Principles of Feed Formulation

The Case for Using Nutrient vs. Ingredient Specifications for Optimal Feed Formulations

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USSEC IAFFD Feed Formulation Workshop Day 1

Most Aquaculture Feed Manufacturers:

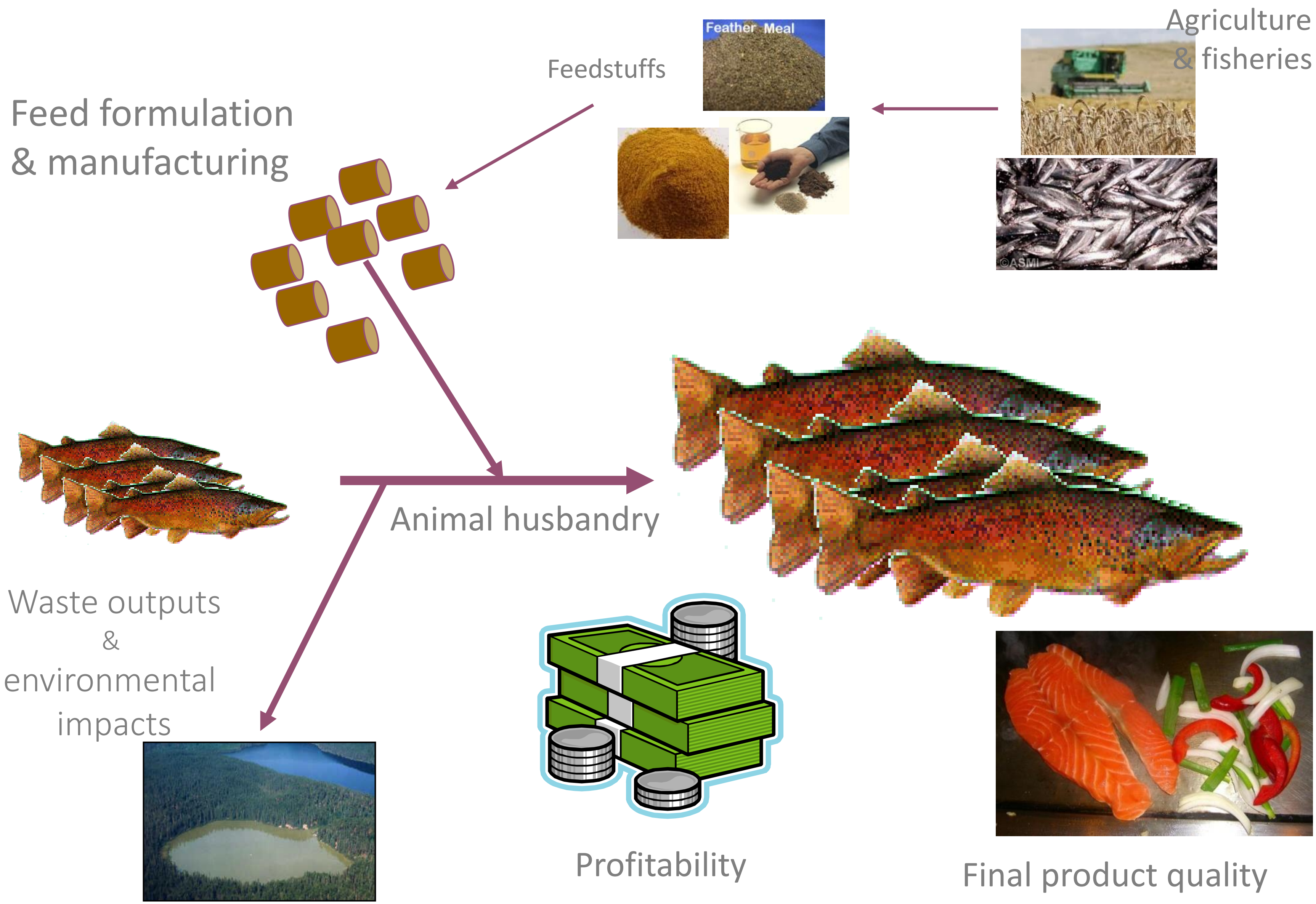
Have to produce feeds:

- for a wide variety of aquatic species and life stages
- with different specs for different market needs (eg. different feed grades)
- while controlling production costs (i.e. have very low profit margins)
- that minimize risks for the corporation and its clients
- for clients with different challenges (diseases, limited tech resources)
- with costly, variable and "imperfect" ingredients
- with limited resources: budget, personnel and time

and Need to:

- rely on published studies for generic information (e.g. nutrient specs.)
- rely on results from trials provided out by different stakeholders (e.g. feed additive suppliers) for value/usefulness of commercial products

Looking at the Issue from a Broad Perspective



Adequately and Cost-Effectively Meeting Requirements

Key Strategies:

1- Determining nutrient requirements/specifications across life stages

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

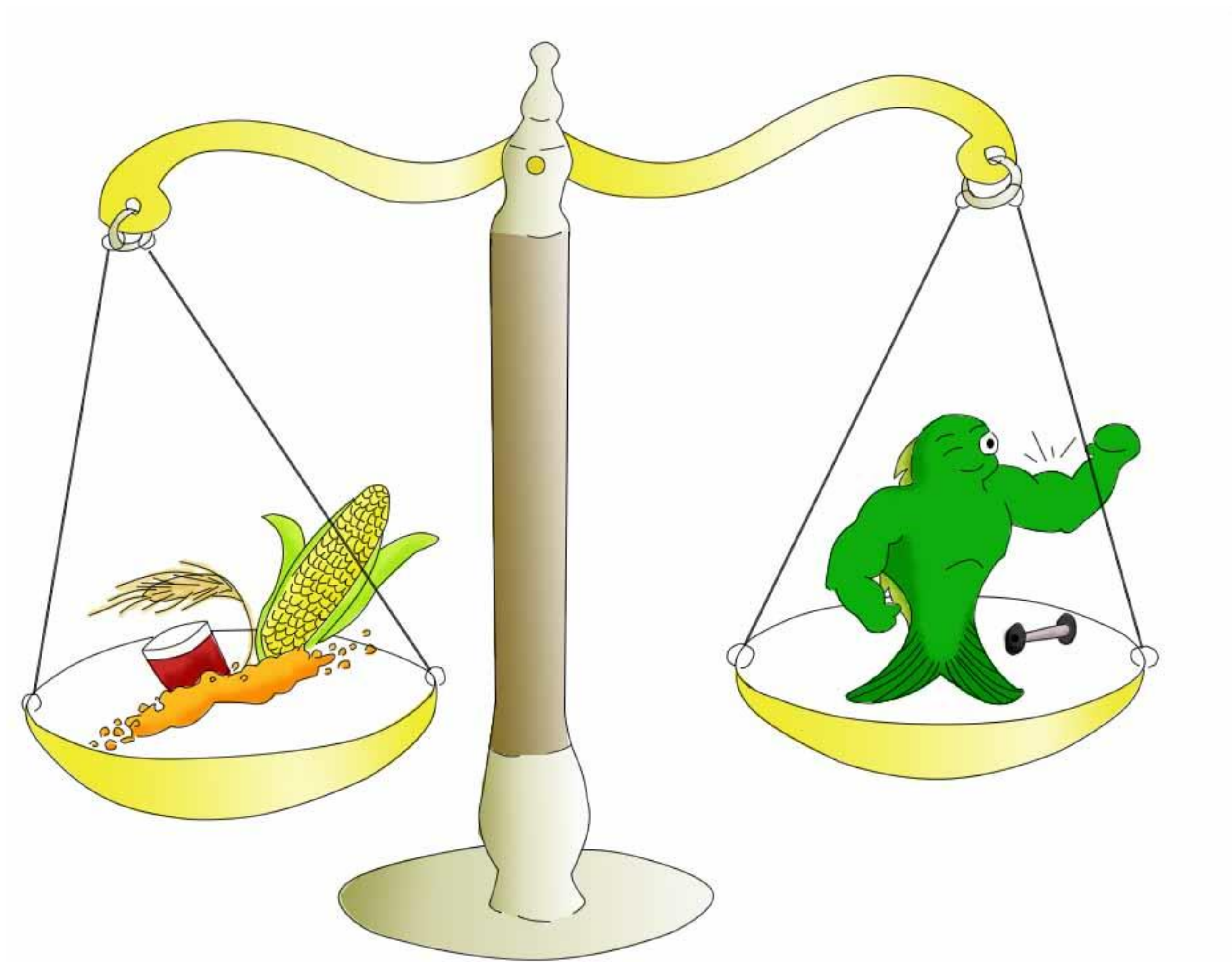
2- Cost-effectively meeting nutrient requirements

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

Balancing our Understanding of Nutritional Requirements and Ingredient Quality



Feed Formulation

- Feed formulation is the process of quantifying the amounts of feed ingredients that need to be combined to form a single uniform mixture (diet) that supplies all of the nutrient required by animal or allow to meet certain production objectives at a reasonable cost (preferably at the least cost)

- Typical formulations indicate the amounts of each ingredient that should be included in the diet, and then provide the concentration of nutrients (composition) in the diet

- Feed formulations are generally compromise between an ideal situation and practical considerations (cost, availability and characteristics of ingredients, etc.).

Feed Formulation – Ingredient Driven

Nutrient	Minimum	Maximum
Soybean meal, dehulled, solvent extracted (%)	20	–
Corn grain (%)	15	–
Cottonseed meal, solvent-extracted (%)	–	25
Wheat middlings (%)	–	25
Corn gluten feed or corn germ meal (%)	–	30
Distillers dried grain with solubles[1] (%)	–	20
Rice bran, solvent-extracted (%)	–	15
Animal protein feedstuff[2] (%)	–	15
Supplemental fat[3]	1.5	3
Mono- or dicalcium phosphate (%)	Meet requirement for phosphorus	
Vitamin premix	Meet all vitamin requirements	
Trace mineral premix	Meet all trace mineral requirements	
Phytase enzyme[4] (FTU[5]/kg)	500	500

Large variation of chemical composition of DDGS samples collected from six plants in Canada

	Mean	SEM (n=12)	Minimum	Maximum
Nutrient Content (% as is)				
Dry Matter	87.68	0.20	85.72	89.85
Crude Protein	26.59	0.29	23.47	31.19
NDF	31.60	0.50	25.48	37.40
Fat	9.99	0.20	7.75	12.40
Starch	2.91	0.45	1.33	13.54
Phosphorus	0.78	0.01	0.59	0.88
Sulphur	0.57	0.02	0.39	1.03

McEwen et al., 2010; Univ. of Guelph

”Same” ingredient but very different nutritional profiles
Does it makes sense to formulate on a % ingredient level then?

Feed Formulation – Proximate Analysis-Driven

Total weight	=	1000.00 kg
Crude protein	>=	280.00 kg
Fat	<=	54.30 kg
Fibre	<=	27.30 kg
Calcium	<=	12.00 kg
Calcium	>=	10.00 kg
Phosphorus	>=	6.00 kg
Dl-Methionine	>=	5.50 kg
Lysine	>=	16.00 kg
Energy	>=	2750 ME Kcal kg^{-1}
Vitamin/mineral premix	>=	2.50 kg
Vitamin/mineral premix	<=	3.00 kg
Salt	>=	2.50 kg
Salt	<=	3.50 kg
Blood meal	<=	50.00 kg

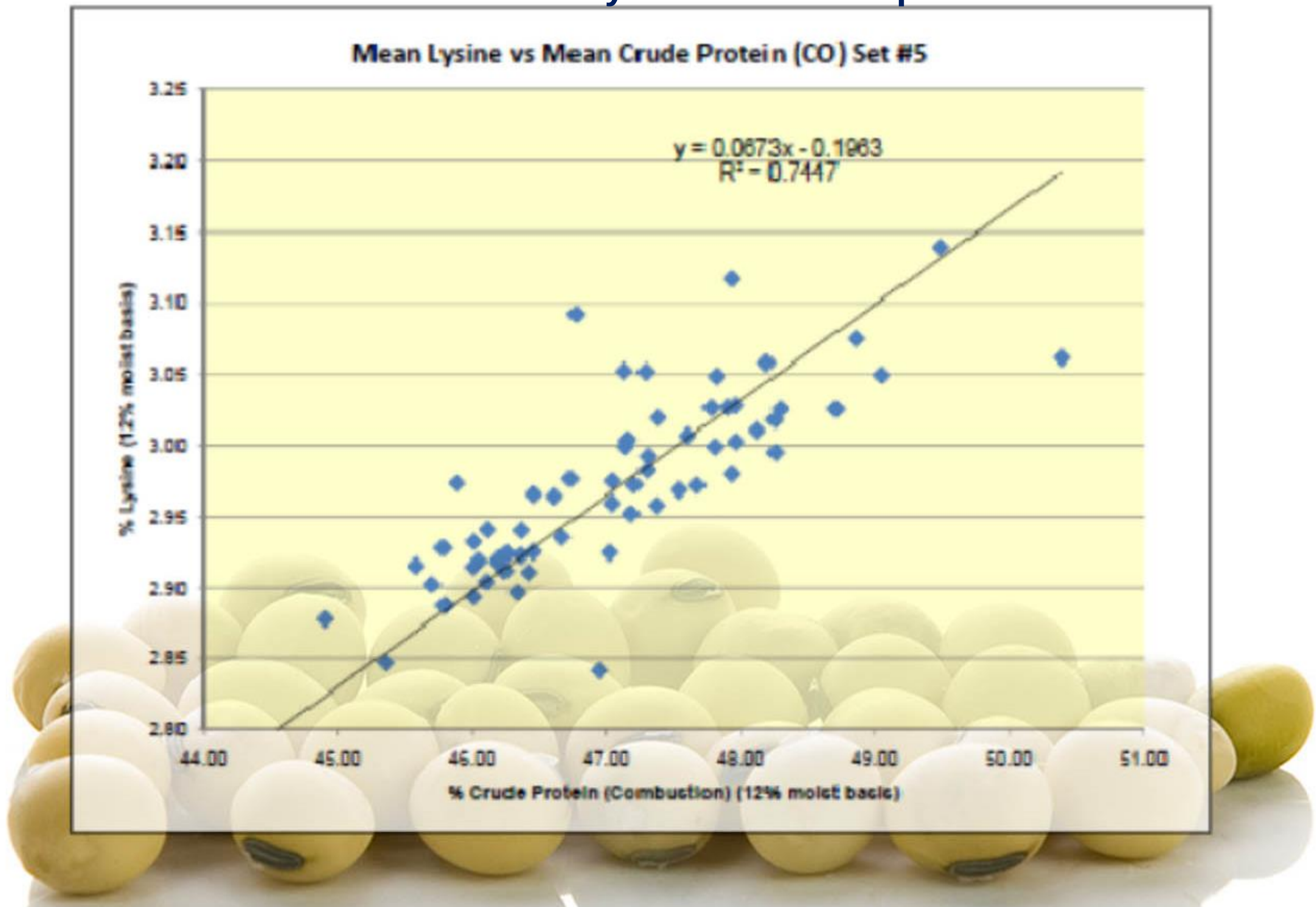
Nutritional Quality of DDGS

Nutrient*	MN/SD DDGS	Low Quality DDGS	NRC (1998)
Dry matter, %	88.9	88.3	93.0
Crude protein, %	30.2	28.1	29.8
Crude fat, %	10.9	8.2	9.0
Crude fiber, %	8.8	7.1	4.8
Calcium, %	0.06	0.44	0.22
Phosphorus, %	0.89	0.90	0.83
Available phosphorus, %	0.80	?	0.64
Digestible energy, kcal/kg	3,965	3,874	3,441
Metabolizable energy, kcal/kg	3,592	3,521	3,032
Lysine, %	0.83	0.68	0.67
App. digestible lysine, %	0.44	0.00	0.31
Methionine, %	0.55	0.49	0.54
App. digestible methionine, %	0.32	0.24	0.39
Threonine, %	1.13	0.99	1.01
App. dig. threonine, %	0.62	0.36	0.56
Tryptophan, %	0.24	0.22	0.27
App. dig. tryptophan, %	0.15	0.15	0.13

* Values expressed on a 100% dry matter basis.

The “chemical composition” of crude protein can be highly variable even in standard ingredients!

Variability of Lysine Concentration (% as is) in Relation to Crude Protein (% as is) Content of US Soybean Meal Samples



Data courtesy of Paul Smolen and United Soybean Board

Generic names often regroup ingredients that can be widely different. Not buying a "name"

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

Cheng and Hardy (2002)

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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 in Rainbow Trout

	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

Information on EAA content and digestibility is extremely meaningful
for the formulation of cost-effective feeds

Cheng and Hardy (2002)

Apparent Digestibility of Different Blood Meals Assessed with the Guelph System

Drying Technique	Apparent Digestibility	
	Protein	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

Variation in DDGS due to Drying Conditions

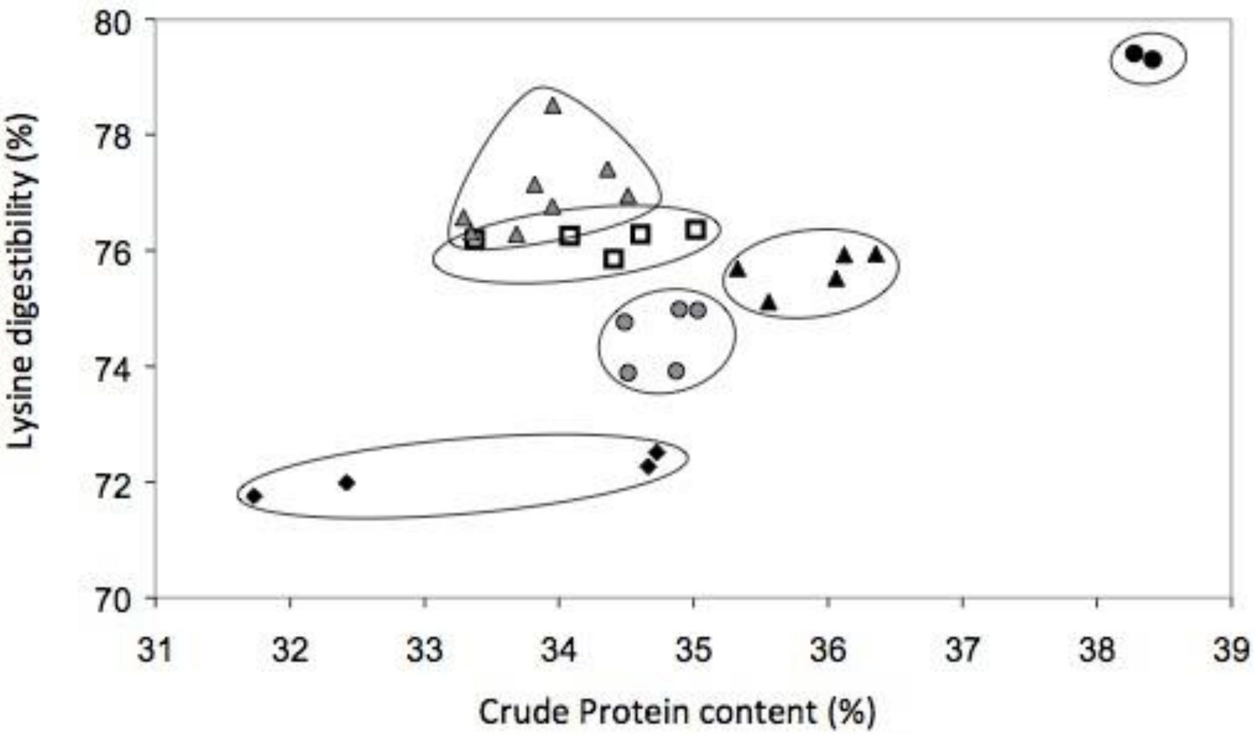
Lysine concentration tended to be highest in light-colored DDGS and lowest in the darkest colored DDGS sources. When the four darkest, burnt smelling sources were fed to chicks, growth rate, feed intake, and feed conversion were compared to chicks fed the lightest-colored DDGS. Results from this study suggest that DDGS that is dark in colored and/or has a burnt smell should not be used in swine or poultry diets.

Source: Cromwell, G.L., K.L. Herkleman, and T.S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distiller's dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679-686.

You can sometimes trust your senses but you have to know what to look for.

Figure 3 Rapeseed meal digestibility is pretty much affected by the manufacturing process

Different symbols represent rapeseed meals from different crushing plants (29 samples from 6 crushing plants)



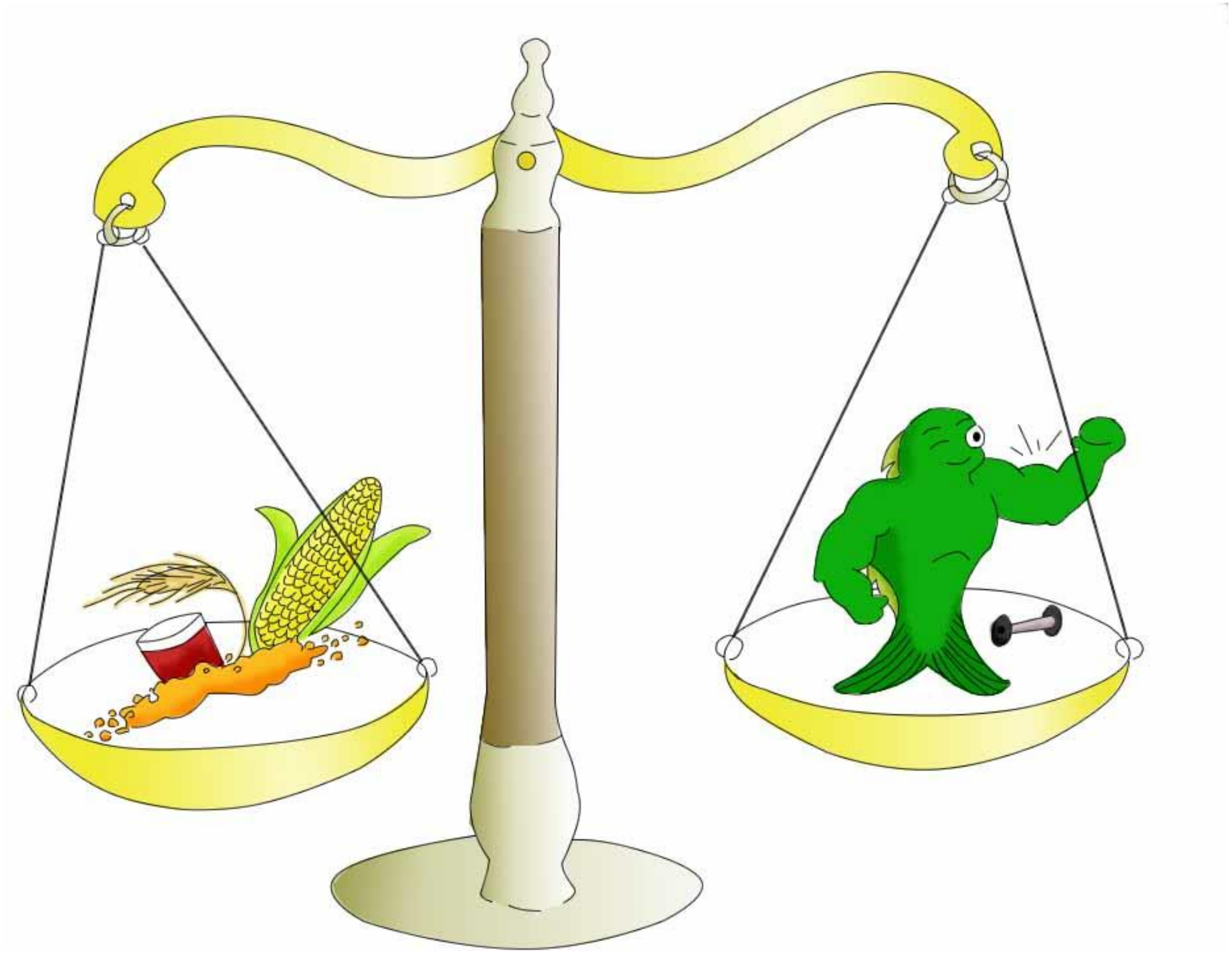
http://gfmt.blogspot.ca/2013/04/adisseo-survey-on-nutritional-value-of.html

Ingredient purchasing, feed formulations and research effort are all still too often based on:

- **Generic name of ingredients**
  - **Soybean meal**
  - **Rapeseed meal**
  - **Poultry by-products meal**
  - **Meat and bone meal**
  - **Blood meal**

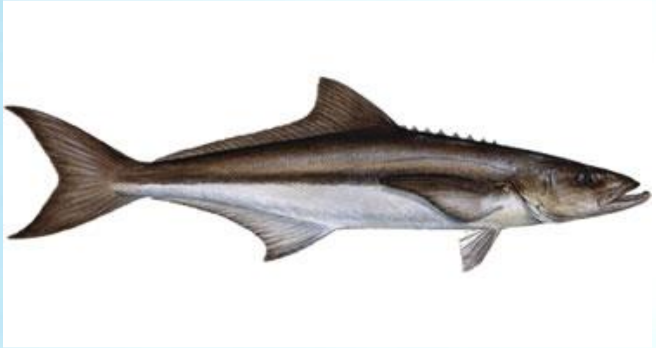
- **Proximate composition :**
  - **Crude protein (N × 6.25)***
  - **Crude lipids (crude fat)***
  - **Ash**
  - **Crude fiber**
  - **Total phosphorus**
  - **Pepsin digestibility (?)**

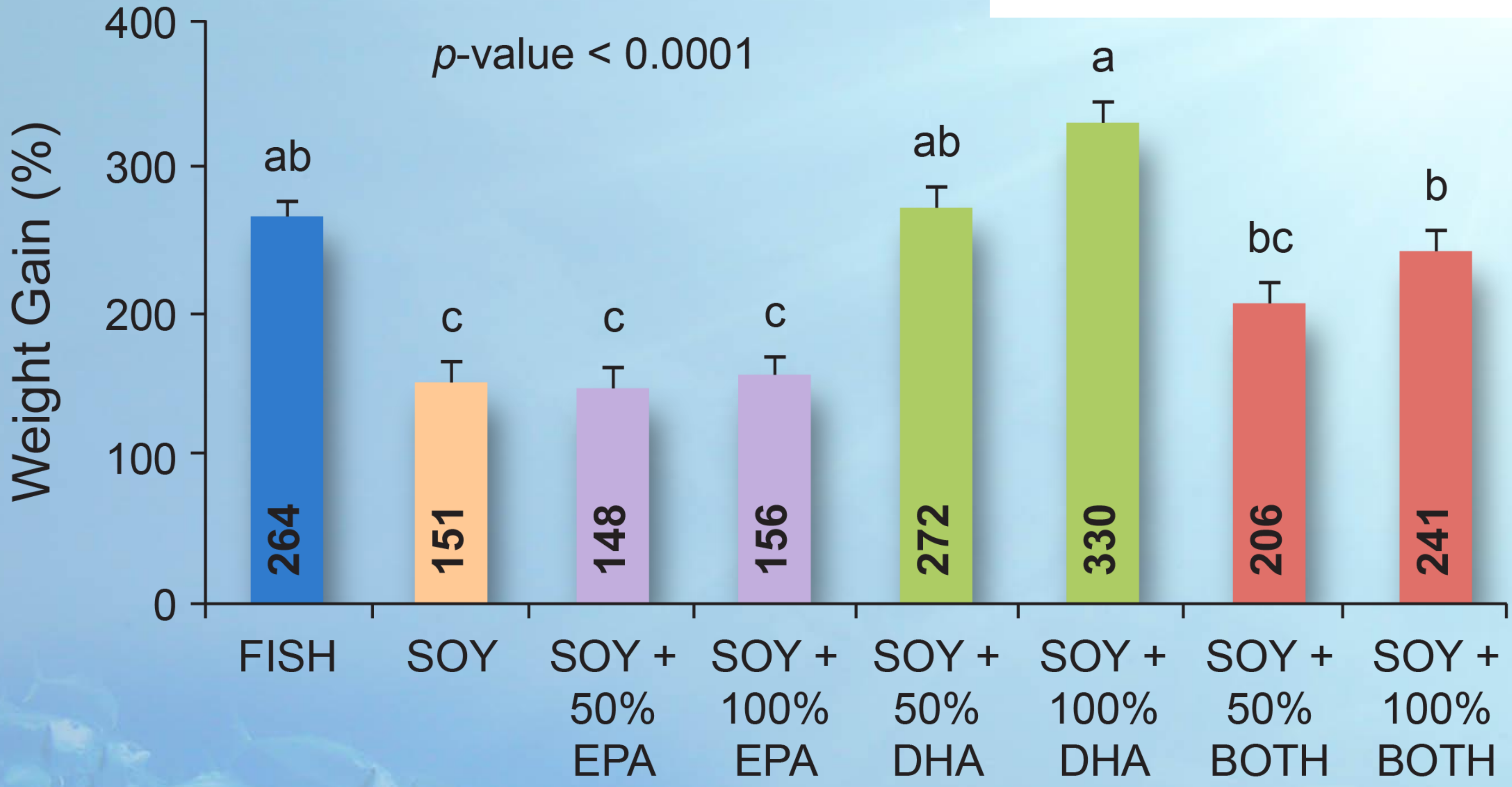
Balancing our Understanding of Nutritional Requirements and Ingredient Quality



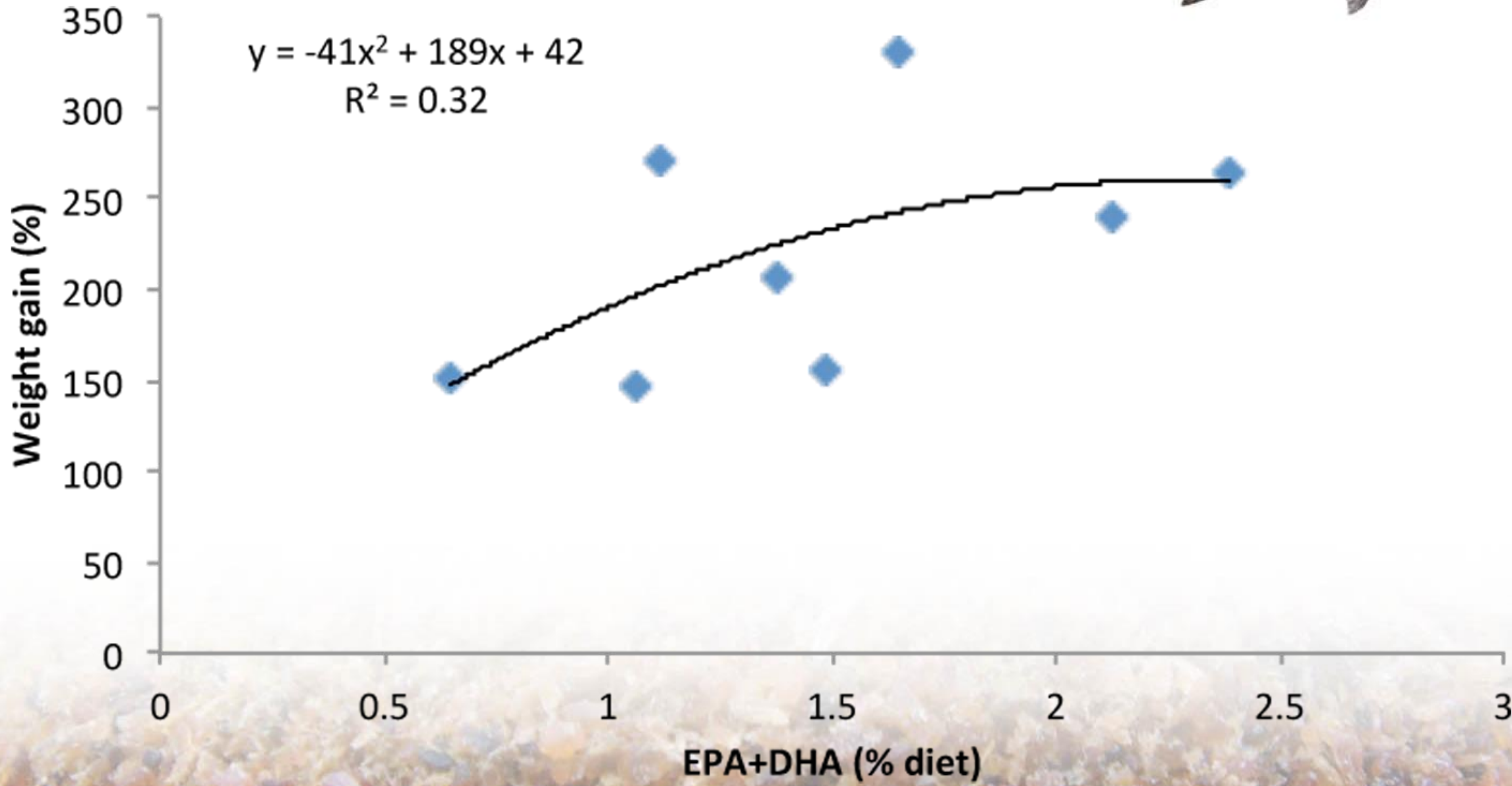
FNRL

Fish Oil Replacement in Cobia



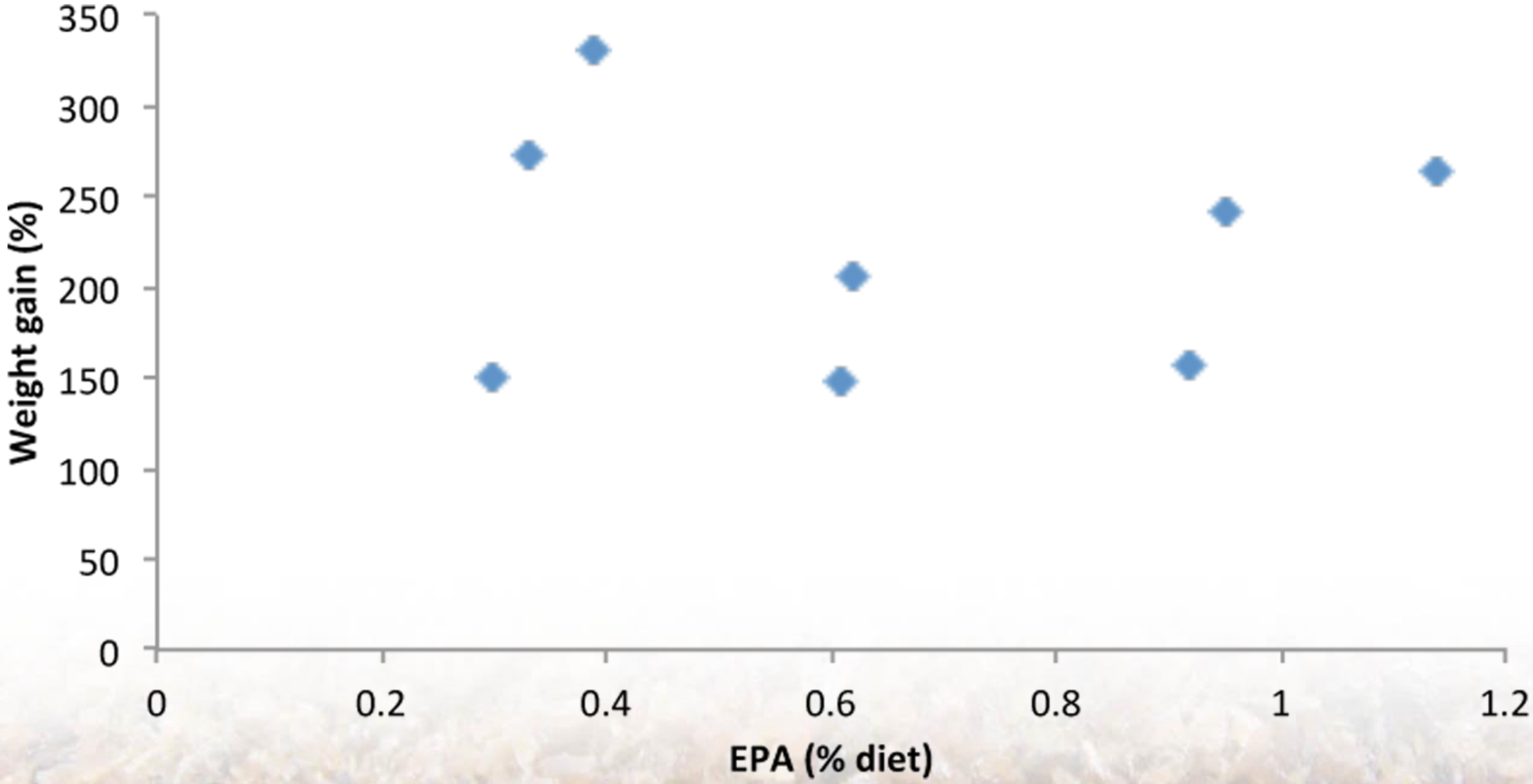


Trushenski et al. (2012)



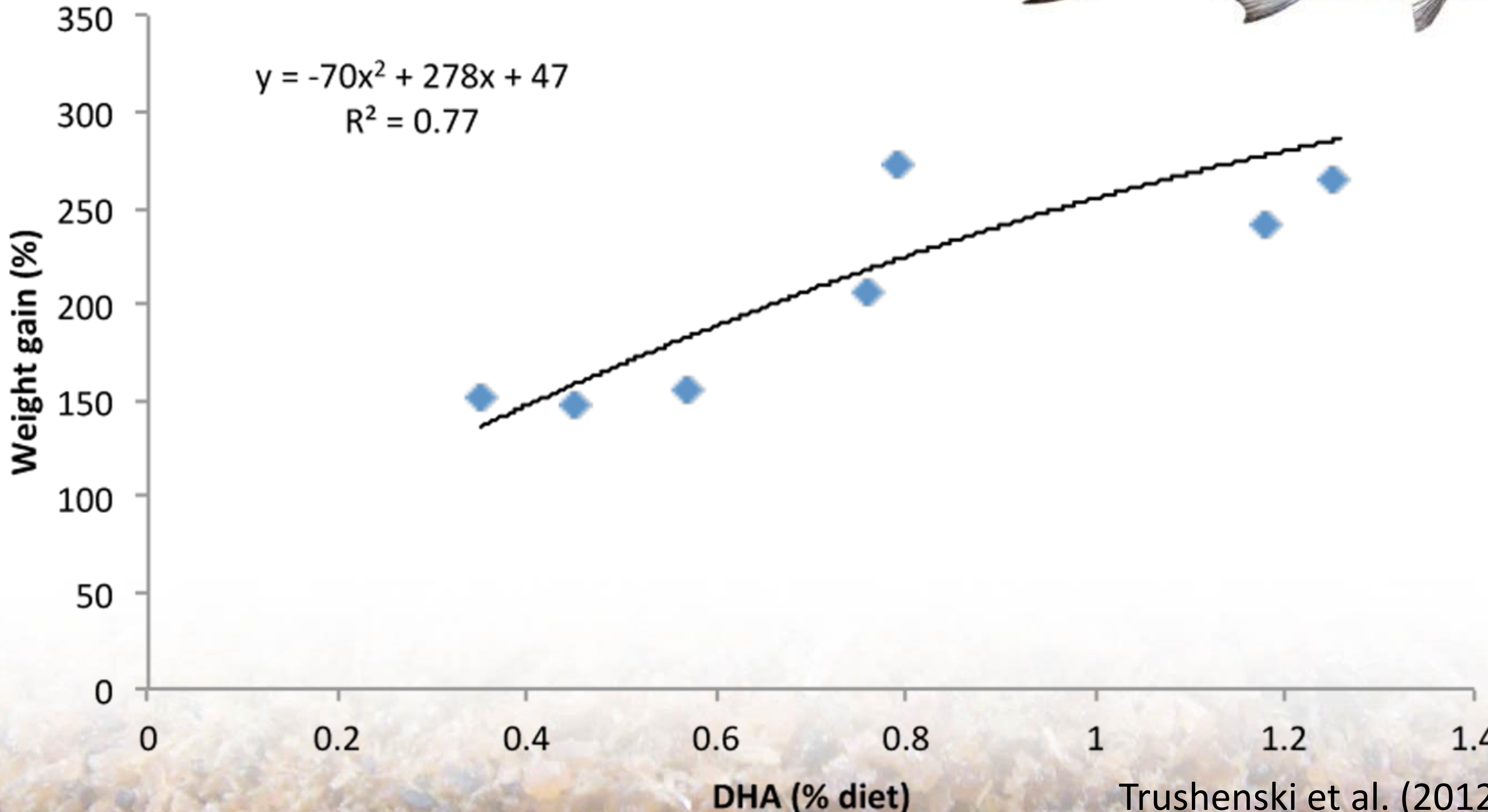
In Cobia, the response of the fish to EPA+DHA is not robust

Trushenski et al. (2012)



Cobia does not appear to respond to EPA !

Trushenski et al. (2012)



Trushenski et al. (2012)

Cobia responds well to the level of DHA only !

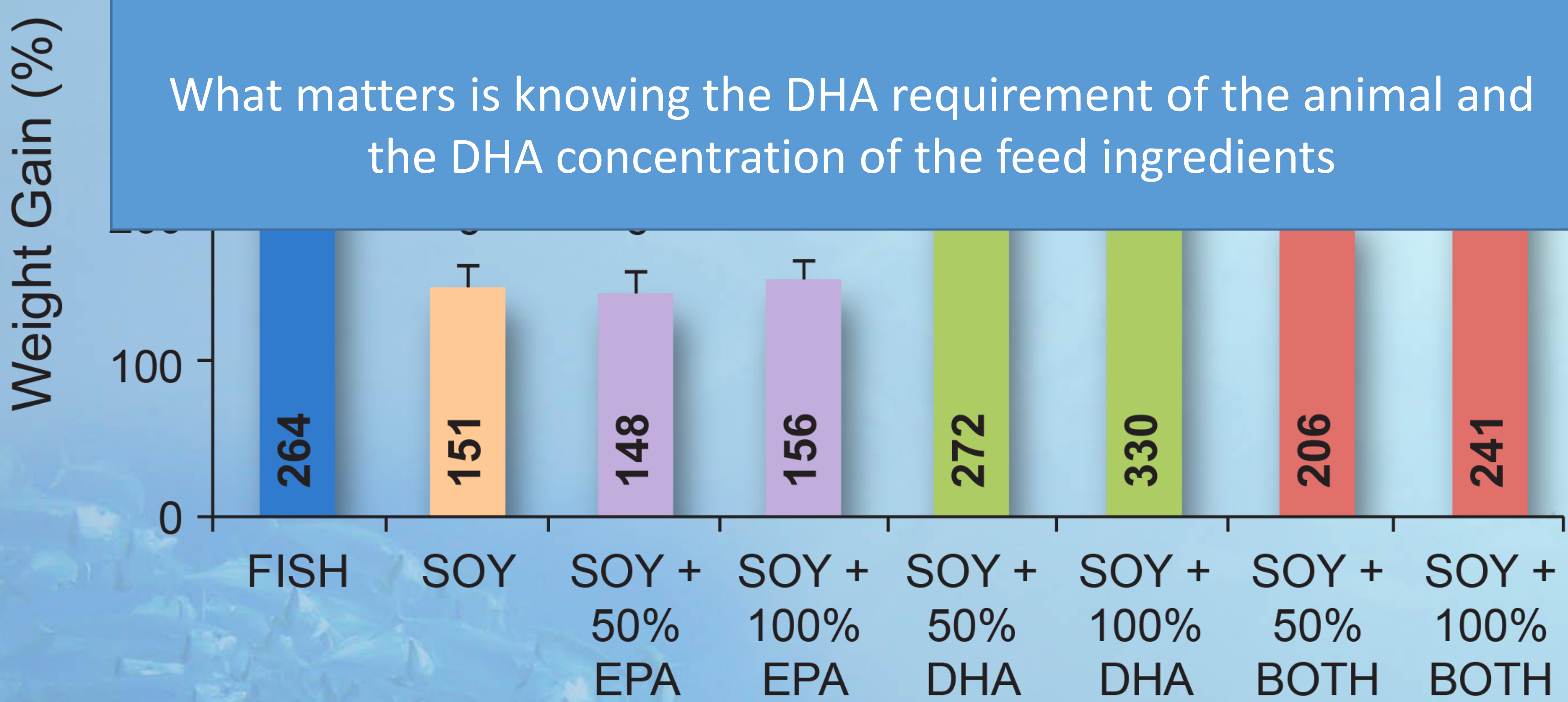
DHA is the essential nutrient and what matters!

Fish Oil Replacement in Cobia

The Issue is not Fish Oil vs. Soy Oil

The issue is meeting the specific nutrient (DHA) requirement of the fish using an effective source of DHA!

What matters is knowing the DHA requirement of the animal and the DHA concentration of the feed ingredients



Trushenski et al. (2012)

Animals Utilize **NUTRIENTS**
not "Ingredient", and not "Proximate Components"

What's important in feed formulation?

- Individual nutrient requirements of animals (with adequate safety margins)
- Nutrient content of feed ingredients and associated variability
- Digestibility and bio-availability of nutrients
- Potential limitations (e.g. contaminants, anti-nutritional factors)
- Impacts (e.g. physical properties, waste outputs, final product quality) of the ingredients

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Effective approach: Benchmarking / production modeling
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Precision Feed Formulation

- Formulation of feed to nutritional specifications that correspond closely to the requirements of the animal and/or production objectives without deficiency or excess

- Important step towards improving the cost-effectiveness of feeds in aquaculture

IAFFD
International Aquaculture Feed
Formulation Database

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 and demands/preferences of the market
    - Feed minimizing cost of formula while maximizing performance
    - Feed resulting in less wastes
    - Feed that is the cheapest per kg of feed
  - Uncertainties
    - Ex: Uncertainties around estimate of nutritional composition, nutritional requirements or potential losses of nutrients requiring use of certain safety margin

Nutritional Specifications are Guidelines, Some are Redundant or Sometime not Useful or Relevant

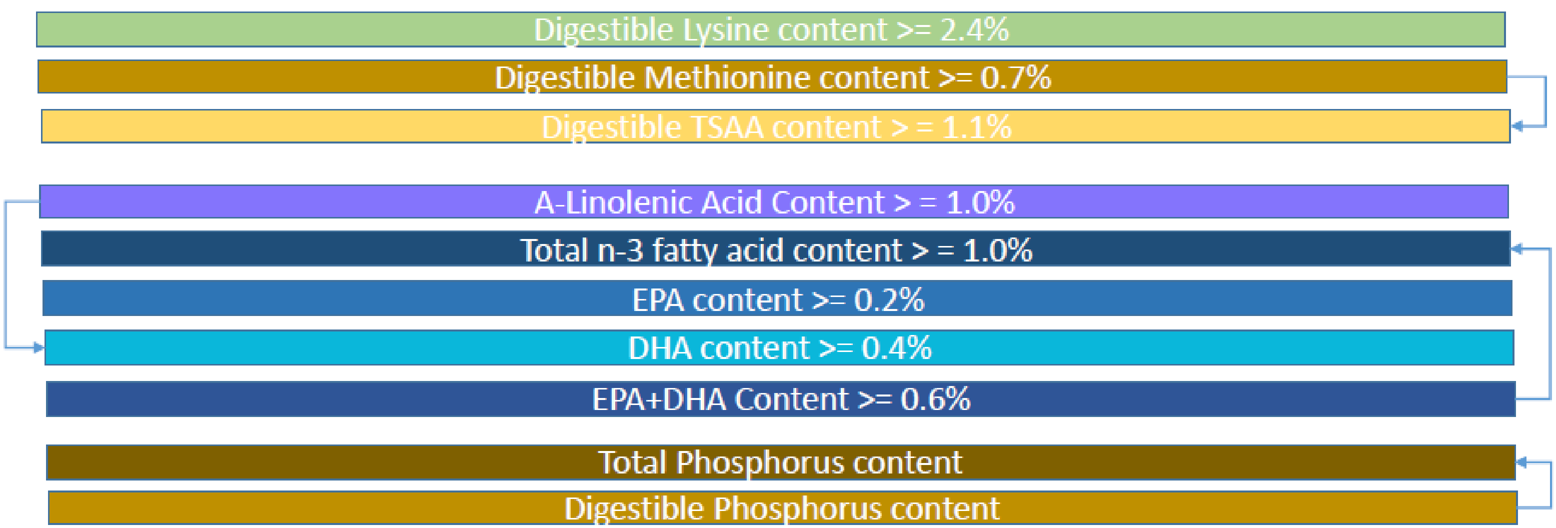
Least Cost Feed Formulation = Linear Programming

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.



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

Nutrition, Feed Formulation and Feed Production
Identifying Specific Priorities and Tasks

Nutrition & Formulation R&D	Raw Material Quality and QA/QC R&D	Feed Technology R&D
Improved nutritional specifications	Characterization of composition (nutrients and anti-nutritional factors)	Feed Processing efficiency (energy, labor, wastage)
Improved formulation guidelines (ingredient restrictions)	Digestibility, bio-availability, nutritive value, Limitations	Special Processes (Liquid dosing, enzymes, etc.)
Potential of feed additives and other technological solutions	Improved / More efficient QA/QC processes	Modulation of physical characteristics (floatability, stability, fines, etc.)
Feed Product Portfolio (Feed grades, phase-feeding, etc.)	Upgrading of ingredient quality (Processing)	
Special feeds (larval feed, diet to improve disease or stress resistance, etc.)	Feed safety (contaminants) and traceability	