth **Most important parameter in aquaculture**

Affected by:
- **Feed (quantity and quality)**
- **Temperature, environment**
- **Genetics**
- **Rearing practices**

Nutrient deposition:

Growth is the result of nutrients deposition (water, protein, lipid, minerals, etc.)

Energy deposited = "average nutrient deposition"

Energy deposited + cost of living and cost of depositing energy
= Digestible energy requirement
= Feed requirement

Determining Energy and Feed Requirements

1- Predict or describe growth

Need appropriate growth model

2- Determine nutrient / energy gains

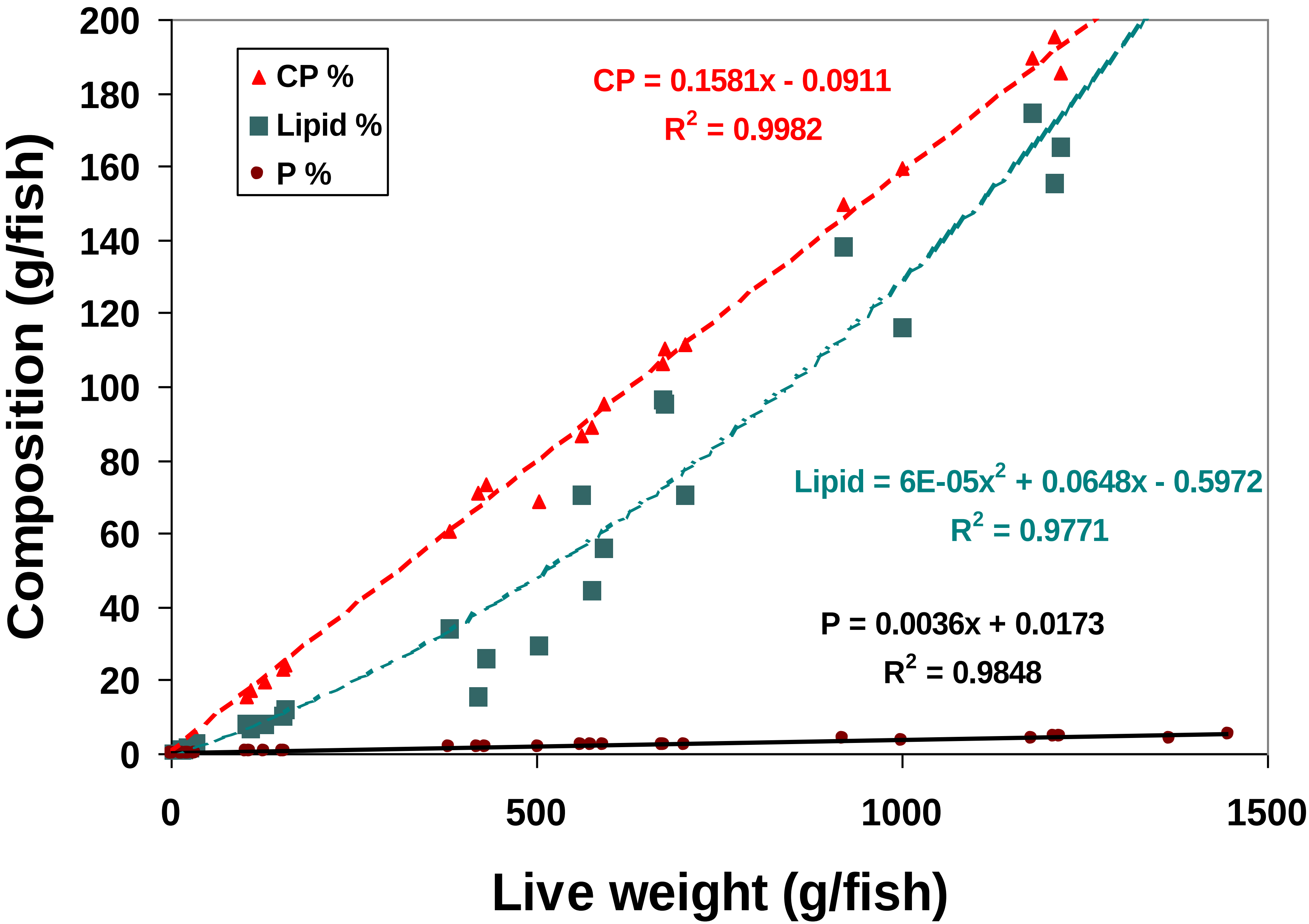
Carcass composition x growth

3- Estimate heat and metabolic losses

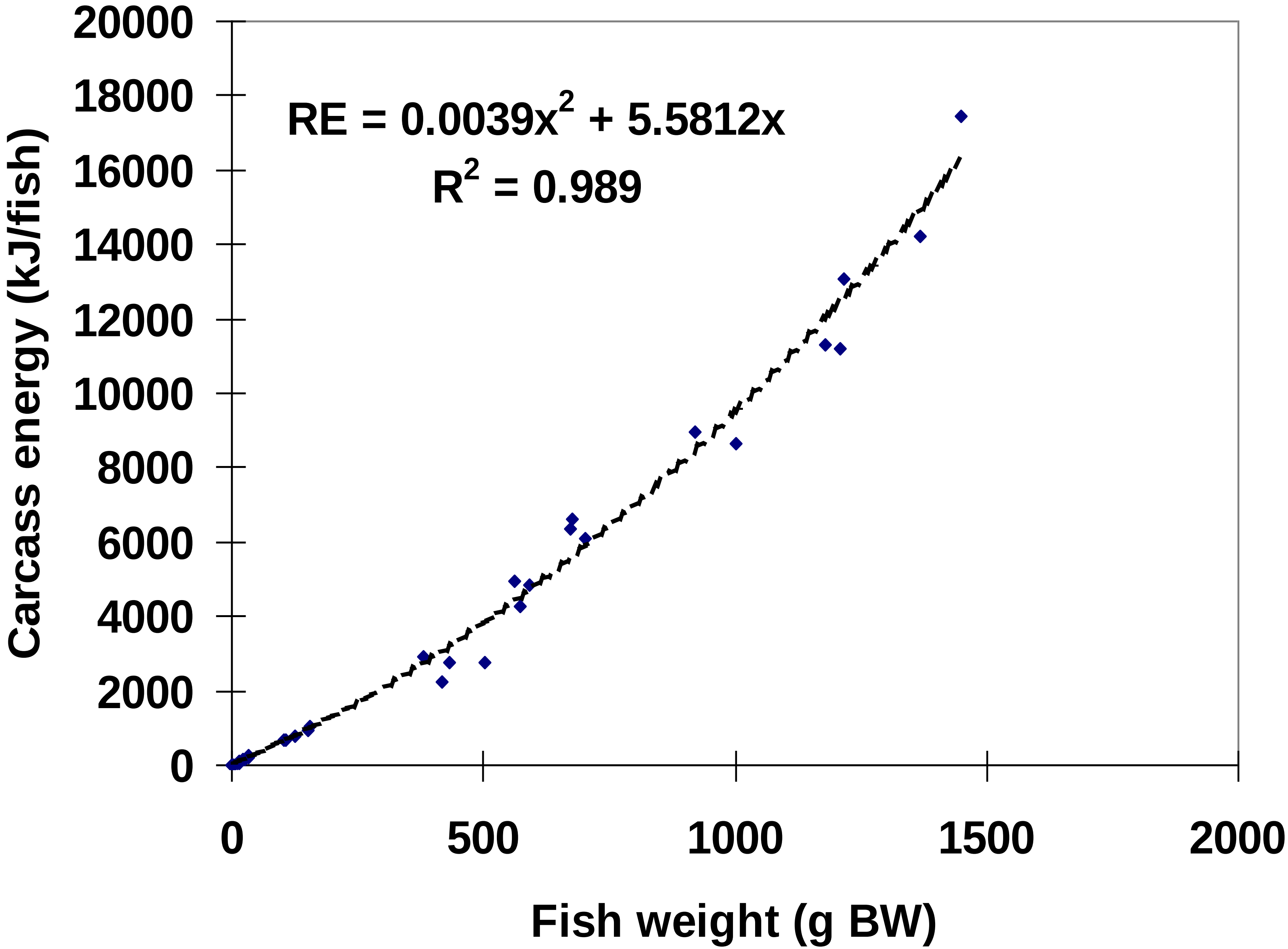
Maintenance (HeE) + Heat increment (HiE)
+ Non-fecal losses (UE+ZE)

4- Digestible energy requirement = sum

DE = RE + HeE + HiE + (UE+ZE)



CP %
Lipid %
P %
CP = 0.1581x - 0.0911
R2 = 0.9982
Lipid = 6E-05x2 + 0.0648x - 0.5972
R2 = 0.9771
P = 0.0036x + 0.0173
R2 = 0.9848
Composition (g/fish)
200
180
160
140
120
100
80
60
40
20
0
0
500
1000
1500
Live weight (g/fish)



RE = 0.0039x2 + 5.5812x
R2 = 0.989
Carcass energy (kJ/fish)
Fish weight (g BW)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0
500
1000
1500
2000

Estimate of basal metabolism (HeE)

Rainbow trout:

$HeE = -0.01+3.26T-0.05T^2$ kJ kg^{-1} MBW d^{-1}

where MBW =

Metabolic body weight = live weight $(kg)^{0.82}$

Rainbow trout: 36 kJ $kg^{0.82}$ 15°C

Homeotherms: 270 kJ $kg^{0.75}$ at 37°C

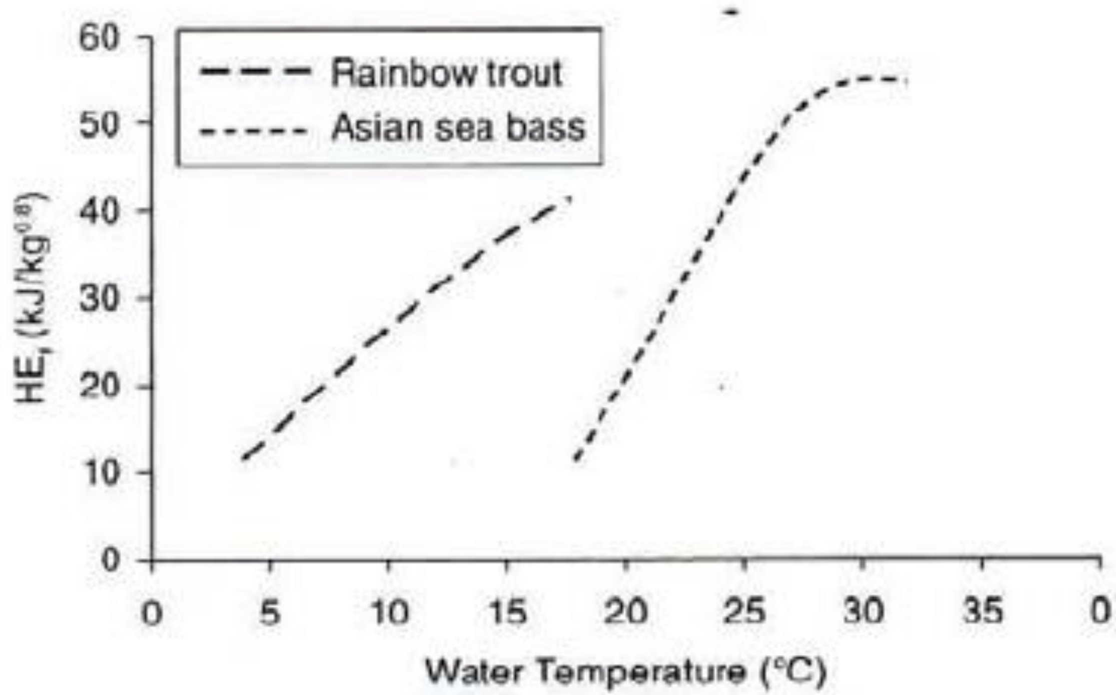
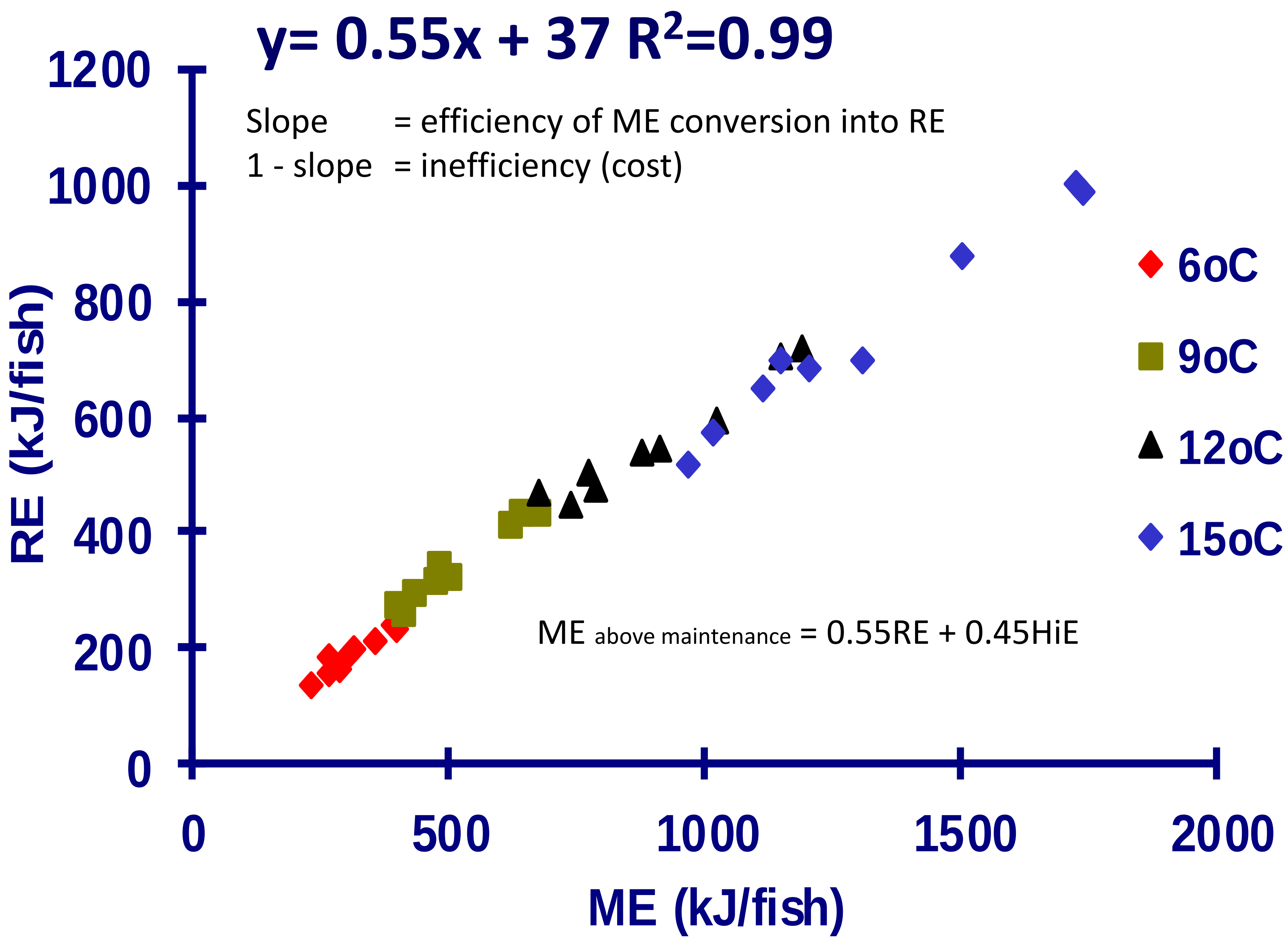


FIGURE 4-2 Fasting heat losses of rainbow trout, *Oncorhynchus mykiss,* and Asian sea bass, *Lates calcarifer* (expressed as HE_f, kJ per $kg^{0.8}$ per day and as a function of water temperature).



y= 0.55x + 37 R2=0.99
Slope = efficiency of ME conversion into RE
1 - slope = inefficiency (cost)
ME above maintenance = 0.55RE + 0.45HiE
RE (kJ/fish)
ME (kJ/fish)
0
200
400
600
800
1000
1200
0
500
1000
1500
2000
6oC
9oC
12oC
15oC

Efficiency of ME Utilization & Estimates of HiE

Results from various energy budget using regression RE as a function of MEI

$$ME_{\text{above maintenance}} = 0.61RE + 0.39HiE$$

or

$$HiE = 0.64\ RE$$

Azevedo et al. (1998)

$$ME_{\text{above maintenance}} = 0.68RE + 0.32HiE$$

or

$$HiE = 0.47\ RE$$

Rodehutscord and Pfeffer (1999)

$$ME_{\text{above maintenance}} = 0.64RE + 0.36HiE$$

or

$$HiE = 0.56\ RE$$

Bureau et al. (2006)

Efficiency of ME utilization not significantly affected by water temperature or feeding level. Nutrient composition (starch level) may affect ME utilization.

Digestible Energy Requirement/ Digestible Energy of Feed

↓

Theoretical Feed Requirement/ kg weight gain

↓

Theoretical Feed Conversion Ratio

Energy Requirements of Asian Sea Bass (*Lates calcarifer*).

Live Weight g/fish	Growth Rate g/d	RE	HeE	HiE+(UE+ZE)	DE Req
			MJ/kg gain		
10	1.1	4.5	1.2	3.1	8.9
50	2.2	5.7	2.3	3.9	11.9
100	3.0	6.3	2.9	4.3	13.6
250	4.4	7.2	4.1	4.9	16.3
500	5.9	8.0	5.4	5.4	18.8
1000	8.0	8.8	7.0	6.0	21.8
2000	10.7	9.7	9.0	6.6	25.4
3000	12.7	10.3	10.5	7.0	27.8

Feed Requirement Model for Nile Tilapia

						Coefficient	Exponent
Initial weight (Nursery)	1.6 g/fish	Number of days	56		Nursery TGC%=	0.148	0.358
Final weight (Nursery)	30.0 g/fish	Average temperature	27		Pre-Growout TGC%=	2.250	0.760
Final weight (Pre-Growout)	222 g/fish	Number of days	70		Growout Linear=	4.500	1.000
Final weight (Growout)	806 g/fish	Number of days	126				

FEED	DM	CP	Lipid	NFE	Ash	GE	Phosphorus	DP %
Nursery	90	40	7	33	9	17.8	1.3	36
Pre growout	90	32	6	41	10	16.7	1.1	28.8
Growout	89	28	5	45	10	16.3	0.8	25.2

Temperature °C	Period 7days	Weight g	Feed %BW	Feed g/fish wk	Feed eff. G:F	FCR F:G	DE MJ/kg gain	Type of Feed
27	0	1.0	12.8	0.90	1.11	0.90	13.9	Nursery
27	1	2.0	9.6	1.34	1.09	0.91	14.1	Nursery
27	2	3.5	7.7	1.87	1.08	0.92	14.2	Nursery
27	3	5.5	6.5	2.48	1.07	0.93	14.4	Nursery
27	4	8.1	5.6	3.17	1.06	0.94	14.5	Nursery
27	5	11.5	4.9	3.94	1.05	0.95	14.6	Nursery
27	6	15.7	4.4	4.79	1.05	0.95	14.7	Nursery
27	7	20.7	3.9	5.71	1.04	0.96	14.8	Nursery
27	8	26.6	3.6	6.70	1.03	0.97	14.9	Nursery
27	9	33.6	5.3	12.45	1.09	0.92	14.1	Nursery
29	1	47.1	4.8	15.86	0.99	1.01	14.5	Pre-Growout
29	2	62.8	3.9	17.21	0.97	1.03	14.8	Pre-Growout
29	3	79.6	3.3	18.47	0.95	1.05	15.0	Pre-Growout
29	4	97.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Pre-Growout
29	5	115.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Pre-Growout
30	6	134.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Pre-Growout
30	7	155.2	2.2	23.82	0.89	1.12	16.1	Pre-Growout
30	8	176.4	2.0	24.90	0.88	1.14	16.4	Pre-Growout
30	9	198.3	2.5	34.12	0.92	1.08	15.5	Pre-Growout
30	1	230	2.2	36.05	0.87	1.14	15.9	Growout
30	2	261	2.0	36.78	0.86	1.17	16.2	Growout
30	3	293	1.8	37.49	0.84	1.19	16.5	Growout
30	4	324	1.7	38.18	0.82	1.21	16.8	Growout
30	5	356	1.6	38.87	0.81	1.23	17.1	Growout
30	6	387	1.5	39.54	0.80	1.26	17.4	Growout
30	7	419	1.4	40.20	0.78	1.28	17.7	Growout
30	8	450	1.3	40.84	0.77	1.30	18.0	Growout
30	9	482	1.2	41.48	0.76	1.32	18.3	Growout
30	10	513	1.2	42.12	0.75	1.34	18.5	Growout
30	11	545	1.1	42.74	0.74	1.36	18.8	Growout
30	12	576	1.1	43.36	0.73	1.38	19.1	Growout

This is a fancy version of Task 5.2

Growth Prediction & Feed Requirement

Waste Outputs Prediction & Oxygen Requirements

Graphs

User Informations

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journal homepage: www.elsevier.com/locate/aqua-online

Bioenergetics-Based Factorial Model to Determine Feed Requirement and Waste Output of Tilapia Produced under Commercial Conditions

M.A. Kabir Chowdhury [a,*], Sohail Siddiqui [b], Katheline Hua [c], Dominique P. Bureau [a]

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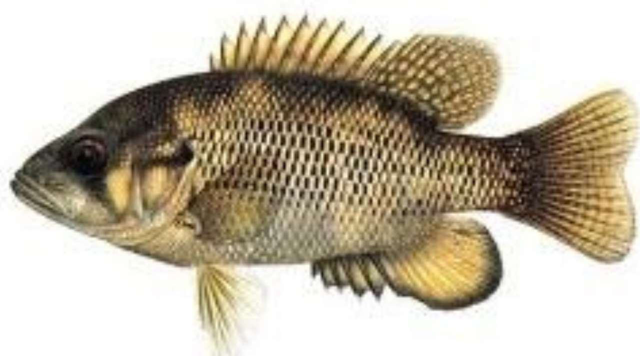
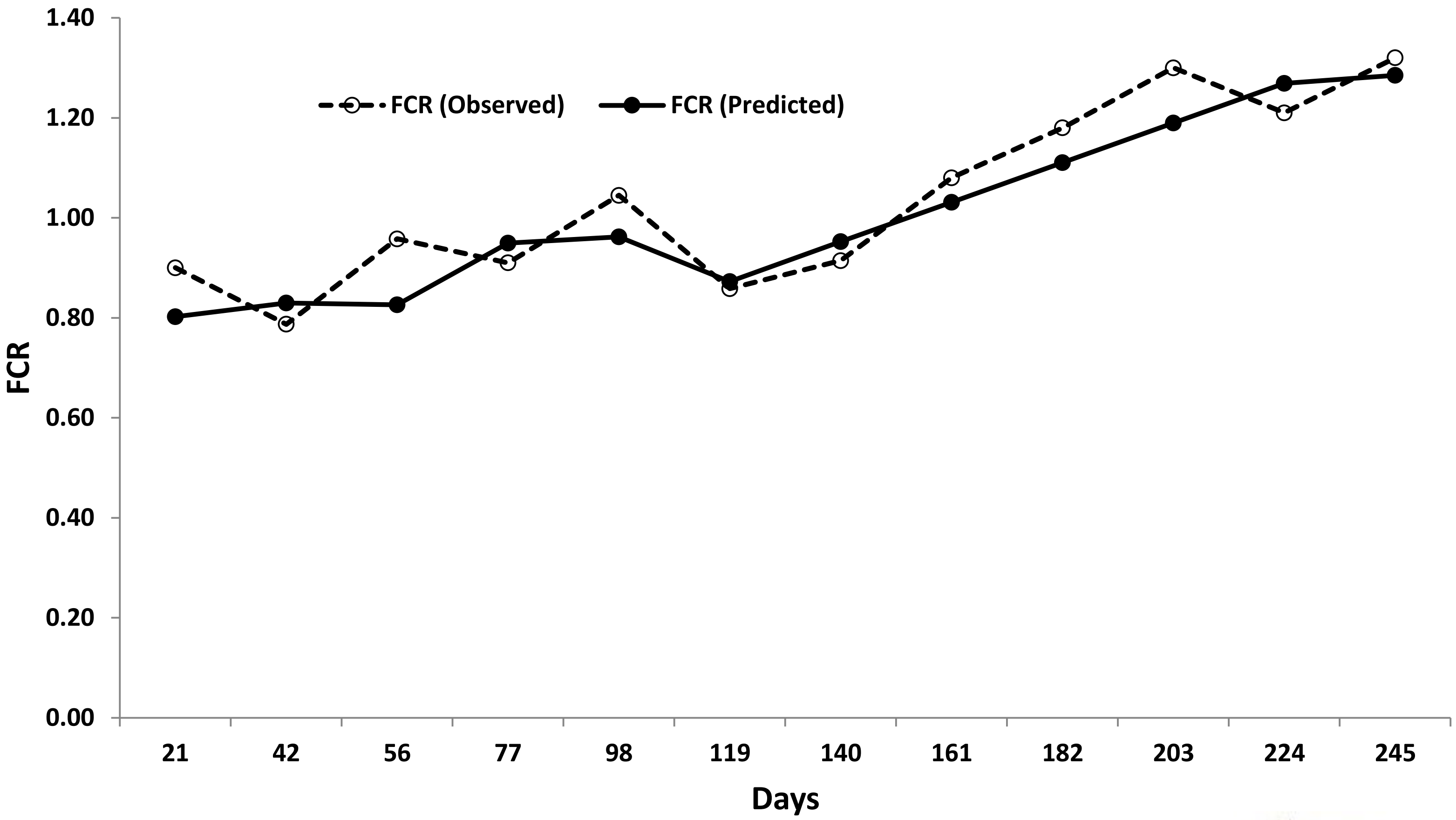
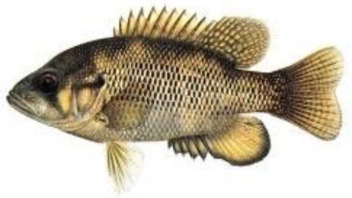
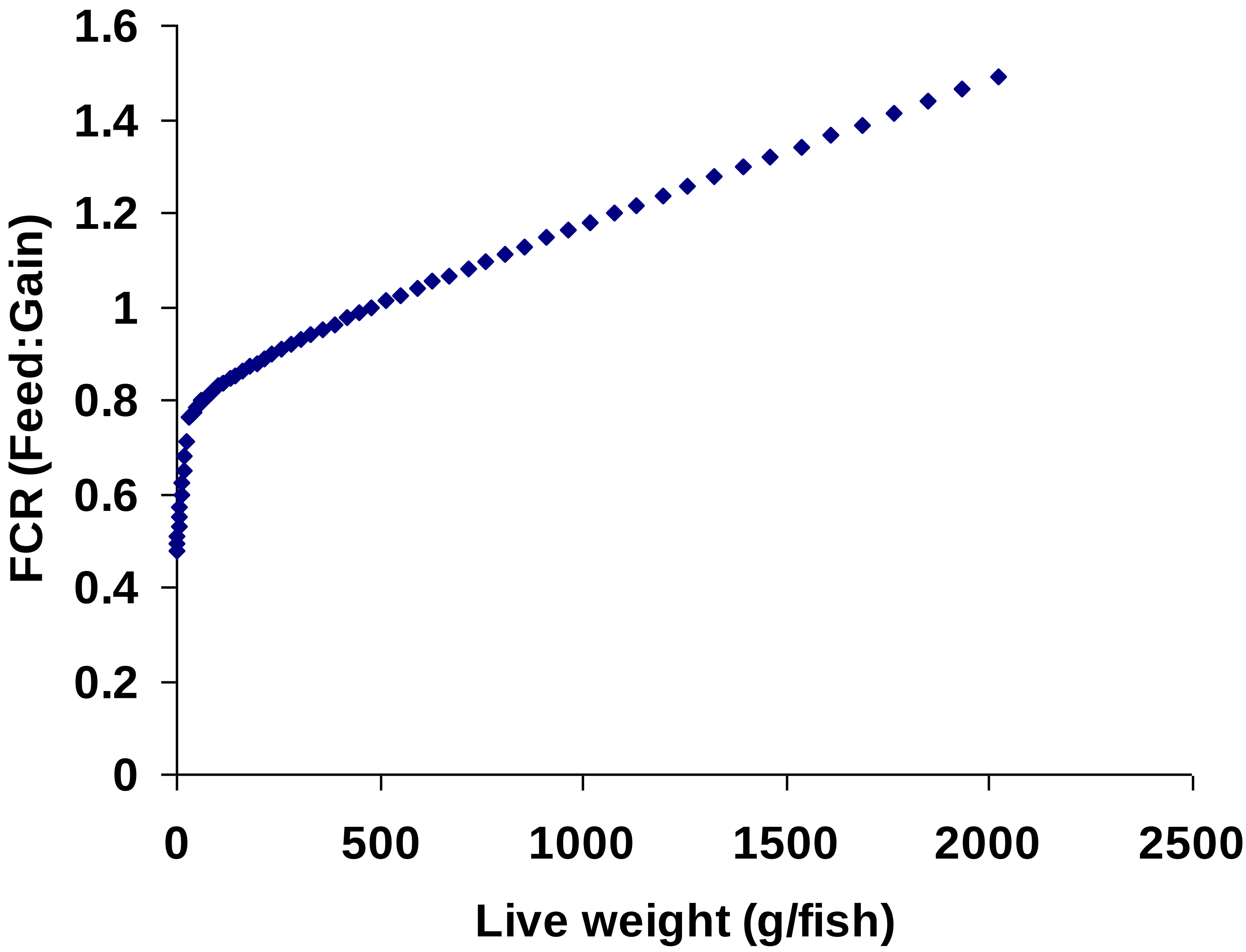


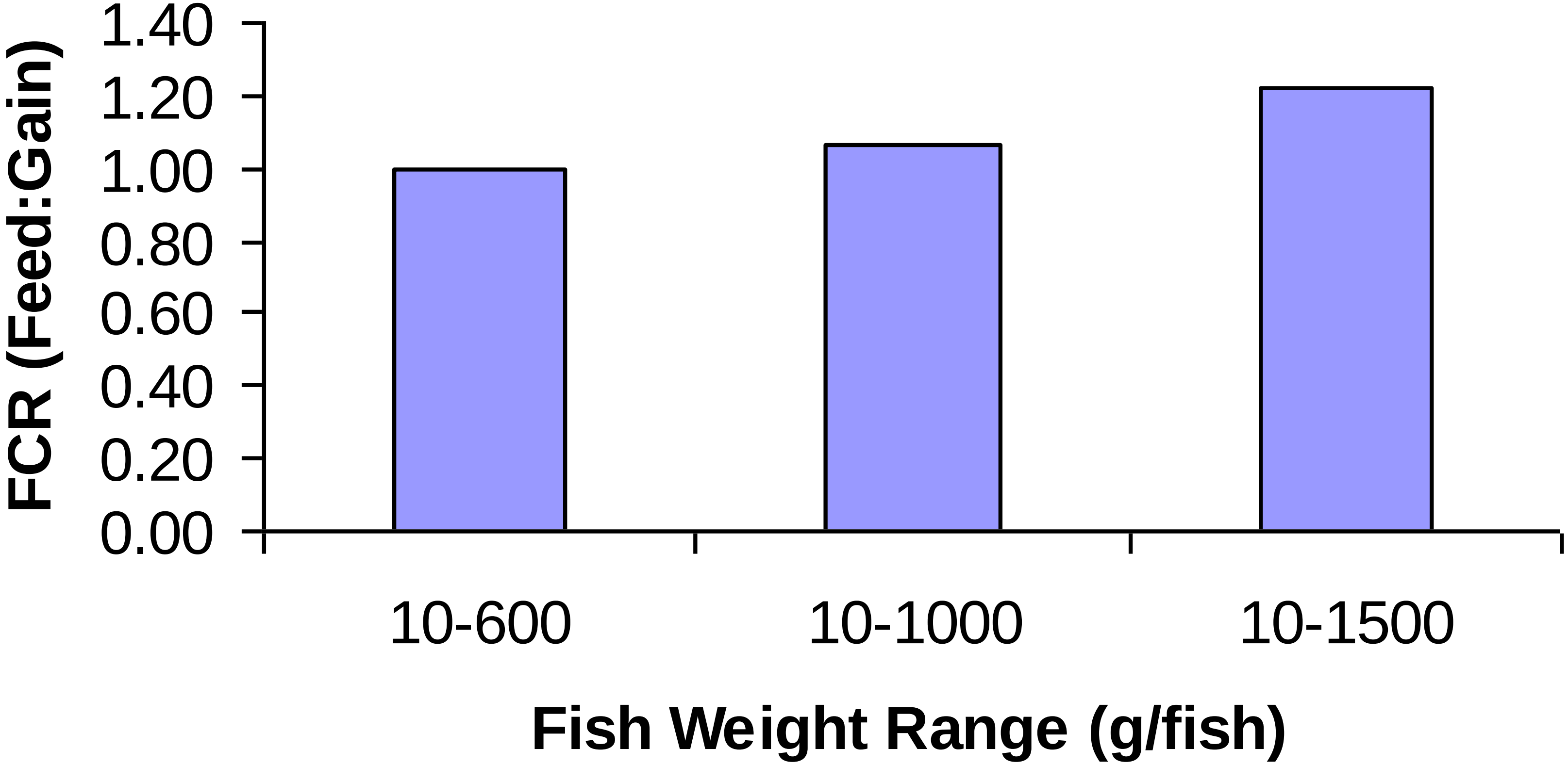
Observed and predicted evolution of feed conversion ratio (feed:gain) of Nile tilapia during a pilot-scale trial






1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
FCR (Feed:Gain)
0
500
1000
1500
2000
2500
Live weight (g/fish)

Expected FCR of fish reared to different harvest weights



Feed: 37% DP, 20 MJ DE