The Nutritive Value of Processed Animal Proteins to Different Aquaculture Species

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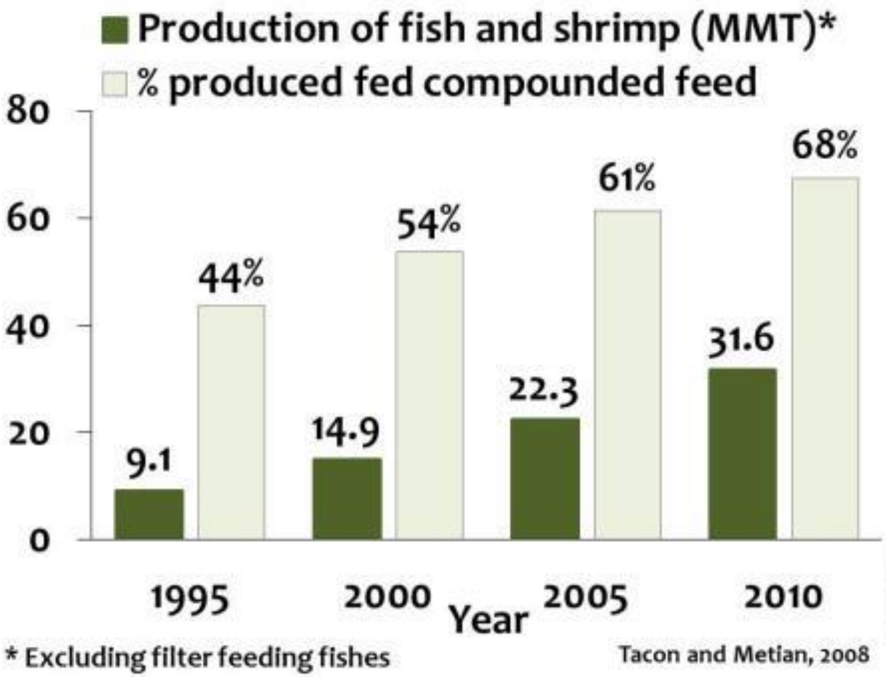
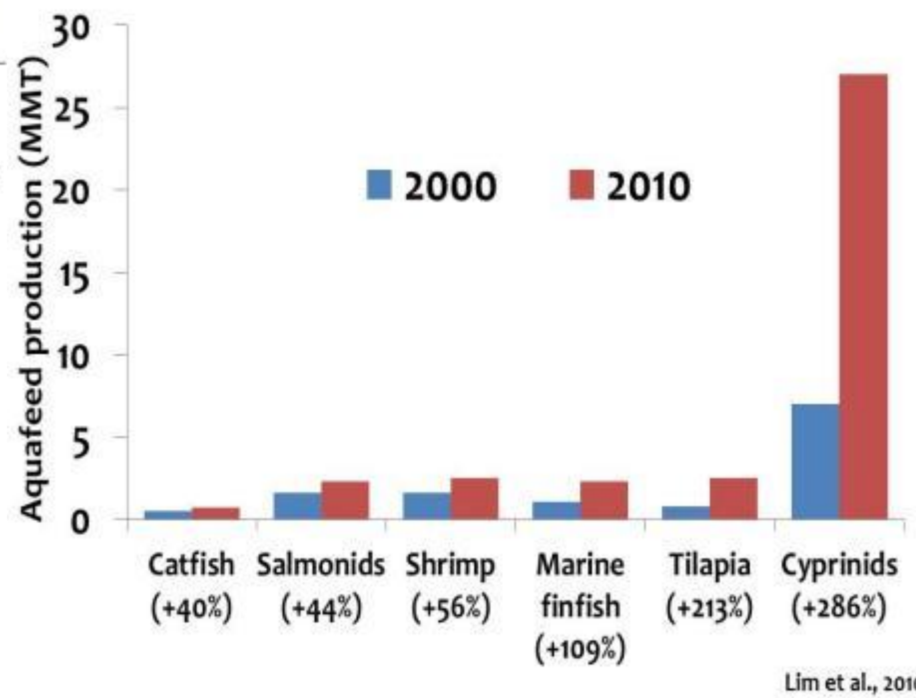
AQUACULTURE = Diversity of Species

AQUACULTURE FEED = a growing industry





Trout Farm (Raceway) – a Typical Fish Farm???

Shrimp Farming Area in Java (Indonesia)

Cage Production of Tilapia in South America (Brazil, Columbia)

Top fed aquaculture & livestock producers – 2009

(FAO – FISHSTAT/FAOSTAT, 2011)

Values in million tonnes - Mt

Top fed aquaculture species	
Grass carp	4.16 Mt
Common carp	3.22
Nile tilapia	2.54
Catla	2.42
Whiteleg shrimp	2.32
Crucian carp	2.06
Atlantic salmon	1.44
Roho labeo	1.22
Pangasius catfish	1.19
∑ 66% of total fed species production	
Total fed species production : 31.4 Mt	
APR 8.5% since 1980	

Top fed livestock species	
Pig	106.3 Mt
Chicken	80.3
Cattle	62.8
Sheep	8.2
Turkey	5.3
Goat	5.0
Duck	3.8
Buffalo	3.3
∑ 97%	
Total meat production - 284 Mt	
APR 2.55% since 1980	

Slide courtesy of Dr. A.J. Tacon

What Do Fish and Shrimp Require?

Traditional Essential Nutrients:

Same for all species:

10 Essential amino acids
Fat and water soluble vitamins
Minerals

Same nutrients as other livestock species but with some differences

Nutrients with some aspects of essentiality that are species and life stage-specific:

Essential fatty acids ω-3, ω-6
Vitamin-like compounds (choline, *myo*-inositol)

Nutrients who essentiality are species and stage-specific:

Taurine
Phospholipids (a very wide class of chemicals)
Cholesterol ?
Nucleotides ?
Other compounds?

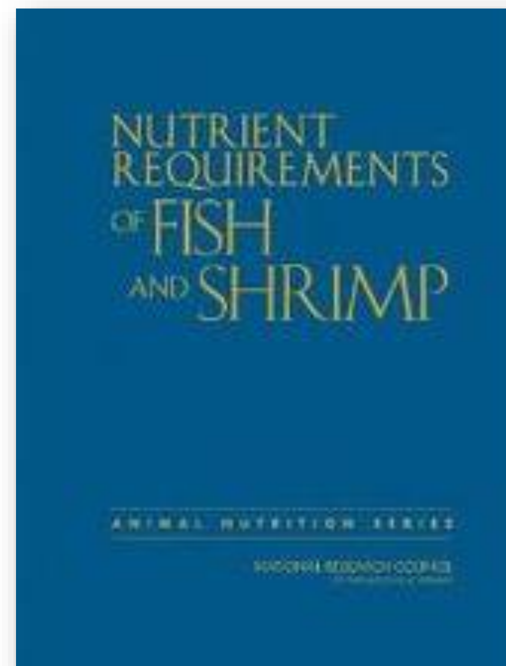
NRC Committee of Nutrient Requirements of Fish and Shrimp (2009-2011)

NRC 2011

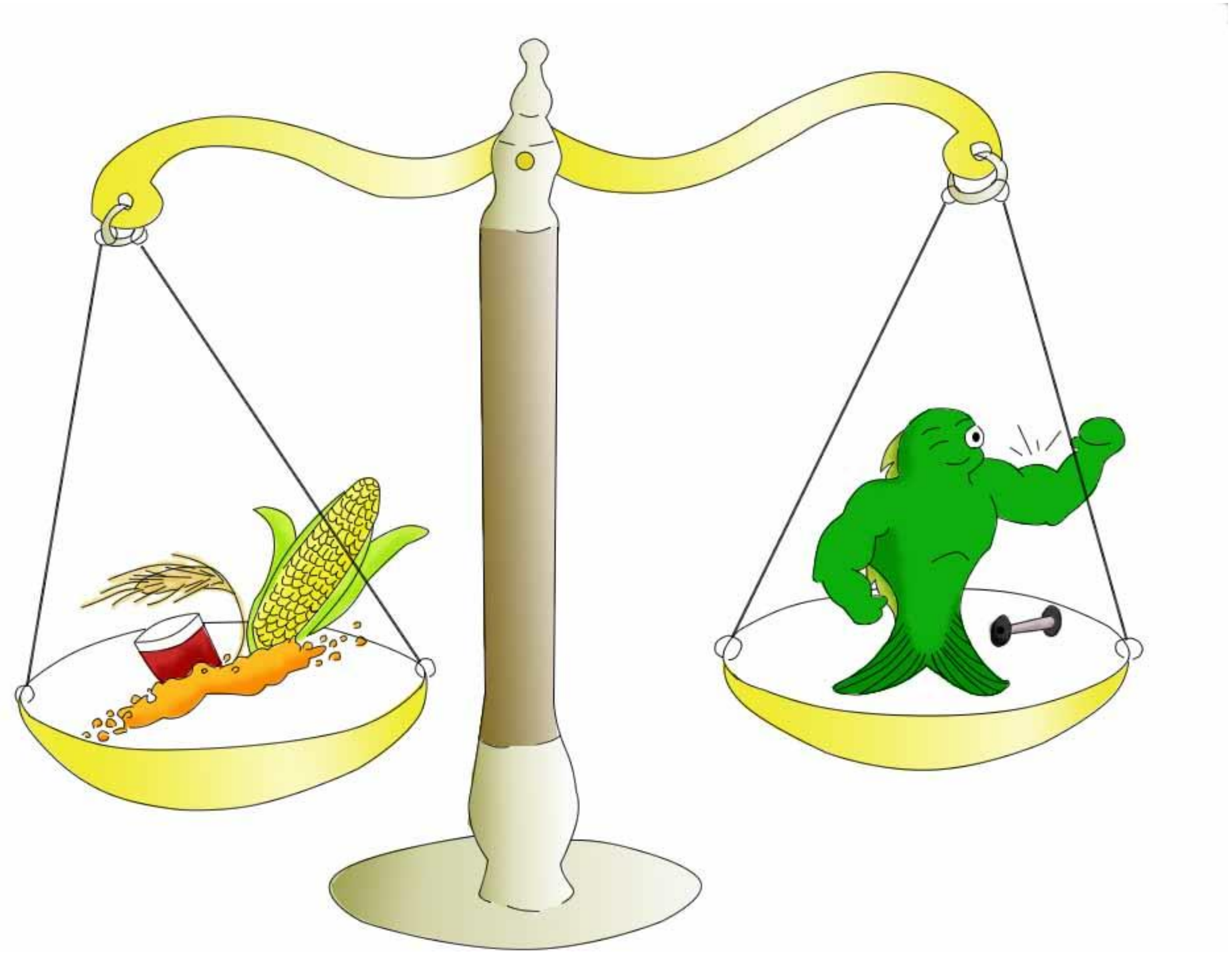
Review of state-of-the-art

Committee reviewed 1000s of papers

Imperfect document and recommendations represent best effort



Animal Nutrition = Balanced Understanding of Nutritional Requirements and Ingredient Quality



Animals utilize **NUTRIENTS, not ingredients!**

What matters is meeting individual nutrient requirements of the animal

Dependent on:

- Chemical/nutrient composition of the ingredients
- Digestibility / bio-availability of nutrients in ingredients

The Roles and Value of Processed Animal Proteins

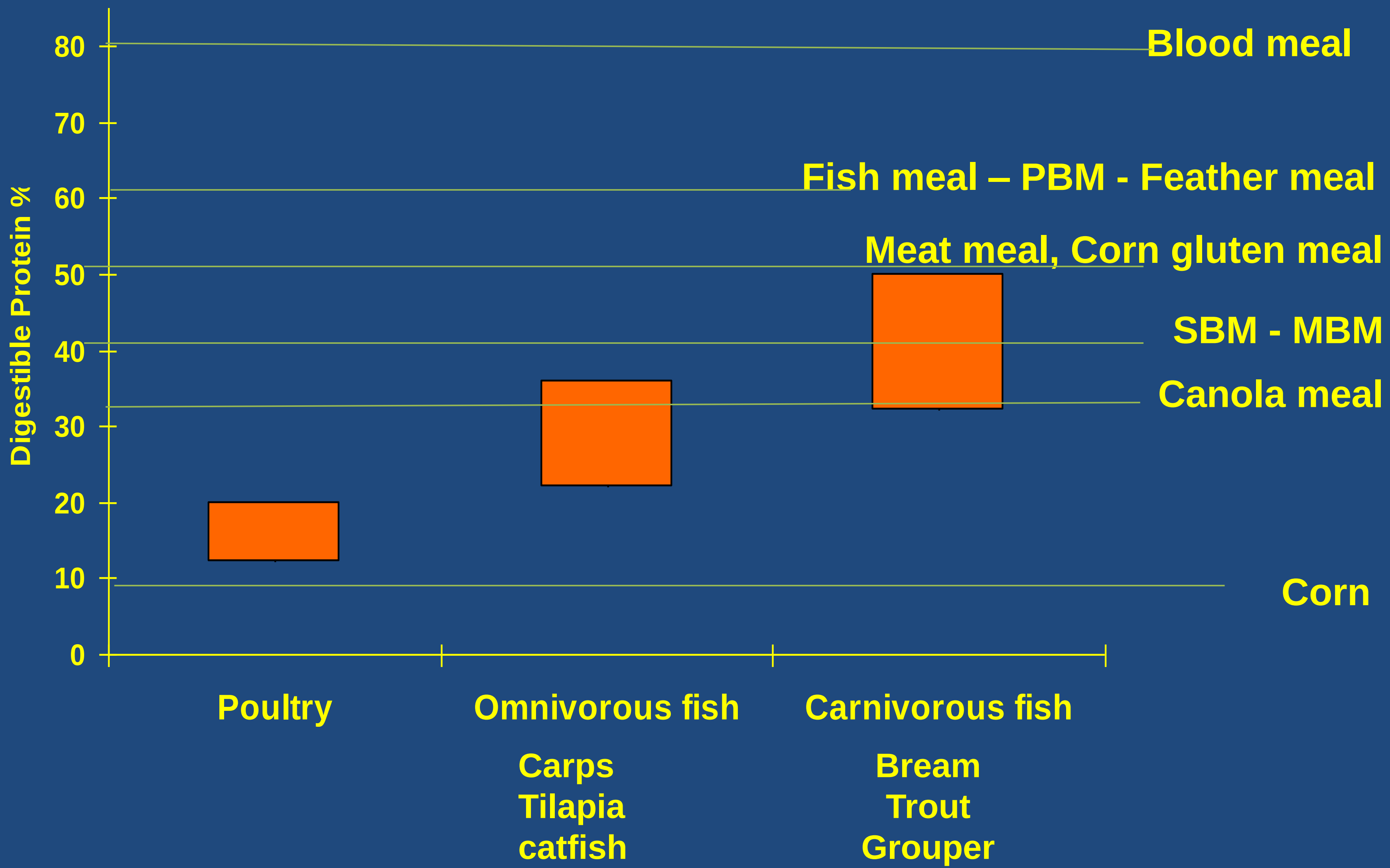
Comparison of the Cost of Different Protein Sources

Feedstuffs	Crude Protein %	Price* USD $/tonne	Apparent Digestibility of Protein** %	Price $/tonne Crude Protein	Price $/tonne Digestible protein
Fish meal	65	1700	90	2,615	2,906
Rapeseed (Canola) meal	38	400	87	1,053	1,210
Corn Gluten meal	60	600	93	1,000	1,075
Soybean meal, 48% USA	48	550	89	1,146	1,287
DDGS, USA	35	280	80	800	1,000
Poultry by-products meal, USA	57	530	87	930	1,069
Meat and bone meal, USA	50	460	85	920	1,082
Feather meal, USA	80	630	75	788	1,050

* Source: Hammersmith Marketing Ltd - Grain Trading
WEEKLY FEED GRAIN AND PROTEIN REPORT May 18, 2013

** Practical estimates of digestibility of crude protein

Digestible Protein Concentration: Species, Feeds and Ingredients



Processed Animal Proteins (PAPs)
Perspectives from Asia and the Americas

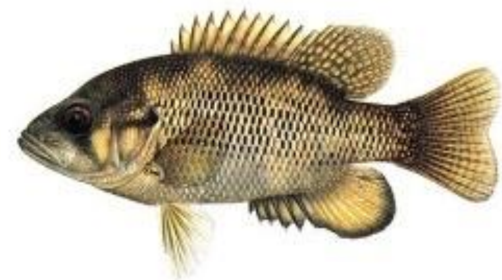
Aquaculture feed are increasingly formulated on a "nutrient" basis (as opposed to an ingredient or proximate composition basis)

Processed animal protein ingredients are generally cost-effective and increasingly "<u>trusted</u>" and "<u>digestible</u>" sources of several keys nutrients:

Essential amino acids
Phosphorus
Essential fatty acids
Micro-minerals
Phospholipids
Cholesterol, etc.

They are playing an increasingly strategic role, notably in the context of very high fish meal price

Example of Formulation for Commercial Extruded Feed (32% CP) for Nile Tilapia in South East Asia



Global production : > 2.5 MMT

Ingredients	%
Grains & tubers (corn, wheat, cassava, rice) + milling by-products (bran)	40
Soybean meal	35
Processed animal proteins (poultry meal, MBM, feather meal, blood meal)	*12*
Functional ingredients	5
Fish meal, local or imported	3
Soybean oil, lecithin, palm oil	2
Fish oil	1
Minerals, vitamins, amino acids and additives	2

Example of Formulation for Commercial Feed (36% CP) for Crucian Carp (*Carassius auratus gibelio*) in China

Global production : > 2 MMT

Ingredients	%
Grains & tubers (corn, wheat, cassava, rice) + milling by-products (bran)	25
Rapeseed meal	23
Soybean meal	19
Processed animal proteins (poultry meal, MBM, feather meal, etc.)	*15*
Cottonseed meal	8
Fish meal	4
Soybean oil and other fat sources	3
Minerals, vitamins, additives	3

Essential Amino Acid Composition of some Processed Animal Proteins

Ingredients	ARG	HIS	ILE	LEU	LYS	MET	PHE	THR	VAL	TRP
					% DM					
Fish meal, herring	4.8	1.5	2.6	4.7	3.9	1.4	2.7	2.7	3.3	1.1
Meat and bone meal	3.4	1.1	1.5	3.2	2.5	0.9	1.8	1.9	2.1	0.4
Poultry by-prod. meal, low ash	5.1	1.6	2.4	5.1	4.3	1.6	2.9	3.1	3.2	0.7
Poultry by-prod. meal, high ash	5.0	1.5	2.4	4.9	4.2	1.5	2.7	2.9	3.2	0.7
Hydrolyzed feather meal	6.4	0.7	4.3	7.2	2.7	0.6	4.3	4.2	6.5	0.6
Spray-dried blood meal	3.6	6.7	0.3	11.5	7.0	0.8	6.1	2.8	6.6	1.3
Porcine meat meal	5.2	1.3	2.4	4.2	3.8	1.2	2.4	2.3	3.0	0.4[b]

Characterizing the Nutritive Value of Processed Animal Proteins

Informal Research Partnership (1994-2004)

Renderers

- National By-Products (USA)
- West Coast Reduction (Canada)
- Sanimal (Canada)
- Rothsay (Canada)

Feed Manufacturers

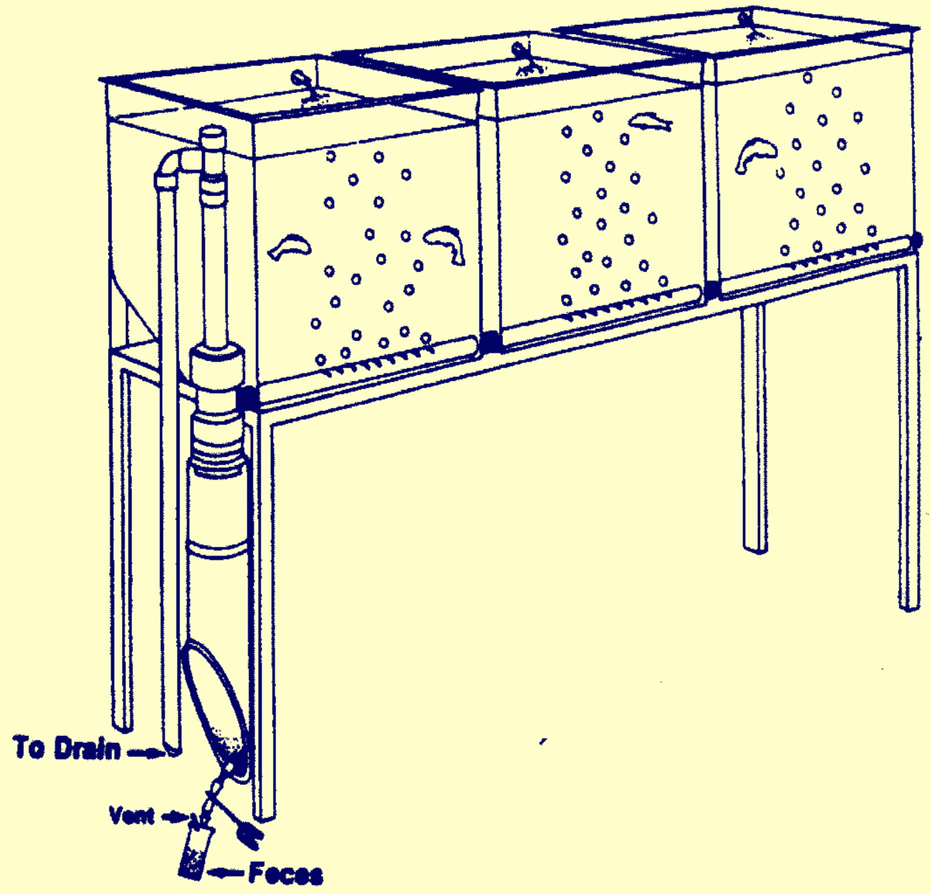
- Shur-Gain (Canada)
- Martin Mills (Canada)

UG Fish Nutrition Research Laboratory

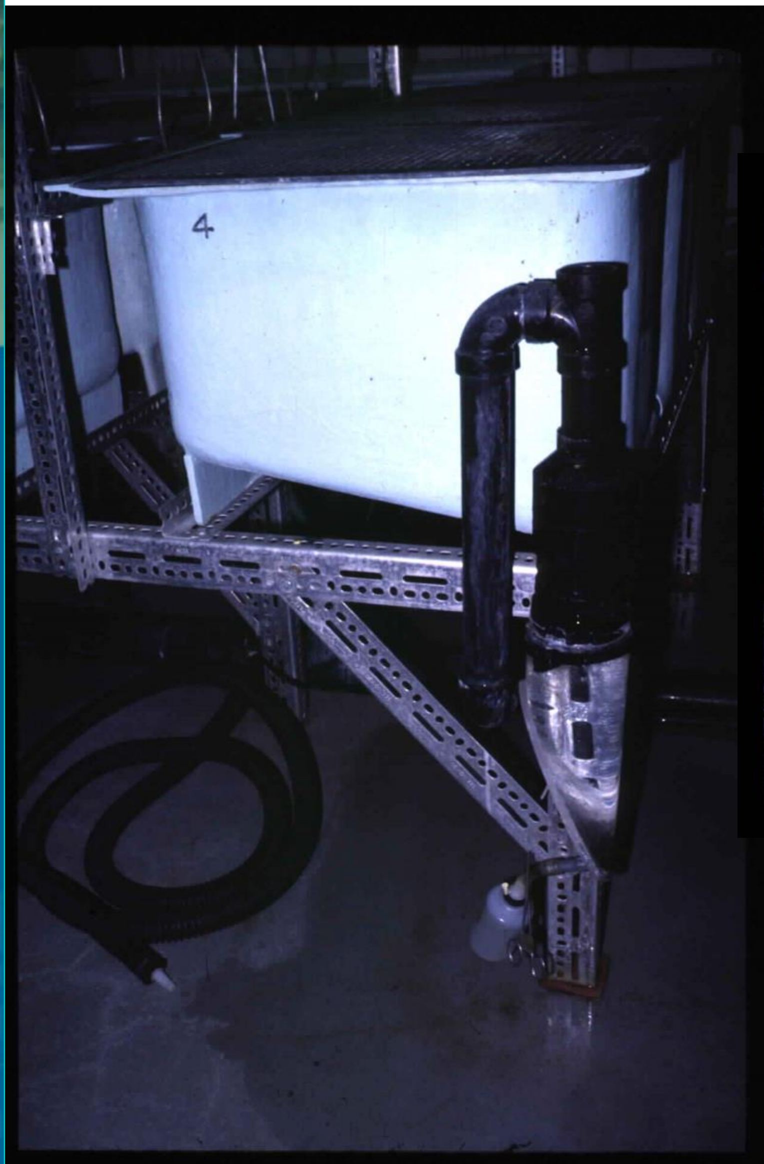
Funding

- Fats and Proteins Research Foundation (USA)
- Ontario Ministry of Agriculture (OMAF) (Canada)
- Canadian Renderers Association (Canada)
- Dept. of Fisheries and Oceans (DFO) (Canada)
- Ontario Ministry of Natural Resources (OMNR) (Canada)
- National Renderers Association (USA)

The Guelph System (Cho et al., 1982)



Guelph Digestibility System



Apparent Digestibility of Processed Animal Proteins in the late 1990s

Ingredients	Apparent Digestibility Coefficients (%) DM	CP	GE
Trial #1			
Feather meal 1	82	81	80
Feather meal 2	80	81	78
Feather meal 3	79	81	76
Feather meal 4	84	87	80
Meat and bone meal 1	61	83	68
Meat and bone meal 2	72	87	73
Trial #2			
Meat and bone meal 3	72	88	82
Meat and bone meal 4	66	87	76
Meat and bone meal 5	70	88	82
Meat and bone meal 6	70	89	83
Trial #3			
Feather meal 5	86	88	84
Feather meal 6	83	86	81
Feather meal 7	83	88	83
Meat and bone meal 7	78	92	86
Meat and bone meal 8	72	89	81
Meat and bone meal 9	69	88	80

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Apparent Digestibility of Feather Meals

Guelph System	ADC Protein	ADC 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%

Data obtained using the same facilities and methodology. There is value in using standard methodological approaches consistently over many years.

Apparent Digestibility of 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%

Data obtained using the same facilities and methodology

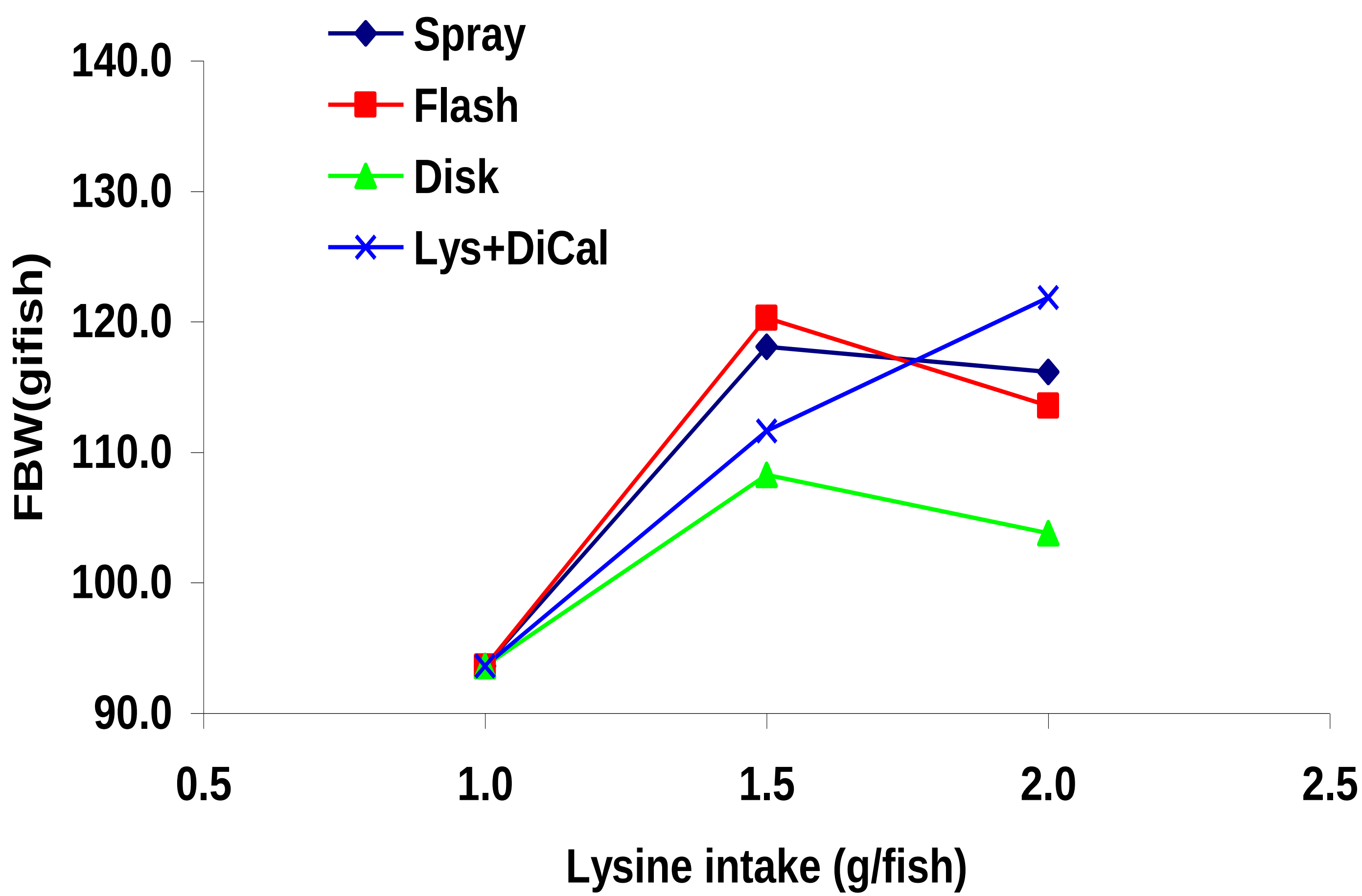
Blood Meal

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

Bureau et al. (1999)

Different drying equipments can greatly affect apparent digestibility

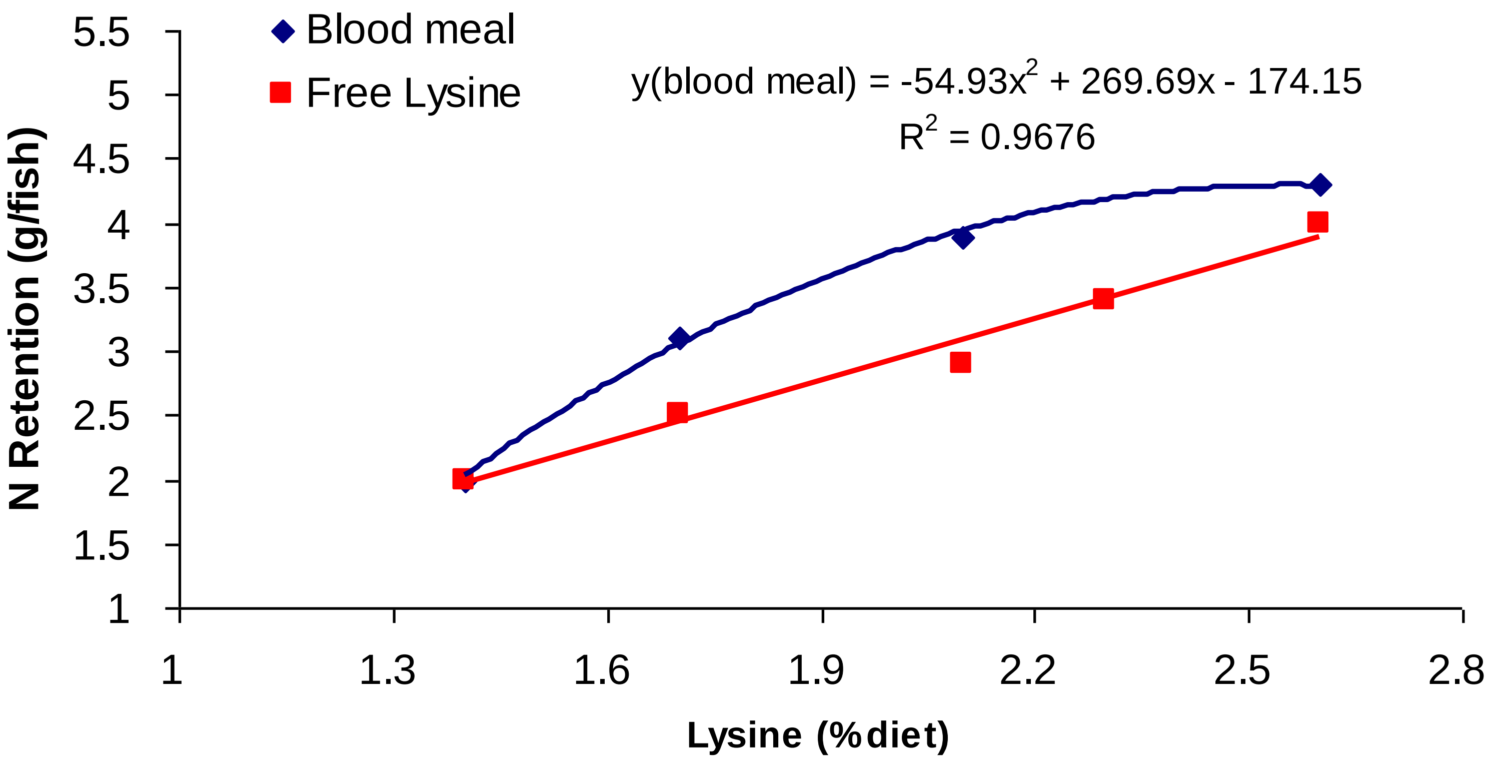
Final Body Weight - Lysine Bio-Availability Trial



Shows that differences exist in the bioavailability of lysine in blood meals produced with different drying equipment

El Haroun and Bureau (2006)

N gain of rainbow trout fed lysine deficient basal diet supplemented with free L-Lysine or spray-dried blood meal (two sources of "highly digestible" lysine).



Digestible lysine from high quality blood meal is apparently of slightly higher bioavailability (bio-efficacy) than crystalline L-Lysine

Nutrient Composition of Different Fish Meals and Poultry by-Products Meals

	Fish meal		Poultry by-Products Meal		
Composition	**Herring**	**Menhaden**	**Feed-grade**	**Prime**	**Refined**
Dry matter, %	93	91	97	96	97
Crude Protein, %	71	61	62	66	70
Crude fat, %	9	9	11	8	10
Ash, %	12	22	15	15	11
Phosphorus, %	2.4	3.1	2.6	2.8	2.0
Lysine, %	5.4	4.2	3.7	3.7	4.6
Methionine, %	1.8	1.5	1.2	1.3	1.5
Histidine, %	2.2	1.2	1.4	1.2	1.5
Threonine, %	3.1	2.4	2.5	2.4	3.0

Fish meal is not fish meal and poultry by-products meal is not poultry by-products meal. These are generic names that regroup ingredients that can be widely different.

Cheng and Hardy (2002)

Apparent Digestibility of Nutrients of Different Fish Meals and Poultry By-Products Meals

	Fish meal		Poultry by-Products Meal		
Component	**Herring**	**Menhaden**	**Feed-grade**	**Prime**	**Refined**
			%		
Dry matter	81	71	71	72	75
Crude Protein	90	86	83	85	87
Crude fat	92	91	80	83	80
Phosphorus	58	47	49	46	56
Lysine	95	95	89	92	93
Methionine	95	95	92	95	94
Histidine	92	93	85	89	89
Threonine	90	92	82	85	85

Digestibility of essential amino acids of poultry by-products meal is high but slightly less good than that of high quality fish meal (e.g. herring meal in this example)

Cheng and Hardy (2002)

From the Laboratory to the Field…

Commercial Extruded Feeds Based on Herring Meal, Menhaden Meal or Poultry by-Products Meal

	1	2	3	4	5	6
Ingredients	MM10	MM20	HM10	HM20	NFM	Profishent
Fish meal, herring	-	-	100	200	-	+
Fish meal, menhaden	100	200	-	-	-	-
Poultry by-prod. meal	300	200	300	200	400	+
Soybean meal	90	80	120	120	70	+
Corn gluten meal	150	150	120	90	150	+
Feather meal	50	70	50	70	70	+
Wheat	100	100	110	130	100	+
Fish oil, herring	120	110	120	110	130	+
Poultry Fat	60	60	60	60	50	+

Unit: kg/tonne of feed

Growth and Feed Efficiency of Rainbow Trout Fed the Commercial Extruded Feeds for 16 weeks at 15ºC.

Diet	Initial weight (g/fish)	Final weight (g/fish)	Weight gain (g/fish)	Feed intake (g/fish)	FE (gain/feed intake)	TGC (%)
MM10	15.5	205	189.2	180.1	1.05[b]	0.199
MM20	15.5	193	177.3	158.4	1.12[ab]	0.192
HM10	15.4	203	187.5	161.0	1.16[ab]	0.199
HM20	15.8	222	206.4	171.7	1.20[a]	0.208
NFM	16.0	208	192.1	182.2	1.06[b]	0.199
Profishent	15.9	203	187.5	165.3	1.13[ab]	0.197
SEM		6.2	6,2	5.2	0.03	0.03

[1] Values with different subscript letters are significantly different ($P<0.05$)

No fish meal, main protein source = poultry by-products meal (40%)

Differences in <u>Processing</u> of the ingredients play a far greater role than difference in <u>species</u> to which the ingredients are fed

Processed Animal Proteins in the Diet of High Value Marine Fish Species:

Research Trials by Prof. Wang Yan
Zhejiang University, P.R. China

Trials funded by Fats and Proteins Research Foundation (FPRF) and National Renderers Association (NRA) - Asia Region

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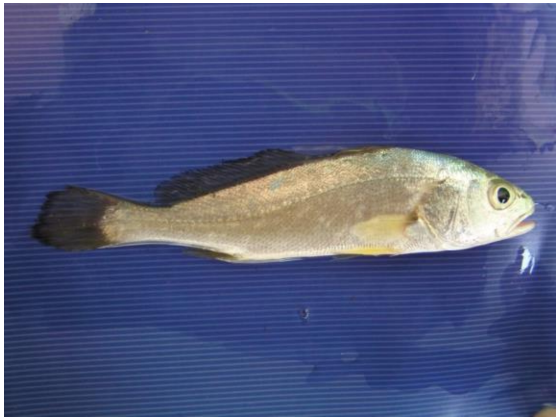
Marine Fish Cage Farm on Nanao Island, Guangdong, China

Marine Fish Cage Farm, Guangdong, China

First Experiment (2002)

Trash fish
(what farmers were using)

Cuneate drum



Lab-made extruded dry feed
Formulated to different protein
to digestible energy levels

Local farmers’ perception

Effects of dietary protein and energy levels on growth, feed utilization and body composition of cuneate drum (*Nibea miichthioides*)

Table 1
Formulation (%), chemical composition (%) and energy content (MJ kg^{-1}) of the test feeds

	Feeds									
	L1	L2	L3	M1	M2	M3	H1	H2	H3	RF
Feed formulations										
Herring meal	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	
Rapeseed meal	9.0	10.0	10.0	11.0	15.0	9.0	15.0	9.5	9.5	
Blood meal	3.5	4.0	5.0	4.5	4.5	7.0	6.5	9.0	9.5	
Soybean meal	8.0	9.0	9.0	11.0	11.0	11.0	10.0	9.0	10.0	Trash fish
Poultry by product meal	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	
Wheat flour	29.5	20.0	11.0	23.5	11.5	9.0	18.5	17.0	8.0	
$CaHPO_4$	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
DL-methionine	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Fish oil	5.0	12.0	20.0	5.0	13.0	19.0	5.0	10.5	18.0	
Vitamin premix[a]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Mineral premix[b]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	

Effects of dietary protein and energy levels on growth, feed utilization and body composition of cuneate drum (*Nibea miichthioides*)

Table 4
Final body weight (g $fish^{-1}$), specific growth rate (% day^{-1}), feed intake (% day^{-1}) and feed conversion ratio of cuneate drum in the experiment (Mean ± S.E., $n = 3$)

Feeds	Final body weight	Specific growth rate	Feed intake	Feed conversion ratio
L1	92.4 ± 3.3^{bc}	2.86 ± 0.06^{bcd}	2.9 ± 0.1^{a}	1.24 ± 0.05^{ac}
L2	99.2 ± 1.5^{ac}	2.99 ± 0.05^{ad}	2.7 ± 0.1^{ab}	1.11 ± 0.03^{bc}
L3	81.1 ± 3.9^{b}	2.60 ± 0.07^{b}	2.8 ± 0.1^{ab}	1.38 ± 0.08^{a}
M1	99.7 ± 2.5^{ac}	2.88 ± 0.05^{cd}	2.9 ± 0.1^{a}	1.25 ± 0.03^{ac}
M2	102.0 ± 4.0^{ac}	2.98 ± 0.01^{ad}	2.8 ± 0.1^{ab}	1.16 ± 0.05^{abc}
M3	89.6 ± 6.4^{bc}	2.69 ± 0.08^{bc}	2.6 ± 0.2^{ab}	1.14 ± 0.09^{abc}
H1	103.7 ± 1.2^{ac}	3.02 ± 0.05^{ad}	2.7 ± 0.0^{ab}	1.13 ± 0.06^{abc}
* H2	115.8 ± 0.6^{a}	3.24 ± 0.02^{a}	2.5 ± 0.0^{b}	0.95 ± 0.02^{b} *
H3	104.9 ± 4.9^{ac}	3.06 ± 0.07^{ad}	2.3 ± 0.0^{b}	0.92 ± 0.01^{b}
RF	111.7 ± 2.9	3.18 ± 0.04	2.7 ± 0.1	1.05 ± 0.03

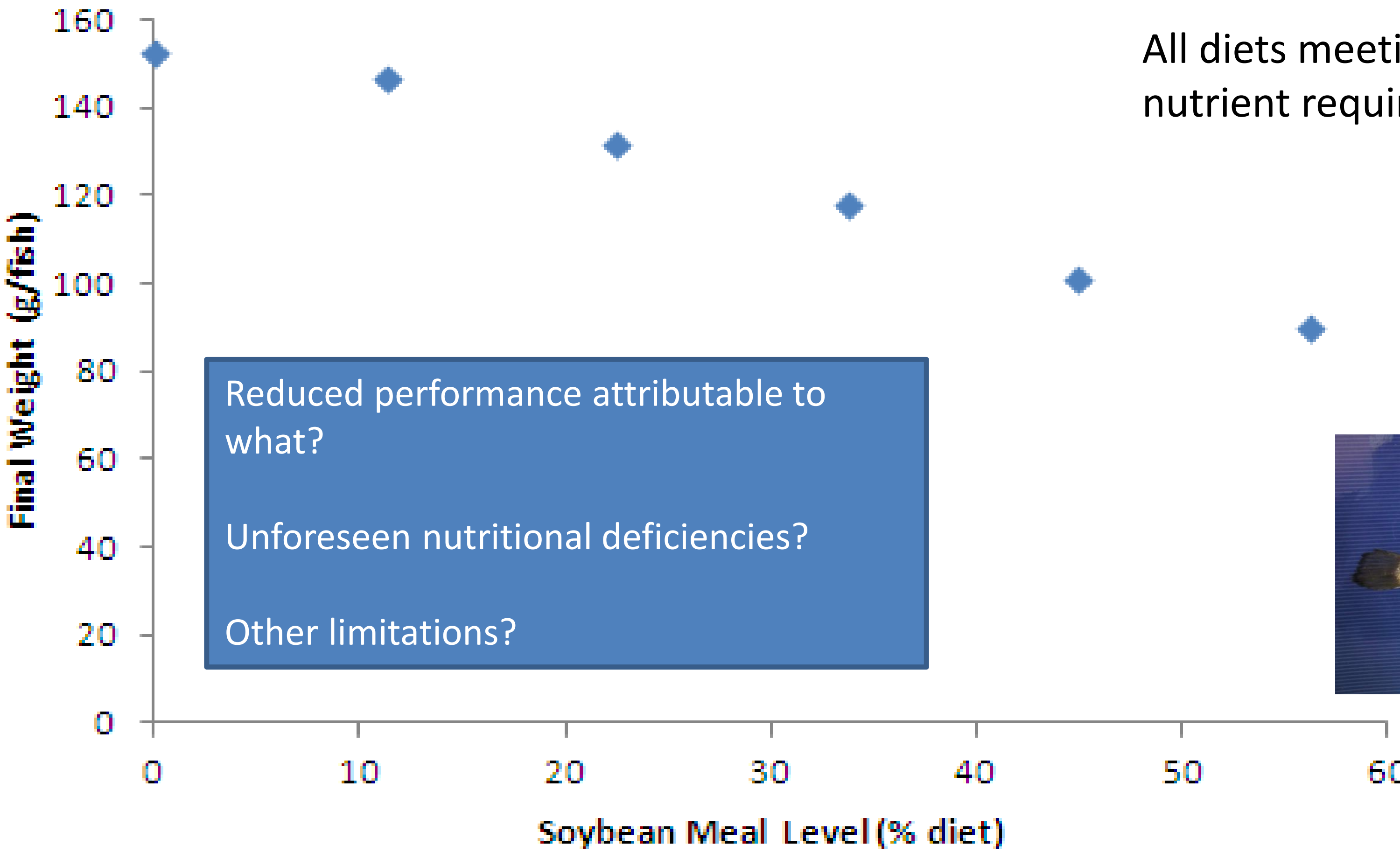
The superscripts present results of Tukey HSD test among fish fed the formulated feeds or Student's *t*-test between fish fed the raw fish (RF) and feed containing 40% DP and 16 MJ kg^{-1} DE (H2). The values within the same column with different superscripts are significantly different at $P < 0.05$.

Take Home Message:
A feed with 45% protein and 15% fat formulated with 30% fish meal, 11% poultry by-products meal, 9% blood meal, 9% rapeseed meal, 9% soybean meal is as good as raw fish (while being more economical, convenient and a lot less polluting)

Effect of replacing fish meal with soybean meal on growth, feed utilization and carcass composition of cuneate drum (*Nibea miichthioides*)

Yan Wang [a,*], Ling-Jun Kong [a], Cui Li [a], Dominique P. Bureau [b]

All diets meeting all known nutrient requirements



Reduced performance attributable to what?

Unforeseen nutritional deficiencies?

Other limitations?

Aquaculture Nutrition

Aquaculture Nutrition **2010 16;** 37–43 doi: 10.1111/j.1365-2095.2008.00638.x

The potential of land animal protein ingredients to replace fish meal in diets for cuneate drum, *Nibea miichthioides*, is affected by dietary protein level

Y. WANG[1,2], L. KONG[2], C. LI[2] & D.P. BUREAU[3]

[1] *College of Animal Sciences, Zhejiang University, Hangzhou, China;* [2] *College of Aqua-Life Science and Technology, Shanghai Fisheries University, Shanghai, China;* [3] *Department of Animal and Poultry Science, University of Guelph, Guelph, ON, Canada*

Aquaculture Nutrition

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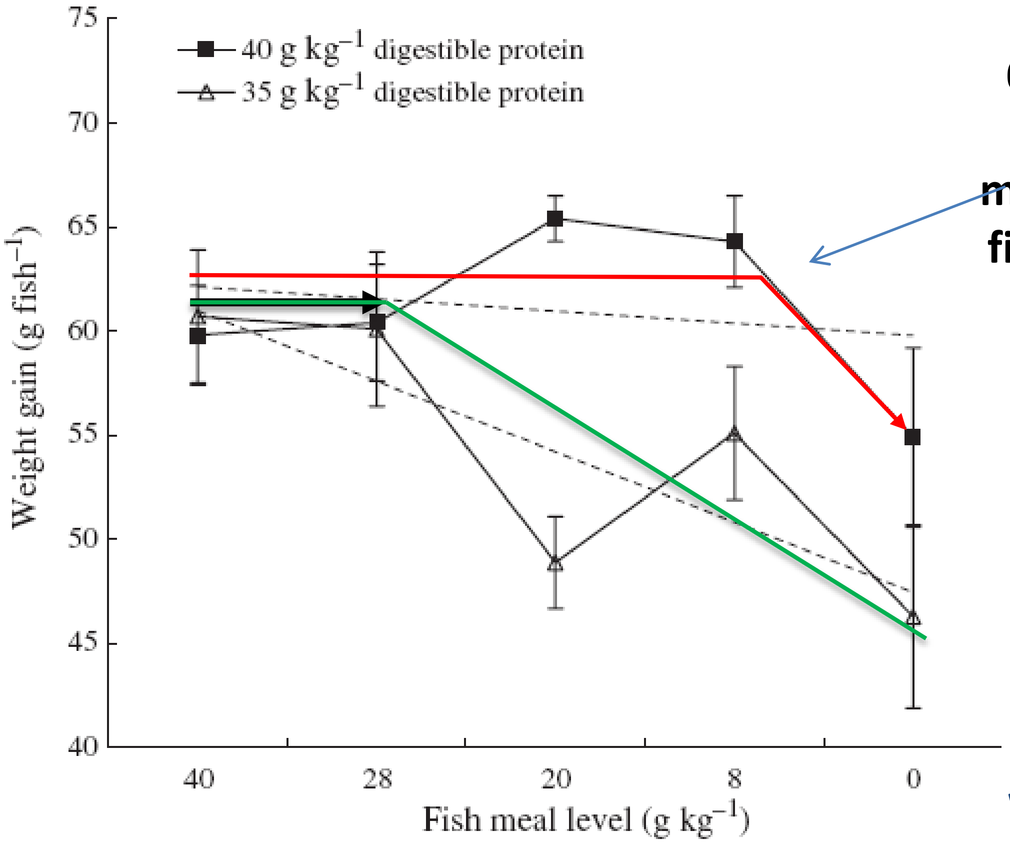
The potential of land animal protein ingredients to replace fish meal in diets for cuneate drum, *Nibea miichthioides*, is affected by dietary protein level

Ingredient	Diets HC	HR1	HR2	HR3	HR4	LC	LR1	LR2	LR3	LR4
Fish meal	400	280	200	80		400	280	200	80	
Protein blend[1]		105	177	282	352		105	177	282	352
Blood meal	74	61	76	72	65	10	8	6	11	15
Soybean meal	200	230	200	216	243	180	200	200	200	200
Rapeseed meal	50	50	50	50	50	50	50	50	50	50
Wheat flour	186	180	212	210	200	240	248	252	257	263
$CaHPO_4$	15	15	15	15	15	15	15	15	15	15
DL-Met	5	5	5	5	5	5	5	5	5	5
Fish oil	50	50	45	50	50	80	69	75	80	80
Vitamin premix	10	10	10	10	10	10	10	10	10	10
Mineral premix	10	10	10	10	10	10	10	10	10	10

[1] Protein blend comprises of 600 g kg^{-1} poultry by product meal, 200 g kg^{-1} meat and bone meal, 100 g kg^{-1} feather meal and 100 g kg^{-1} blood meal.

Effect of replacement of a fish meal by a mixture of processed animal proteins in feeds formulated to two different protein levels



6-8% fish meal is sufficient for a marine carnivorous fish if good quality PAPs are used!

Wang et al. (2010)

At higher protein levels, essential amino acids (EAA) deficiencies occur at lower fish meal (higher alternative ingredient) levels. It is the EAA intakes that matter, not the "fish meal level" or "relative level" of essential amino acids of the diet (as % protein).

Effect of dietary ratio of fish meal to poultry by-product meal on growth, feed utilization and waste output of Japanese sea bass (*Lateolabrax japonicus*)

Fei Wang[a,b], Yan Wang[a*], Wen-Xiu Ji[a], Xu-Zhou Ma[b]

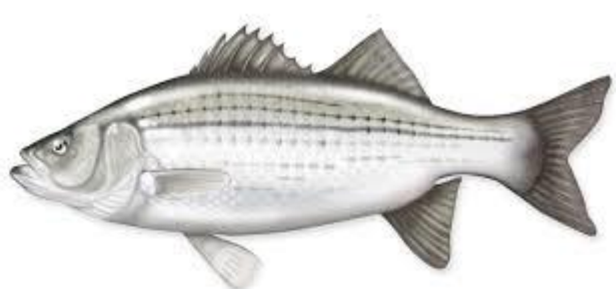


Table 2 Formulation (g kg^{-1}), proximate composition (g kg^{-1}) and energy content (MJ kg^{-1}) of the test diets

Ingredient	C	PM1	PM2	PM3	PM4	PM5
Fish meal	400	320	240	160	80	0
Poultry by-product meal	0	97	194	291	387	482
Rapeseed meal	80	80	80	80	80	80
Soybean meal	200	200	200	200	200	199
Brewer's yeast	30	30	30	30	30	30
Starch, gel.	20	20	20	20	20	20
Wheat flour	165	153	142	132	120	112
$CaHPO_4$	10	10	10	10	10	10
DL-Met	5	7	6	6	8	8
Vitamin premix	10	10	10	10	10	10
Mineral premix	10	10	10	10	10	10
Fish oil	70	63	58	52	46	40

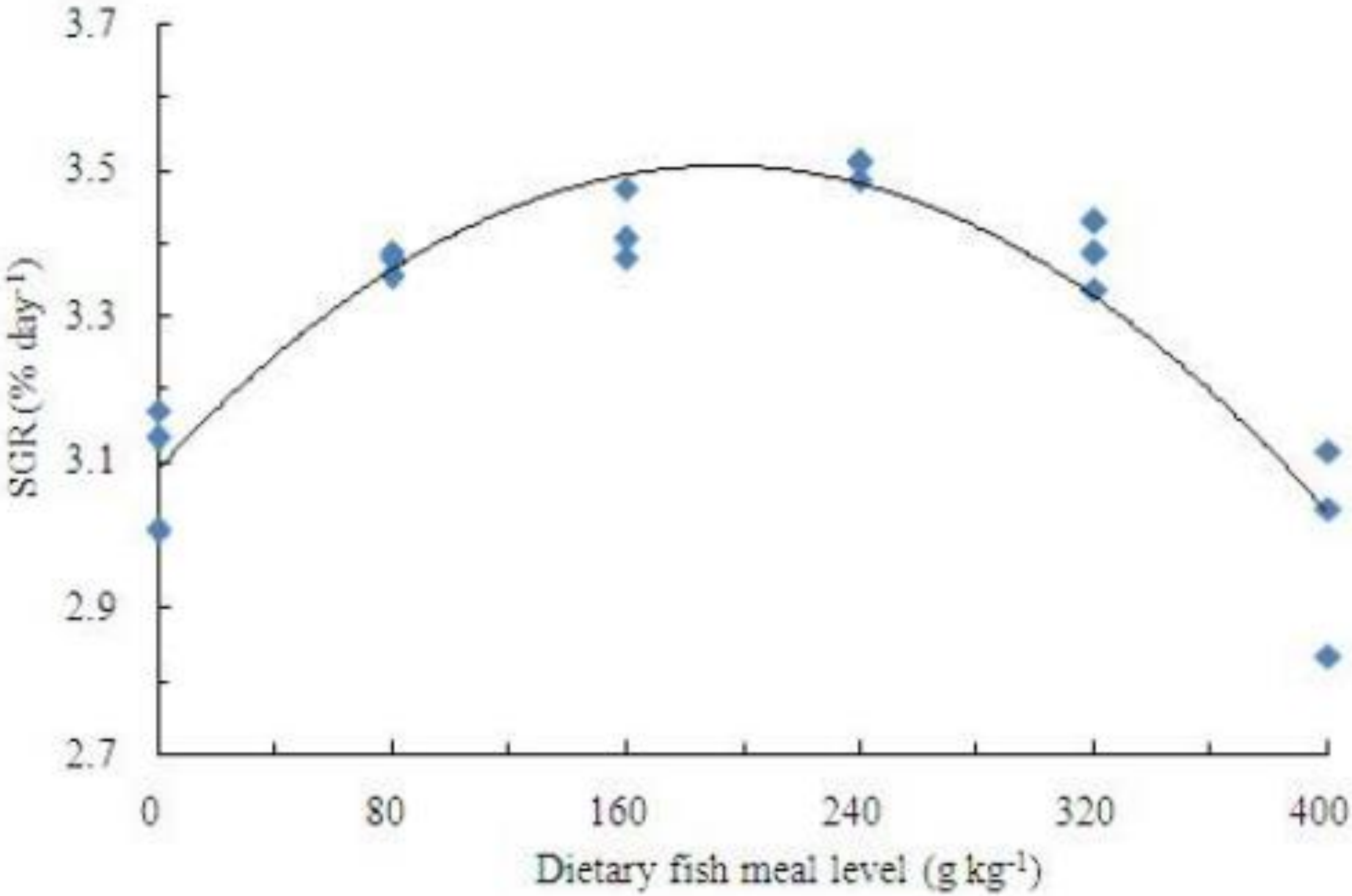
Table 4 Body weight (g $fish^{-1}$), weight gain (g $fish^{-1}$), feed intake (% d^{-1}), feed conversion ratio (feed $gain^{-1}$), nitrogen retention efficiency (%) and energy retention efficiency (%) of Japanese sea bass fed the test diets (Mean ± S.E., n = 3)

	C	PM1	PM2	PM3	PM4	PM5
Final body weight	45.7 ± 1.9^{b}	56.9 ± 0.8^{a}	60.7 ± 0.2^{a}	57.6 ± 1.0^{a}	56.4 ± 0.3^{a}	48.4 ± 1.4^{b}
Weight gain	37.1 ± 1.9^{b}	48.4 ± 0.8^{a}	52.2 ± 0.2^{a}	49.0 ± 1.0^{a}	47.9 ± 0.2^{a}	39.9 ± 1.3^{b}
Feed intake	2.80 ± 0.1^{b}	2.82 ± 0.0^{b}	2.83 ± 0.0^{b}	2.95 ± 0.0^{ab}	2.97 ± 0.0^{ab}	3.07 ± 0.0^{a}
Feed conversion ratio	1.15 ± 0.1^{ab}	1.07 ± 0.0^{b}	1.05 ± 0.0^{b}	1.11 ± 0.0^{ab}	1.13 ± 0.0^{ab}	1.23 ± 0.0^{a}
Nitrogen retention efficiency	31.4 ± 1.4^{ab}	32.4 ± 0.6^{a}	33.2 ± 0.2^{a}	32.6 ± 0.5^{a}	32.1 ± 0.2^{a}	28.7 ± 0.5^{b}
Energy retention efficiency	27.2 ± 0.7^{b}	31.4 ± 0.5^{ab}	33.2 ± 0.8^{a}	32.5 ± 2.1^{a}	32.2 ± 0.4^{a}	29.7 ± 0.9^{ab}

Feed intake and feed conversion ratio are expressed on a dry matter basis.

S.E. < 0.05 is expressed as S.E. = 0.

Values within same row with different superscripts are statistically different at $P < 0.05$.


3.7
3.5
3.3
3.1
2.9
2.7
SGR (% day-1)
0
80
160
240
320
400
Dietary fish meal level (g kg-1)

Take Home Messages from Marine Fish Research in China

Processed animal proteins are very valuable protein ingredients for marine fish

They allow the formulation of cost-effective, less polluting dry feeds

A small amount of fish meal is still required in marine fish feeds

Probably not an issue of palability but rather an issue of nutrient deficiency

Research underway to determine which nutrients are deficient in low fish meal feeds

Finding what's is missing in the feed is a bit like chasing a hidden treasure

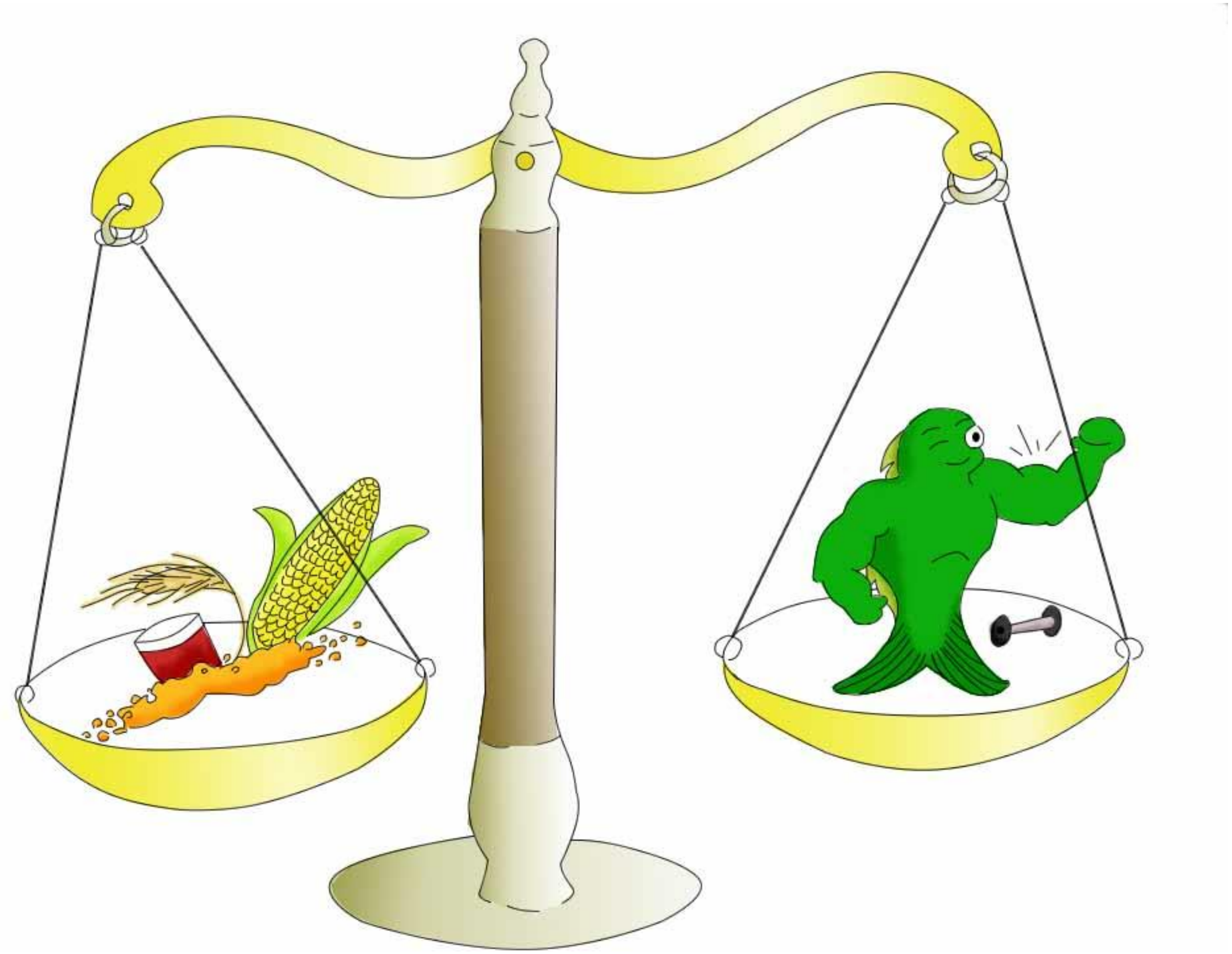
Blood parameters
Hormones
Enzyme activity
Protein leves
Gene expression
Cell assays

Mechanistic studies (i.e. digging deeper) are nice but not always essential for answering practical questions

What Does Fish Meal Bring That Plant Feed Ingredients Don't?

Components/Parameters	Fish meal	Plant Proteins
Essential amino acid profile	Excellent	Excellent/Poor
Digestible amino acids	Excellent/Good	Excellent/Good
LC n-3 HUFA (EPA+DHA)	**Excellent**	**None**
LC n-6 HUFA (ARA)	**Good/Moderate**	**None**
Available phosphorus	Excellent	Moderate/Poor
Digestible energy	Good	Good/Moderate
Micro-minerals	***Excellent***	***Variable/Poor***
Phospholipids	***Excellent***	***Moderate/Poor***
Cholesterol	***Excellent***	***None***
Hormones/ Bio-active compounds	***Moderate/Low***	***Low/Moderate***
Taurine	***Excellent***	***None***
Nucleotides	***Excellent***	***Moderate/None***
Soluble fibers / Oligosaccharides	*Absent*	*Moderate/High*
Insoluble fibers (cellulose, lignin)	*Absent*	*Moderate/High*
Misc. anti-nutritional factors	***Low/absent***	***Moderate/High***
Contaminants	Moderate	Low/Moderate
Phytates	*None*	*High/Moderate*
Attractants	***High***	***Low/Moderate***

Animal Nutrition = Balanced Understanding of Nutritional Requirements and Ingredient Quality



Acknowledgements

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- Fats and Proteins Research Foundation (FPRF)
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- Ontario Ministry of Agriculture, Food and Rural Affairs
- Ontario Ministry of Natural Resources
- NSERC
- EVONIK Degussa
- Martin Mills

Additional Slides

Models to Estimate Digestibility of Phosphorus in Feeds for Different Species

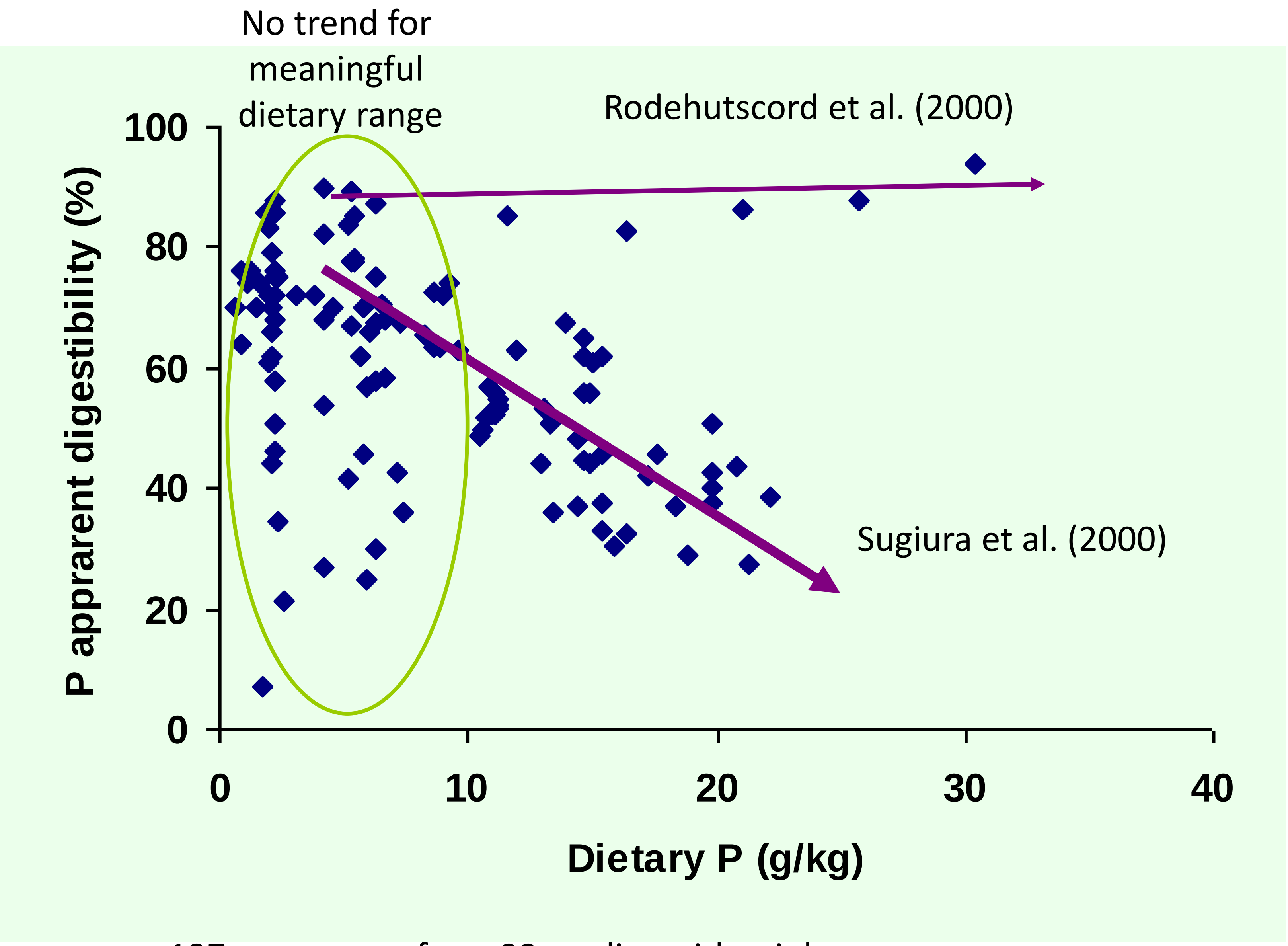
(Hua and Bureau 2006; 2010)

Estimates of Apparent Digestibility Coefficient (ADC) of P in Salmonids feed Ingredients

Ingredient	ADC (%)
Fish meal	17 - 81
Meat and bone meal	22 - 67
Poultry by-products meal	38 - 66
Feather meal	68 - 82
Blood meal	70 - 104
Soybean meal	27 - 46
Corn gluten meal	<10
NaH_2PO_4	95 - 98
$Ca(H_2PO_4)_2$	90 - 94
$CaHPO_4$	54 - 77
$Ca_{10}(OH)_2(PO4)_6$ or $Ca_3(PO_4)_2$	37 - 64

Summarized from various sources in literature

Dietary Phosphorus Digestibility

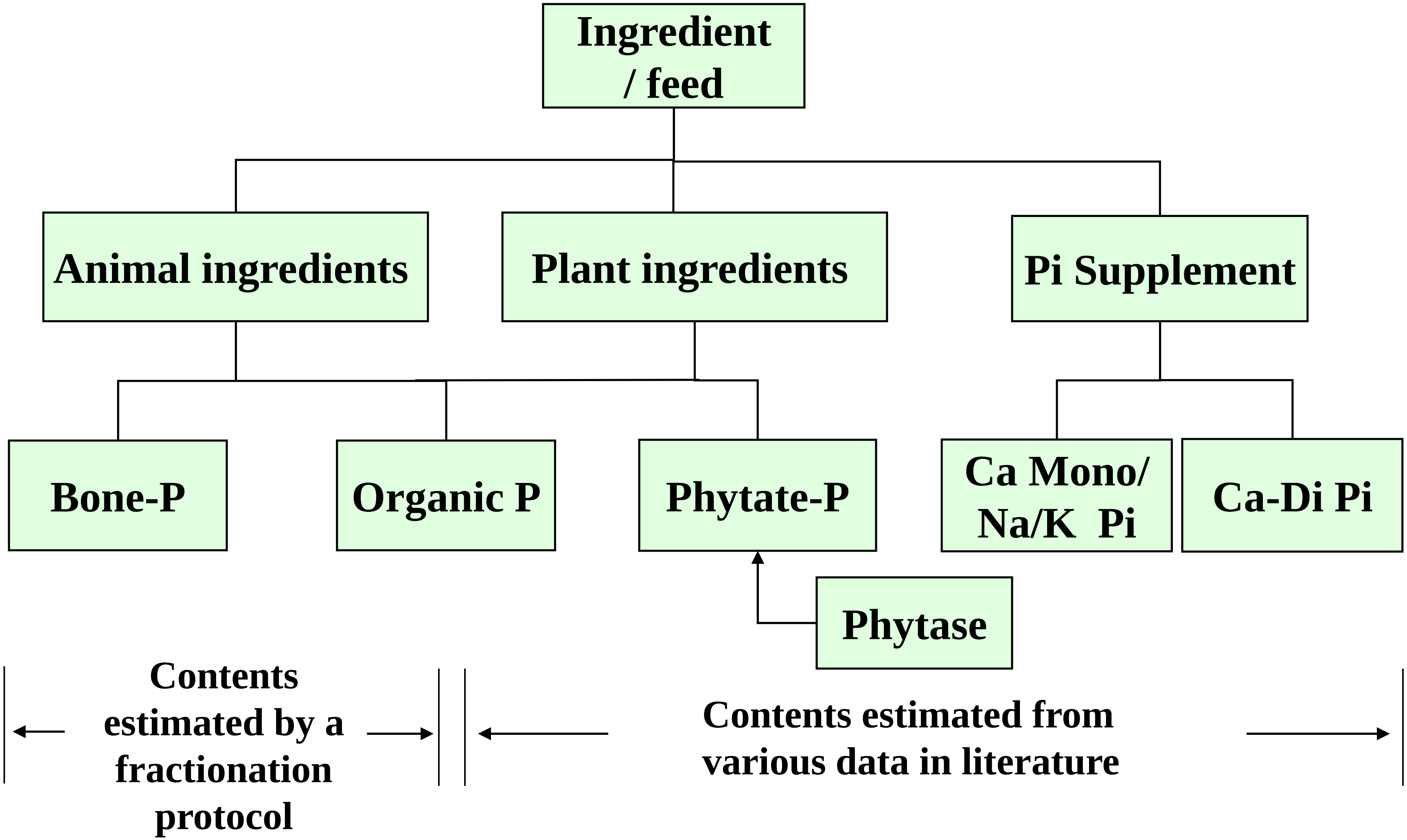


137 treatments from 22 studies with rainbow trout

P Forms Present In Feed

- Inorganic P
  - Bone P : hydroxyapatite $Ca_{10}(OH)_2(PO_4)_6$
  - Inorganic supplement:
    - Monobasic: NaH_2PO_4 , $Ca(H_2PO_4)_2$
    - Dibasic: $CaHPO_4$
- Organic P
  - Phospholipid
  - Phosphoprotein
  - Phosphosugar
  - Nucleic acid
  - Phytate: primary P form in plant ingredients

Classification and Content of P Compounds

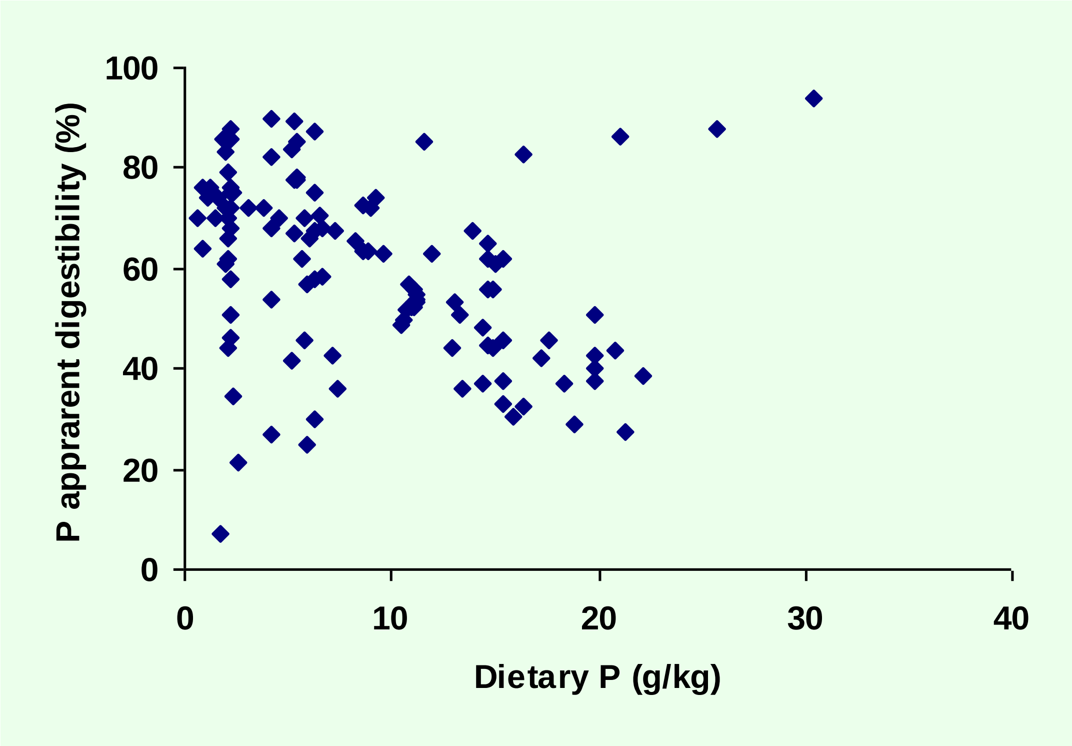


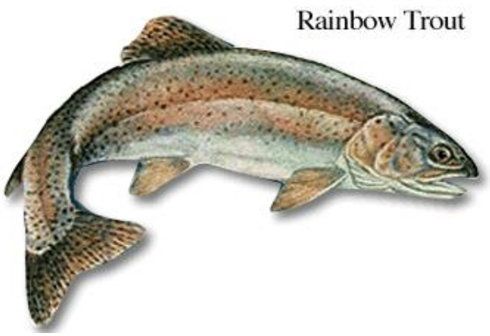
P Digestibility Model

- Dataset: 137 treatments from 22 studies with rainbow trout
- Multiple Regression Approach

Digestible P content

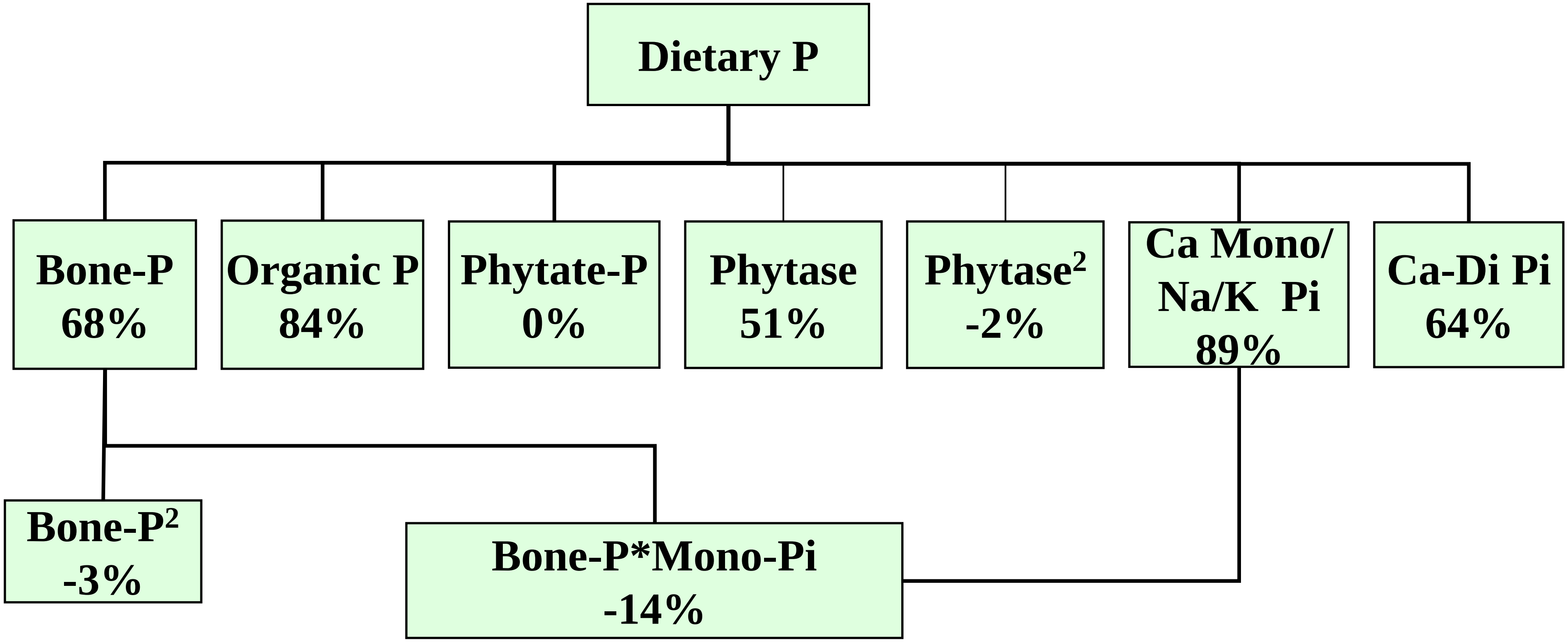
= Σ digestibility of P compounds * inclusion level of P compounds





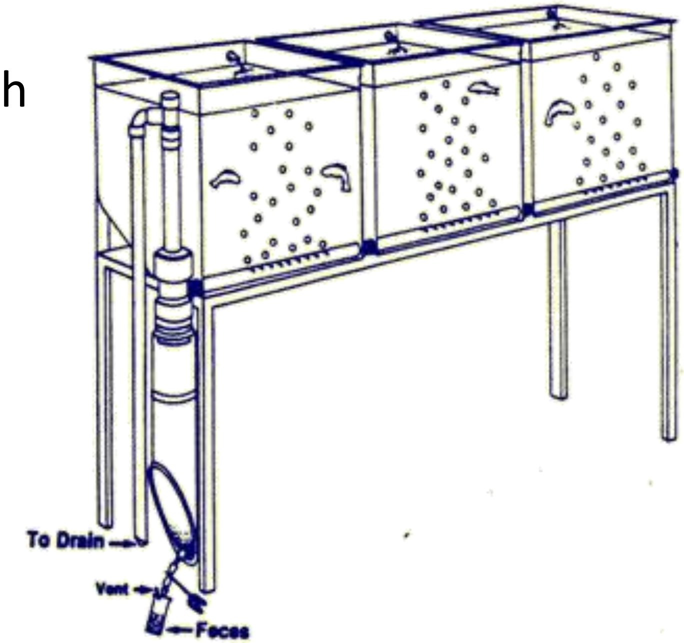
Hua and Bureau (2006)

Results: Parameter Estimates From Multiple Regression



Experimental Validation by Digestibility Trial

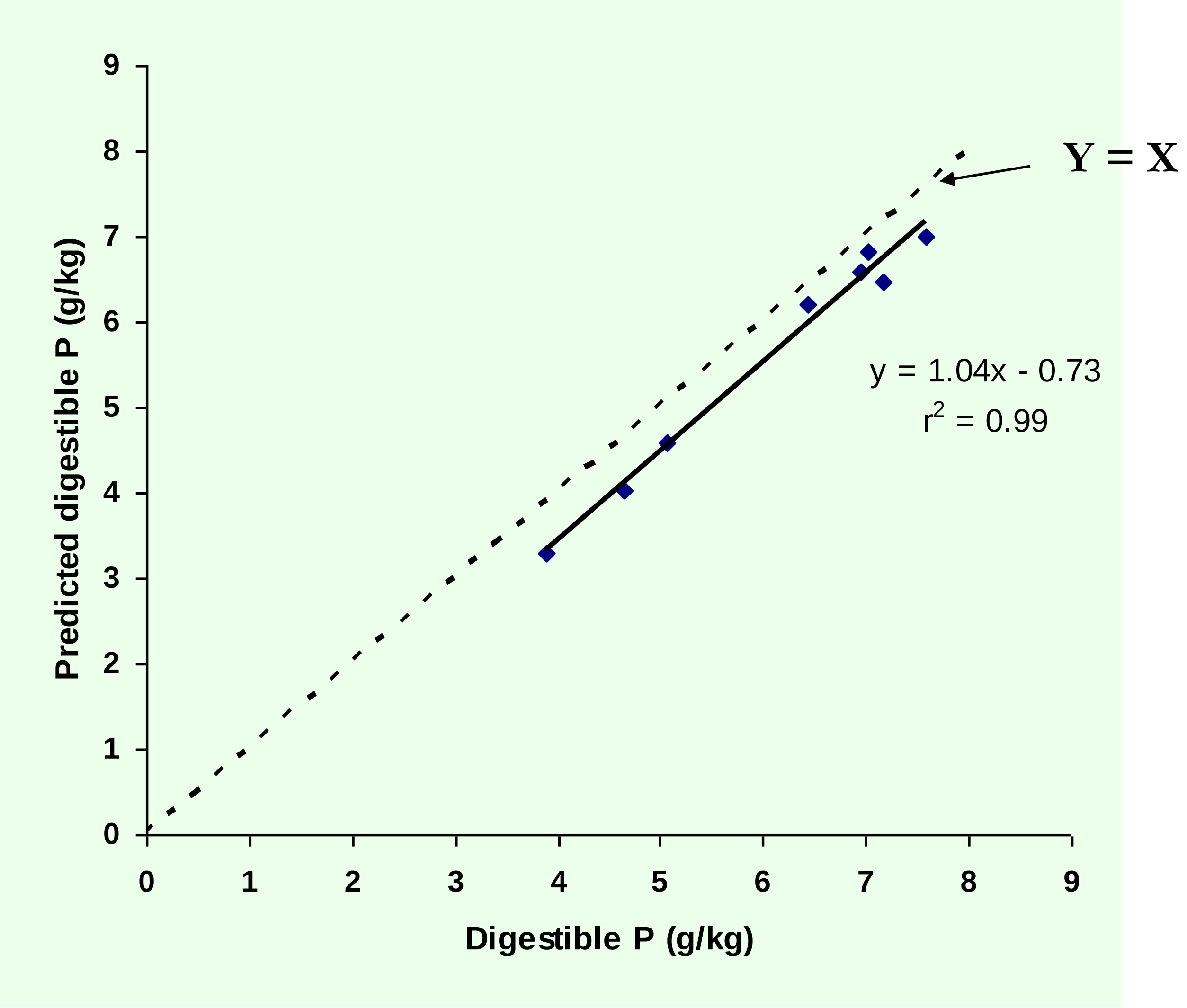
- Digestibility trial conducted with the Guelph system using the protocol of Cho et al. (1982)
- Reference diet:
  - Fish meal/corn gluten meal-based diet
- Test diets:
  - 2 fish meals (high vs. low ash)
  - 1 meat and bone meal
  - 2 poultry by-products meals (high vs. low ash)
  - 2 soy protein concentrates (regular vs. dephytinized)



Hua and Bureau (2006)

ENRL

Results of Experimental Validation



Top fed aquaculture & livestock producers – 2009

(FAO – FISHSTAT/FAOSTAT, 2011)

Values in million tonnes - Mt

Top fed aquaculture species

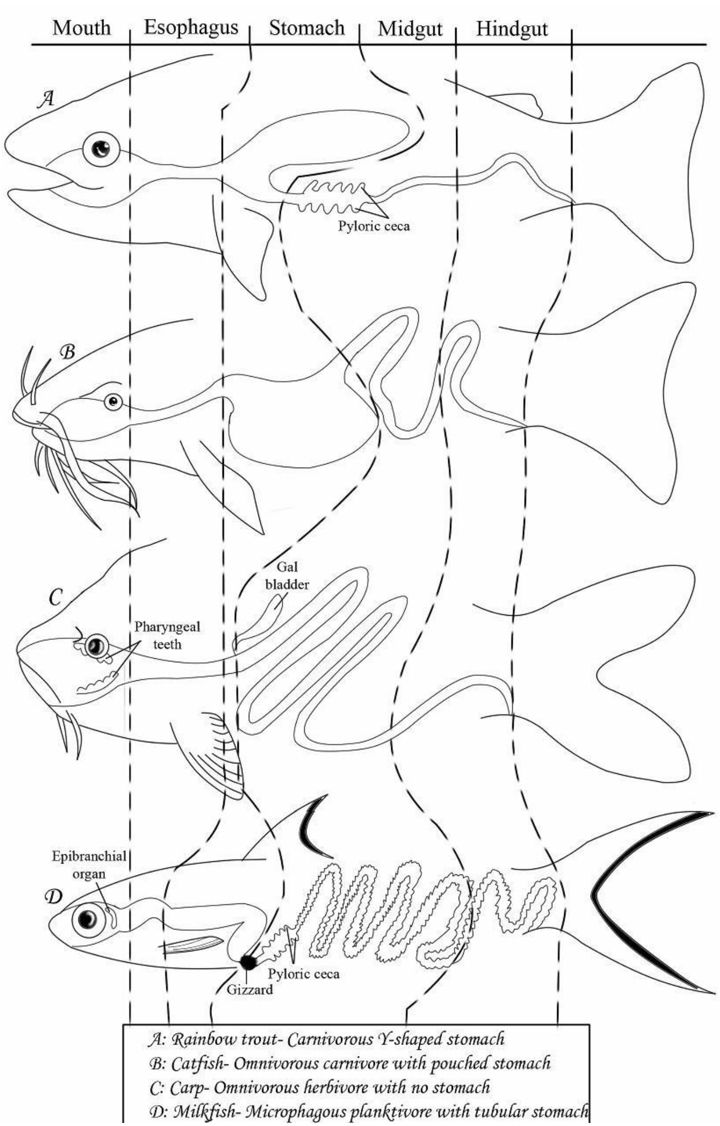
Grass carp	4.16 Mt
Common carp	3.22
Nile tilapia	2.54
Catla	2.42
Whiteleg shrimp	2.32
Crucian carp	2.06
Atlantic salmon	1.44
Roho labeo	1.22
Pangasius catfish	1.19
∑ 66% of total fed species production	
Total fed species production : 31.4 Mt	
APR 8.5% since 1980	

Top fed livestock species

Pig	106.3 Mt
Chicken	80.3
Cattle	62.8
Sheep	8.2
Turkey	5.3
Goat	5.0
Duck	3.8
Buffalo	3.3
∑ 97%	
Total meat production - 284 Mt	
APR 2.55% since 1980	

Slide courtesy of Dr. A.J. Tacon

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?

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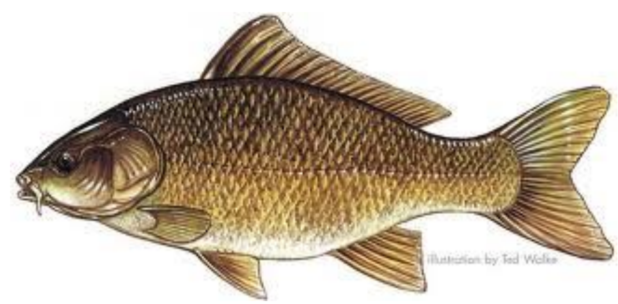
Quantification of differences in digestibility of phosphorus among cyprinids, cichlids, and salmonids through a mathematical modelling approach

K. Hua *, D.P. Bureau

UG/OMNR Fish Nutrition Research Laboratory, Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1



Phosphorus Digestibility Data for Tilapia

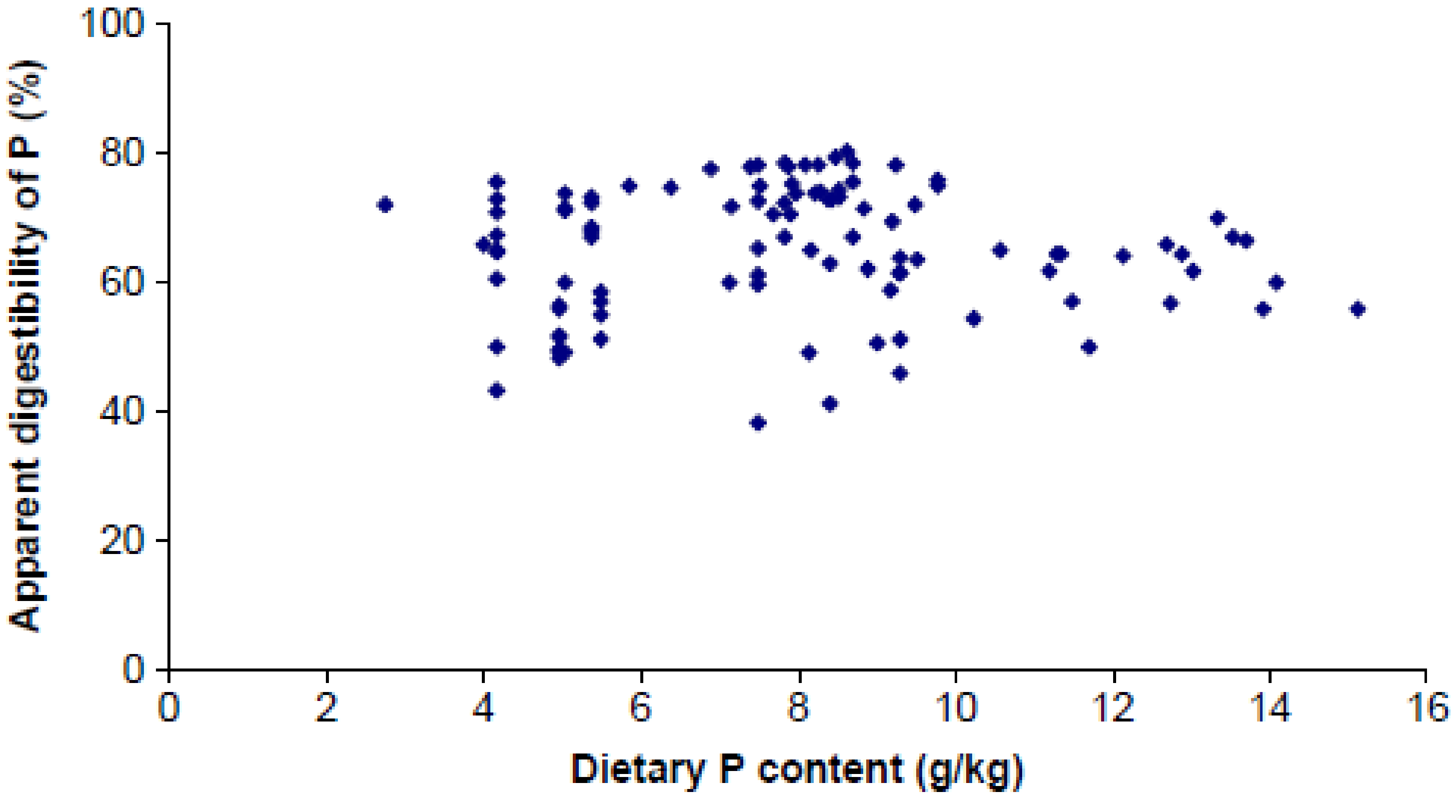


Fig. 1. Modelling data set for tilapia consisted of data from 16 studies. (Data from Kaushik et al. (1995), Furuya et al. (2001a,b,c, 2006), Portz and Liebert, 2004; Schneider et al. (2004), Bock et al. (2006), Phromkunthong and Gabaudan (2006), de Castro Silva et al. (2007), Leenhouwers et al. (2007), Liebert and Portz (2007), Agbo (2008), Madalla (2008), Phromkunthong and Udom (2008), Tudkaew et al. (2008)).

Phosphorus Digestibility Data for Carp

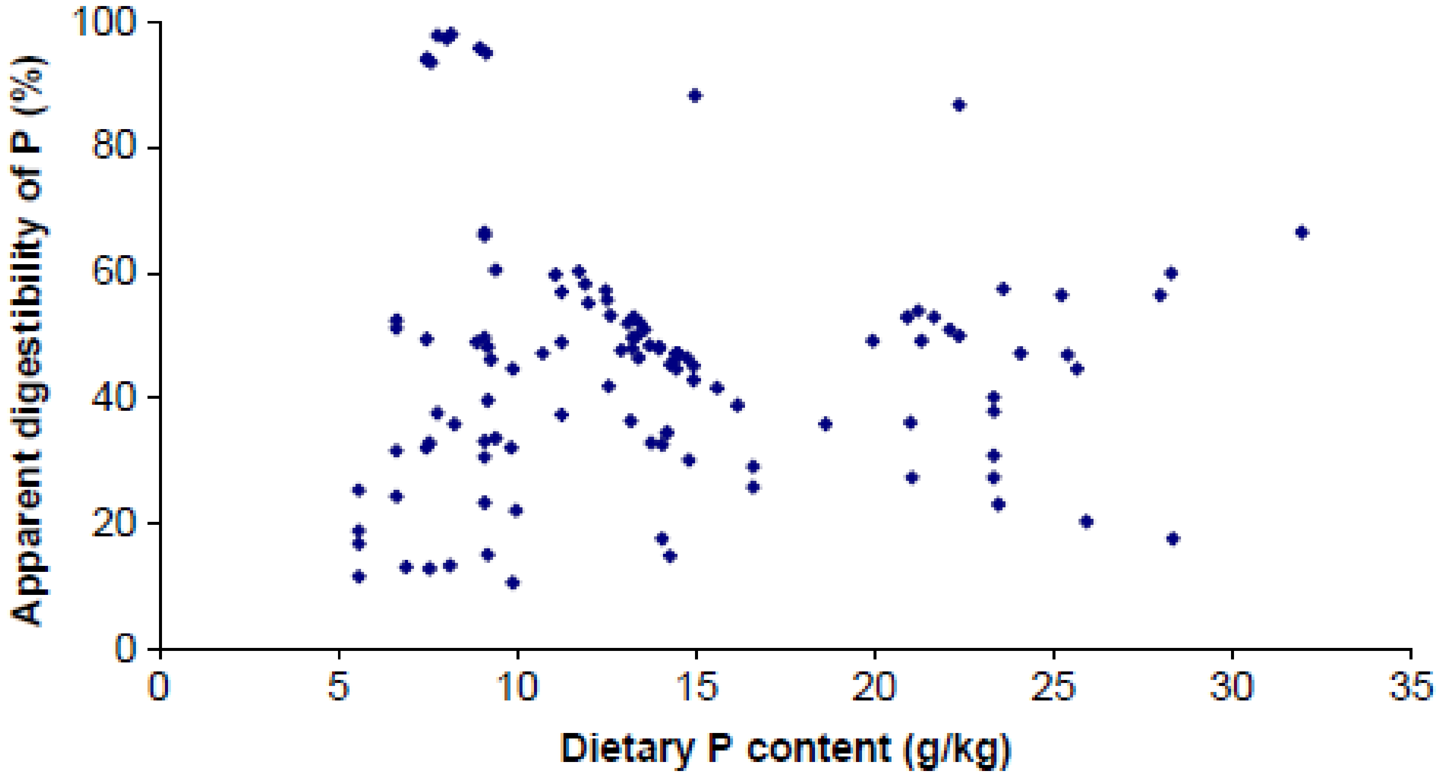
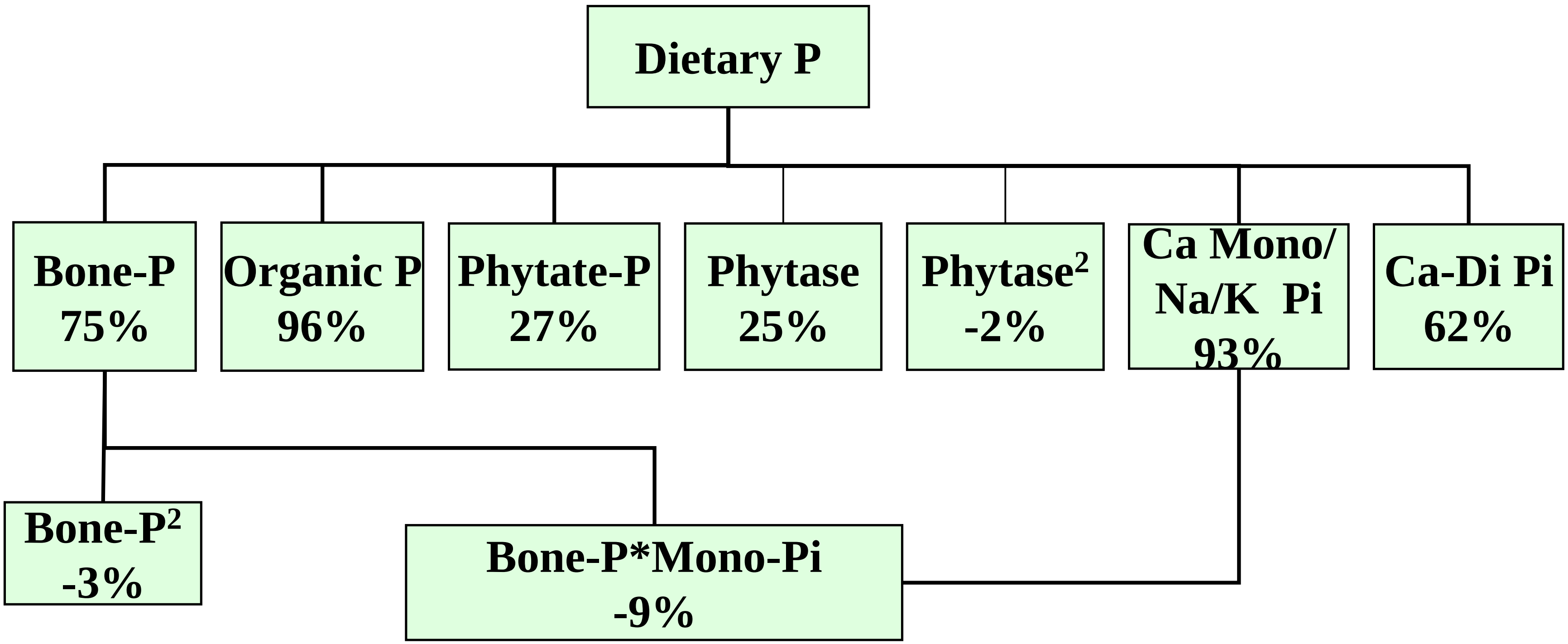


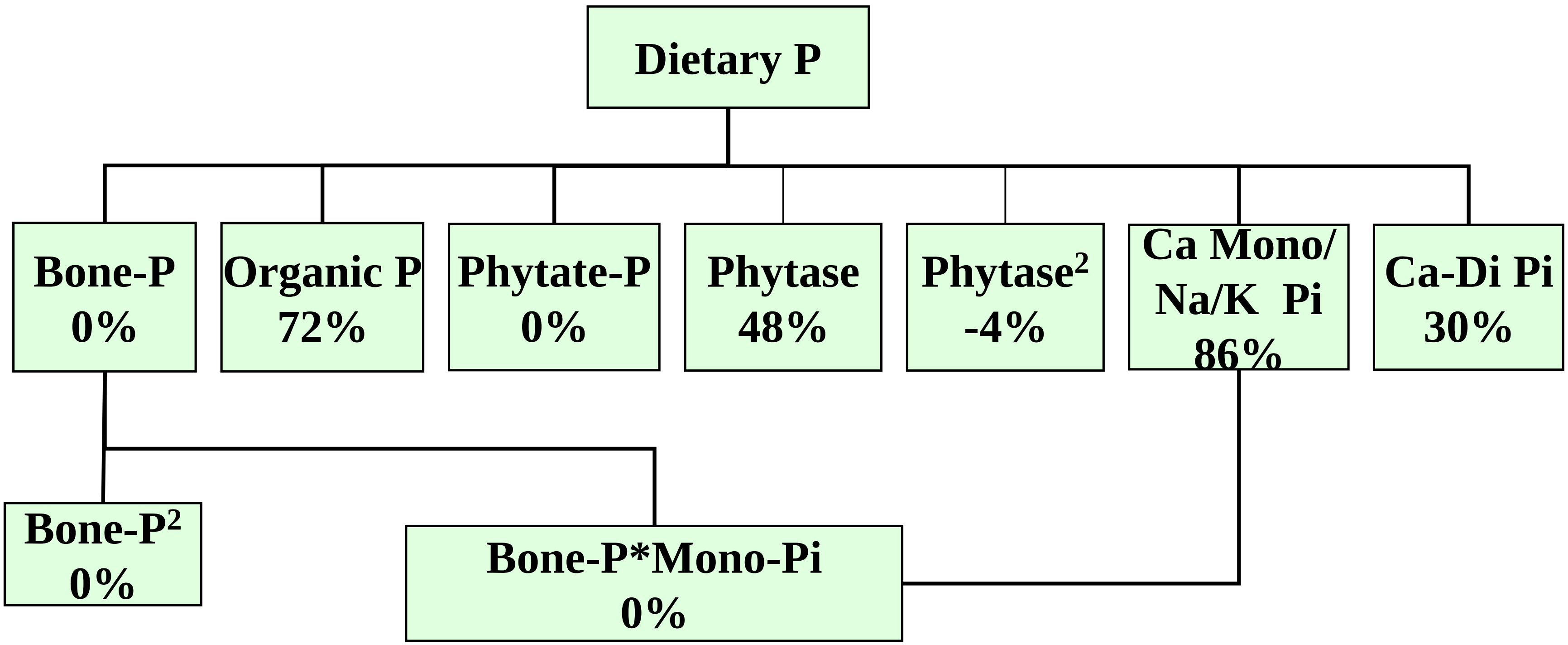
Fig. 2. Modelling data set for carp consisted of data from 22 studies. (Data from Ogino et al. (1979), Watanabe et al. (1987), Takeuchi et al. (1989), Schäfer et al. (1995), Kim et al. (1995, 1998), Satoh et al. (1997), Jahan et al. (2000, 2001, 2002a,b, 2003a,b), Yu and Wang (2000), Cai et al. (2005), Yang et al. (2005, 2006); Zhang et al. (2006), Yamamoto et al. (2007), Nwanna et al. (2007), Nwanna and Schwarz (2007, 2008)).

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



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

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Aquaculture 275 (2008) 260–265
Aquaculture
www.elsevier.com/locate/aqua-online

Replacement of fish meal by rendered animal protein ingredients with lysine and methionine supplementation to practical diets for gibel carp, *Carassius auratus gibelio*

Menghong Hu [a], Youji Wang [a], Qian Wang [a], Min Zhao [b], Bangxi Xiong [a,*], Xueqiao Qian [b], Yujiang Zhao [a], Zhi Luo [a]

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8
Fish meal	18.00	12.00	6.00	0.00	6.00	6.00	0.00	0.00
Poultry by-product meal	0.00	6.00	12.00	18.00	9.00	7.00	12.00	10.00
Meat and bone meal	0.00	0.00	0.00	0.00	4.50	7.00	6.00	10.00
Soybean meal	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
Rapeseed meal	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Cottonseed meal	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Wheat flour	25.08	25.13	25.14	25.28	23.23	22.72	25.09	23.18
Soybean oil	4.00	3.73	3.50	3.17	3.65	3.44	3.20	3.20
Choline chloride [a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
$Ca(H_2PO_4)_2$	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Sodium chloride	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin mix [b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Mineral mix [c]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine·H_2SO_4 [d]	0.00	0.17	0.34	0.49	0.52	0.69	0.62	0.50
MHA-Ca [e]	0.00	0.05	0.10	0.14	0.18	0.23	0.17	0.20
Antioxidant [f]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mildew inhibitor [g]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Binder (sodium alginate)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Chemical composition								
Dry matter	95.39	95.51	95.82	95.45	95.63	95.98	95.28	95.28
Crude protein	37.16	37.21	37.38	37.46	37.11	37.50	37.97	37.79
Crude lipid	7.06	7.10	6.81	6.99	6.89	6.93	7.20	7.31
Ash	9.58	9.29	10.04	8.63	10.04	10.94	9.49	10.75
Crude fiber	5.37	5.42	6.07	5.85	6.07	5.91	6.52	6.31

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

Reference Diet	%
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%)

Apparent digestibility coefficients of nutrients and energy of some ingredients – South America (2013)

	Apparent Digestibility Coefficient (%)				
Ingredient	DM	CP	Lipid	GE	P
Poultry meal	70 ±4	79 ±3	90 ±7	77 ±2	29 ±23
Turkey meal	76 ±5	84 ±2	92 ±3	85 ±4	26 ±14
Feather meal	71 ±2	69 ±5	75 ±13	67 ±2	74 ±24
Porcine meal	75 ±6	85 ±1	90 ±8	82 ±5	30 ±6
Canola meal	74 ±4	87 ±3	93 ±3	76 ±3	46 ±8
Sunflower meal	61 ±5	95 ±3	-	64 ±4	35 ±6
Corn protein concentrate	74 ±3	77 ±5	70 ±14	69 ±1	61 ±5

Performance of rainbow trout fed test diets during a digestibility trial

		Parameter			
Period	Treatment	IBW (g)	FBW (g)	TGC (%)	FE (gain:feed)
1	Diet 1- Reference	76.5	145.6	0.340	1.40
	Diet 2- Poultry meal	81.6	158.6	0.360	1.40
	Diet 3- Turkey meal	68.4	127.6	0.316	1.45
	Diet 4- Feather meal	74.1	142.4	0.342	1.39
	Diet 5- Porcine meal	77.9	153.9	0.360	1.51
	Diet 6- Canola meal	73.5	139.9	0.340	1.32
	Diet 7- Sunflower meal	74.5	139.3	0.330	1.25
	Diet 8- Corn protein conc.	76.1	145.9	0.340	1.49
2	Diet 1- Reference	157.6	213.9	0.341	1.27
	Diet 2- Poultry meal	130.5	178.9	0.331	1.23
	Diet 3- Turkey meal	141.2	192.3	0.333	1.22
	Diet 4- Feather meal	154.4	206.8	0.323	1.22
	Diet 5- Porcine meal	138.8	185.1	0.306	1.22
	Diet 6- Canola meal	145.4	200.7	0.352	1.17
	Diet 7- Sunflower meal	146.2	197.5	0.326	1.17
	Diet 8- Corn protein conc.	149.7	190.1	0.259	1.09

Historical Note (circa 1995)

1970-95 : Review of literature and discussions with aquaculture feed industry personnel and researchers indicate general lack of trust in nutritive value of animal proteins for fish

Why?

Digestibility values of certain animal products reported in the reference literature (up to 1993) were very low, making these ingredients uninteresting to use.

USA National Research Council (1993):

Apparent digestibility coefficient (ADC) of protein

Feather meal	58%
Poultry meal	68%

Data from
Cho & Slinger (1979)
(U of Guelph)

Are these old Guelph reference values realistic?

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Take Home Messages

Aquaculture is a real industry. Widely diverse and dynamic.

Aquaculture feeds represent a dynamic & growing segment of global animal feed market

Processed animal proteins are widely used (outside Europe) in commercial fish and shrimp feeds

Nutritional requirements of commercially important species are relatively well established (some work to be done)

Processed Animal Proteins Sourced from Different Rendering Plants

Table 1
Manufacturing characteristics of the rendered animal protein ingredients used in the digestibility trial #1 and #2 (as provided by the manufacturers)

Feather meal	Raw material	Hydrolysis[a]	Drying	Size
Feather meal 1	chicken and turkey feathers, hog hair	30 min, 276 kPa	disc dryer (1 h)	2.38 mm
Feather meal 2	chicken, turkey and duck feathers	5 min, 448 kPa	disc dryer (1 h, 93°C)	2.00 mm
Feather meal 3	chicken and turkey feathers, hog hair	40 min, 276 kPa	ring dryer	–
Feather meal 4	chicken and turkey feathers, hog hair	40 min, 276 kPa	indirect steam (steam-tube dryer)	–

Meat and bone meal	Raw material	Cooking[a]	System
Meat and bone meal 1	30% pork offal, 30% beef offal, 20% shop fats and bones, 10% poultry, 10% other material	125–130°C, 20–30 min, 17–34 kPa	Carver–Greenfield falling film evaporator (Stord slurry)
Meat and bone meal 2	Same as meat and bone meal 1	Same as meat and bone meal 1	Same as meat and bone meal 1 but air classification of final product to reduce ash content (performed on experimental scale)
Meat and bone meal 3	pork, beef, other (1%)	133°C, 30–40 min 54 kPa (final stage)	Dupps falling fill evaporator (Dupps slurry)
Meat and bone meal 4	beef (80%), pork (20%)	128°C, 20–30 min 17–34 kPa	Carver–Greenfield falling film evaporator (Stord slurry)
Meat and bone meal 5	pork, poultry, beef	132–138°C, 60 min	Stord continuous system
Meat and bone meal 6	pork, poultry, beef	127–132°C, 25 min vacuum during first stage	Carver–Greenfield falling film evaporator (Stord slurry)

Poultry by-product meal	Raw material	Cooking[a]	System
Poultry by-product meal 1	70% offal, 30% feet, legs and meat	138°C, 30 min	Dupps 260J Equacooker
Poultry by-product meal 2	88% chicken, 10% turkey, 2% duck and game birds	132°C, 30–40 min 54 kPa (final stage)	Dupps falling film evaporator (Dupps slurry)

Blood meal	Raw material	Coagulation	Drying
Blood meal 1	Whole blood	Steam injection coagulation (2 stages) — decanter	Rotoplate, 93°C
Blood meal 2	Whole blood	Steam injection coagulation — decanter	Ring dryer

[a]Normal atmospheric pressure = 101.3 kPa. Pressures of 17, 34, 54 kPa are the equivalent of vacuums of 25, 20 and 14 in. mercury, respectively. Pressures of 276 and 448 kPa are the equivalent of 40 and 65 psi, respectively.

Blood Meal

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

Bureau et al. (1999)

Different drying equipments can greatly affect apparent digestibility

Exploring the value of a *in vitro* pH-stat digestibility assay

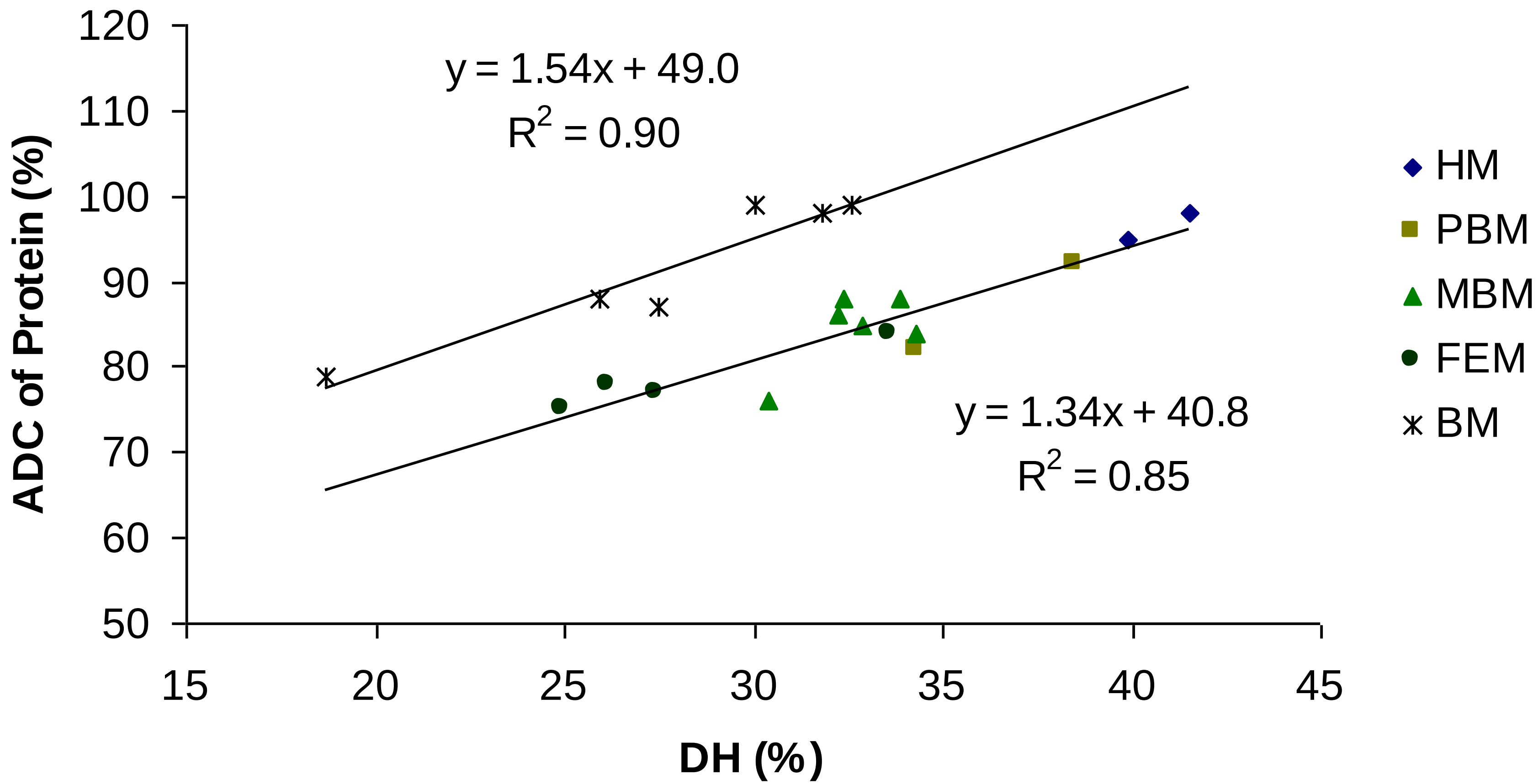
Collaboration with Dr. Adel El Mowafi, Shur-Gain AgResearch

Automated Titrator

TitraLab 854 pH-Stat Titration Workstation

http://www.labsearch.ie/prod_pages/radiometer/TitraLab/ti_index.html#article1

Relationship between degree of hydrolysis (DH) with pH-Stat assay and digestibility of protein (ADC of protein) of animal proteins.



Legends: HM= herring meal, PBM= poultry by-products meal, MBM = meat and bone meal, FEM=feather meal, BM = blood meal

El Mowafi et al.

State-of-The-Art and Limitations

Assessment of nutritional value of processed animal proteins has so far focused on apparent digestibility of proximate components (dry matter, crude protein, gross energy) and very seldom on that of specific nutrients (e.g. as essential amino acids).

Lots of research. However, in most feeding trials, the control diet is formulated with high fish meal levels (> 30%) and all essential nutrients are supplied greatly in excess of requirements. The test ingredient is included at graded levels and effect on growth performance is monitored. *The "absence of effect" of the test ingredient is the "standard".* Yet, the "absence of effect" is highly *dependent on the composition of the diet used.*

Need to refine methodological approaches to focus on meaningfully assessing the available nutrients composition of ingredients.

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Slope Ratio Assay

- Response of parameter of interest, e.g. protein gain, to graded levels of test ingredient is compared to that of graded levels of standard source of nutrient of interest (e.g. synthetic amino acid)

- Indicates the net effect of all components that can affect bioavailability (digestion, absorption and utilization).

UG/OMNR Fish Nutrition Research Laboratory

Processing of the ingredient and not species is the main determinant of the digestibility of Processed Animal Proteins (PAPs) to aquaculture species