Digestive Physiology and Nutrition in Fish

For metabolic function and growth, fish require

- Essential and dispenable amino acids
- Energy-yielding feed ingredients
- Essential fatty acids
- Macro-minerals
- Vitamins
- Trace minerals

Sources of essential amino acids

- EAA from the dietary proteins
- Synthetic amino acids (and analogs)

Sources of dispensable amino acids

- Any amino acid from the diet

Sources of essential fatty acids

- Lipids from the diet

Sources of energy

- Carbo-hydrates from the diet
- Lipids from the diet
- Proteins from the diet

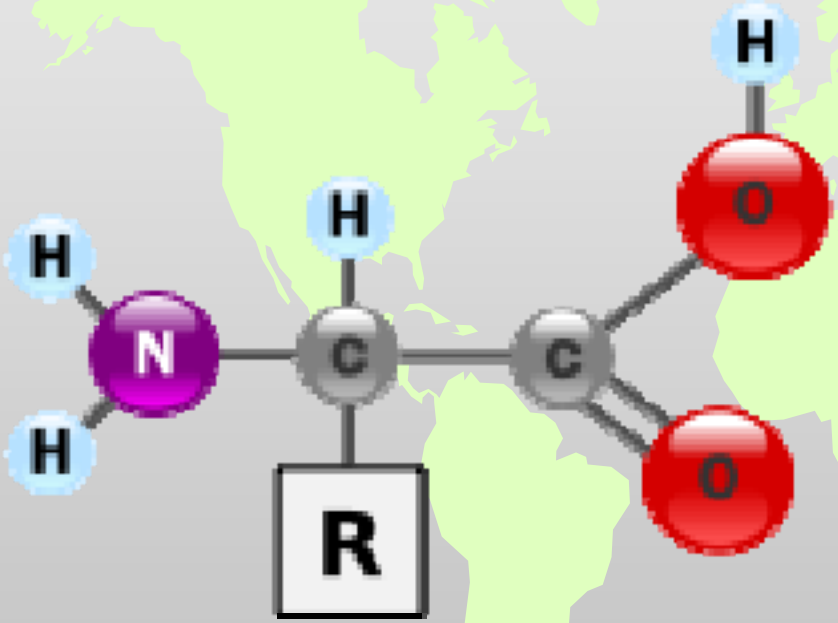
Sources of Vitamins

- Vitamines from the diet

Sources of Macro and Trace Minerals

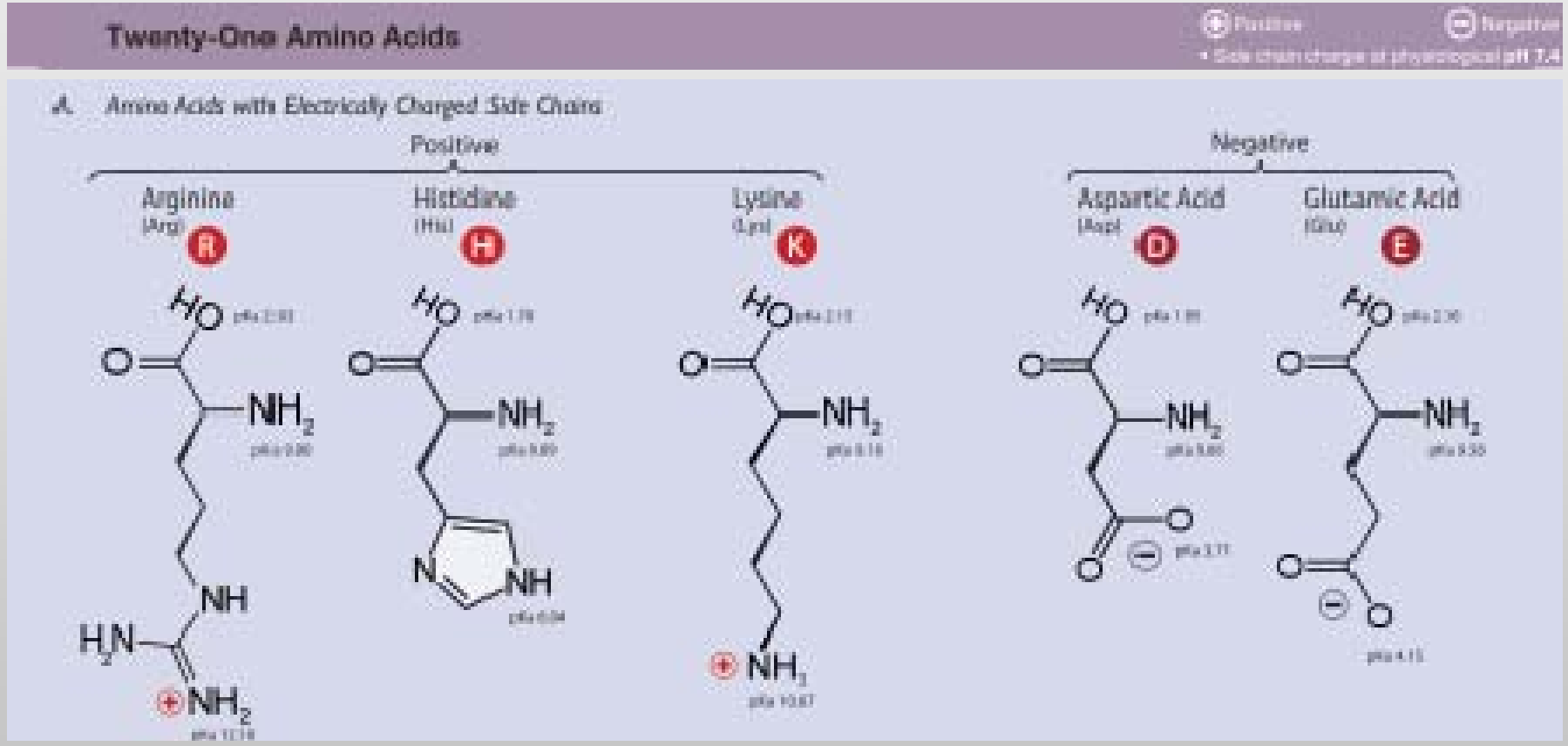
- Minerals from the diet
- Minerals from the water (especially in marine fish)

Amino acids:

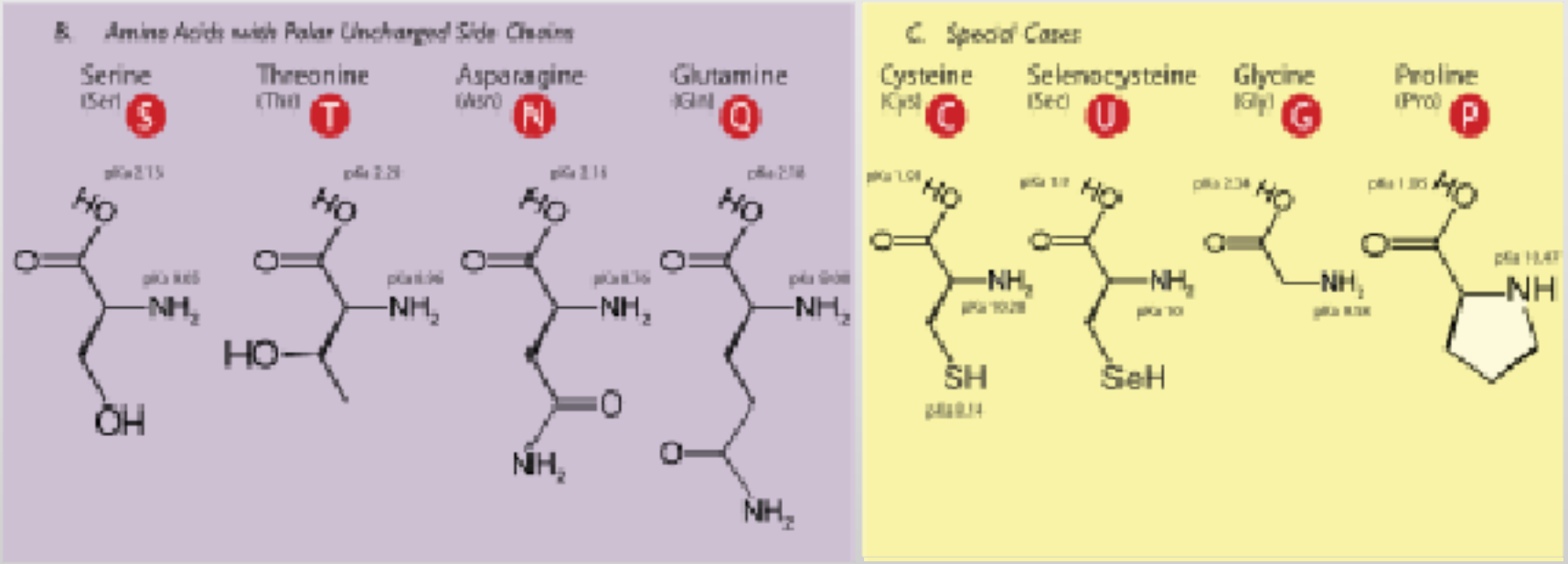


Essential	**Nonessential**
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic acid
Methionine	Cysteine*
Phenylalanine	Glutamic acid
Threonine	Glutamine*
Tryptophan	Glycine
Valine	Ornithine*
	Proline*
	Selenocysteine*
	Serine*
	Taurine
	Tyrosine*

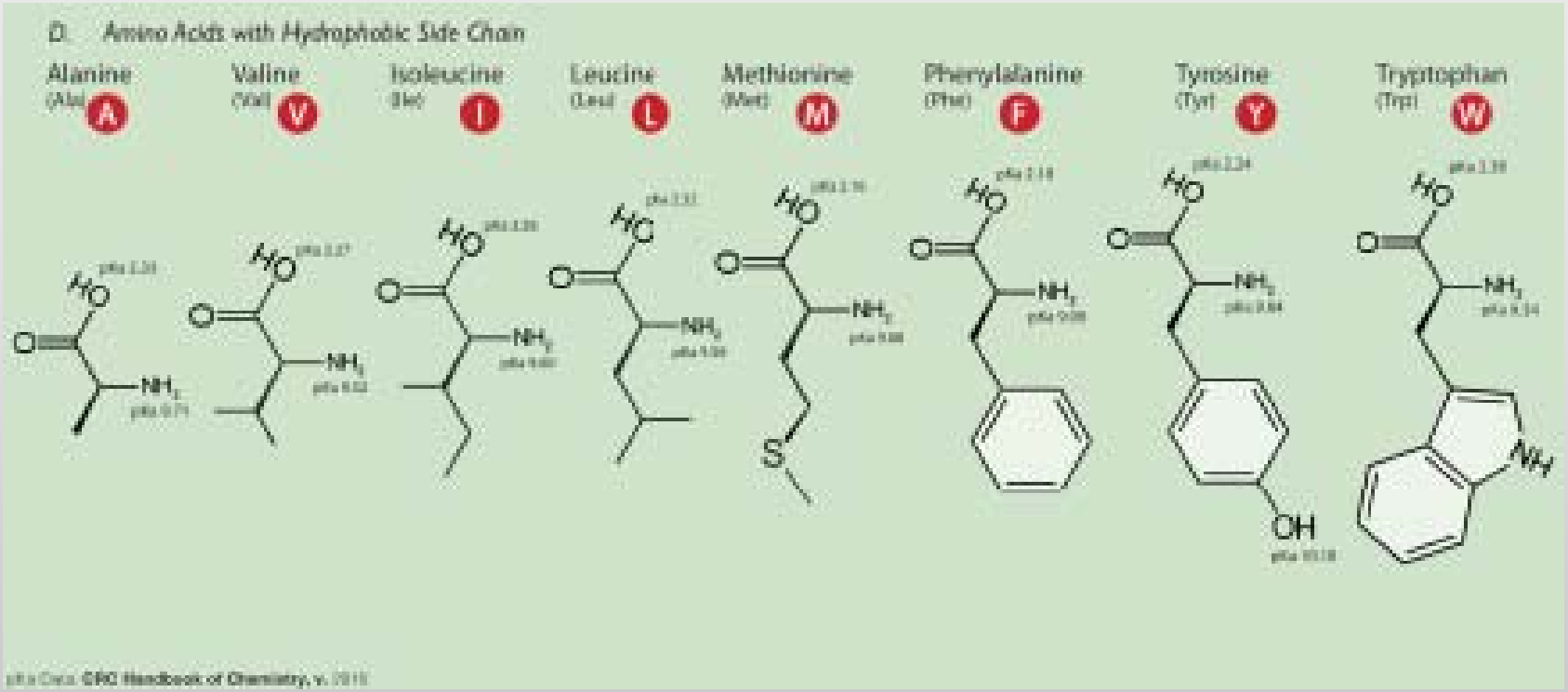
Amino acids:


Twenty-One Amino Acids
A. Amino Acids with Electrically Charged Side Chains
Positive
Negative
Arginine
(Arg)
R
Histidine
(His)
H
Lysine
(Lys)
K
Aspartic Acid
(Asp)
D
Glutamic Acid
(Glu)
E

Amino acids:


B. Amino Acids with Polar Uncharged Side Chains
Serine
(Ser) S
Threonine
(Thr) T
Asparagine
(Asn) N
Glutamine
(Gln) Q
C. Special Cases
Cysteine
(Cys) C
Selenocysteine
(Sec) U
Glycine
(Gly) G
Proline
(Pro) P
SH
SeH
NH

Amino acids:


D. Amino Acids with Hydrophobic Side Chain
Alanine
(Ala)
A
Valine
(Val)
V
Isoleucine
(Ile)
I
Leucine
(Leu)
L
Methionine
(Met)
M
Phenylalanine
(Phe)
F
Tyrosine
(Tyr)
Y
Tryptophan
(Trp)
W

Chemical analysis of foodstuffs

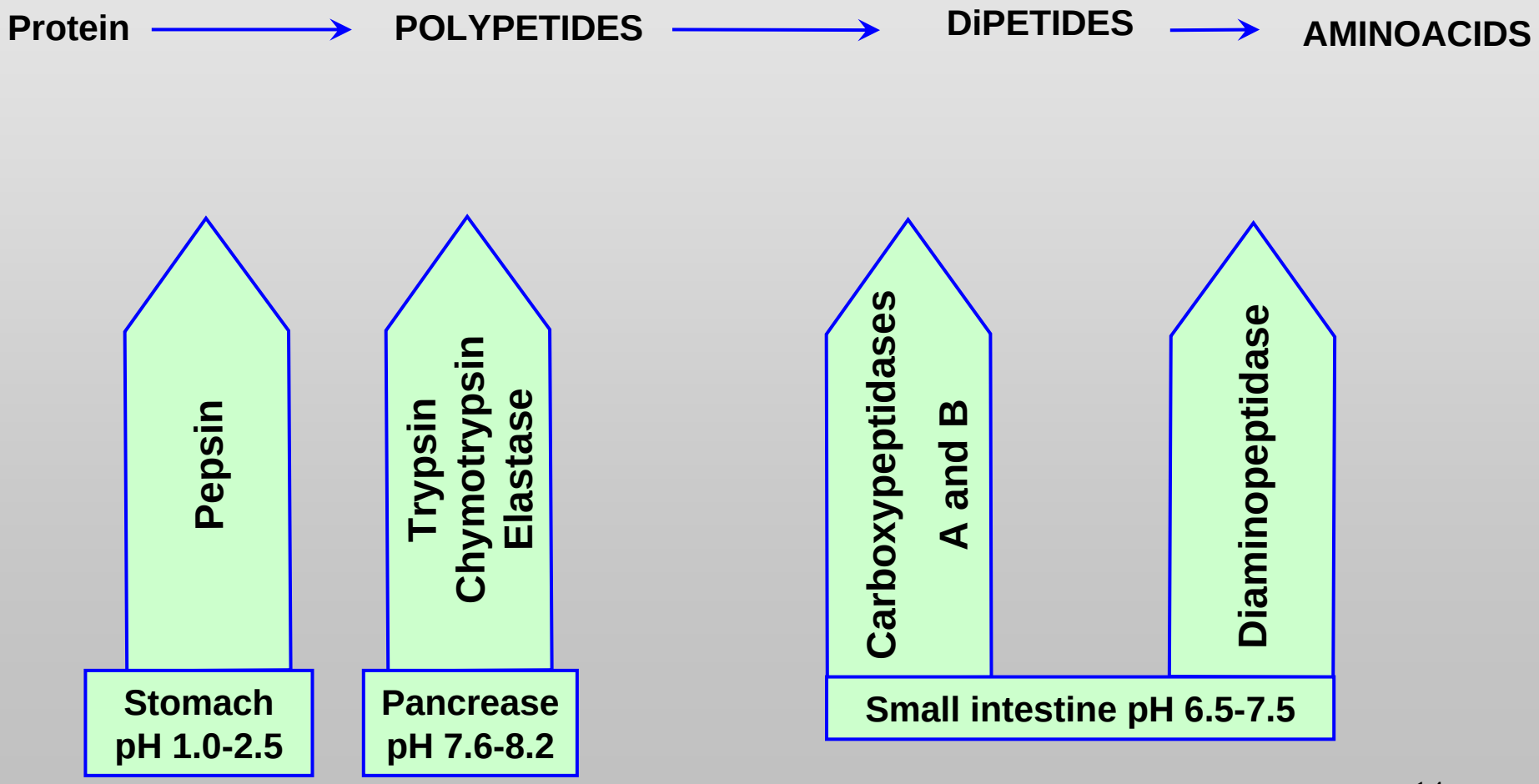
Upon analysis we generally find 6 different components:

- Water
- Carbohydrates
- Protein
- Fat
- Vitamins
- Minerals and trace elements
- Especially in warm countries a great number of so called antinutrients

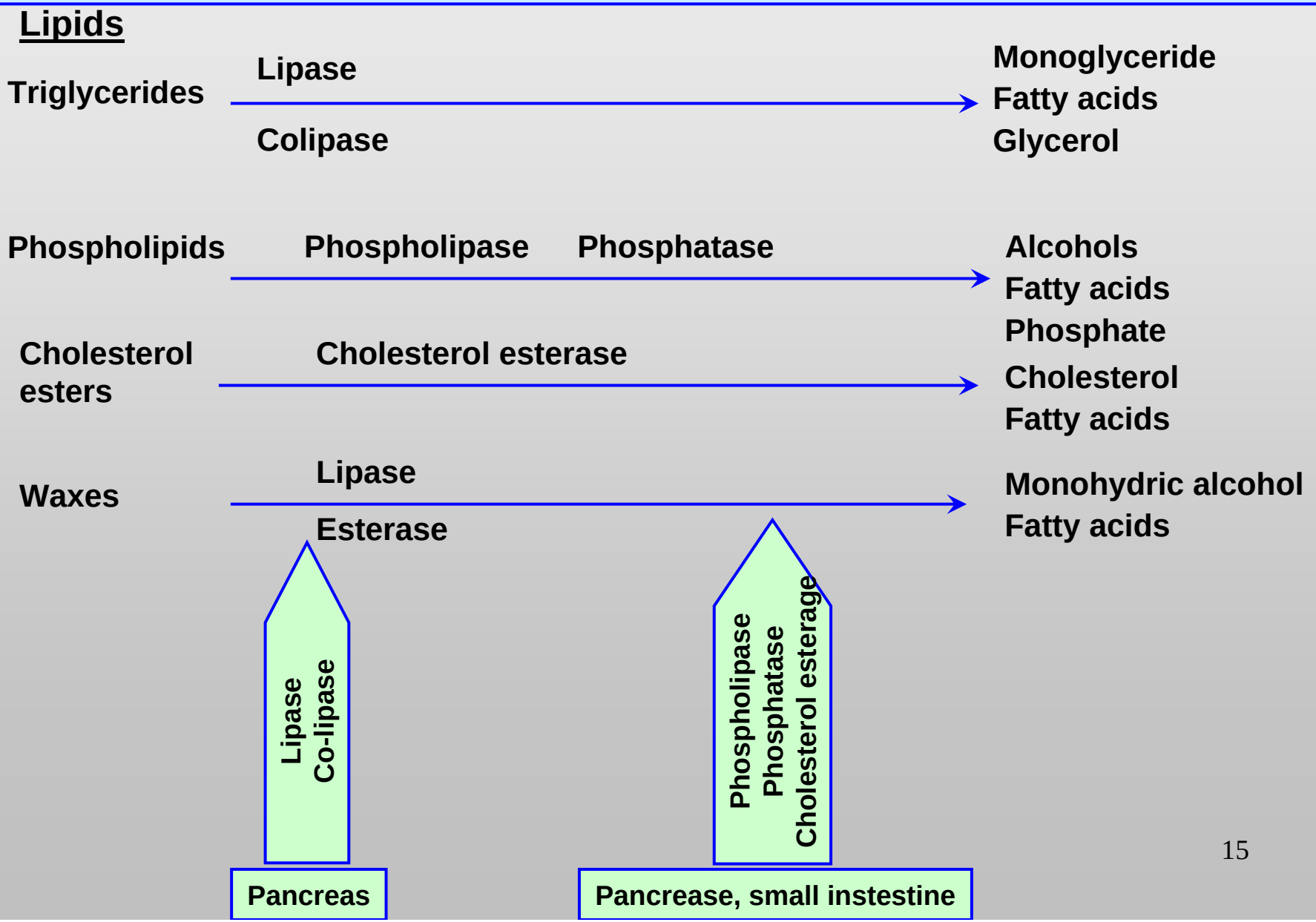
Elemental composition and gross and physiological energy content of the three major nutrient classes

Nutrient	Element composition %		Energy content	
			Gross MJ kg $^{-1}$	Physiological MJ kg $^{-1}$
Protein	C	53	23.86	17.0
	N	16		
	O	23		
	H	7		
	S	1		
Fat	C	76	39.0	38.0
	O	12		
	H	12		
Carbohydrate	C	40	17.4	17.4
	O	53		
	H	7		

Protein digesting endogenous enzymes of vertebrates



Principle lipid digesting endogenous enzymes of vertebrates



Principle carbohydrate digesting endogenous enzymes of vertebrates

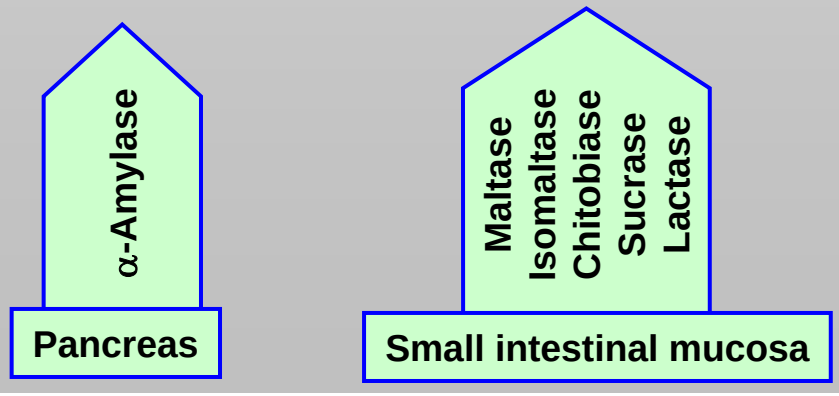
Substrate

Carbohydrates

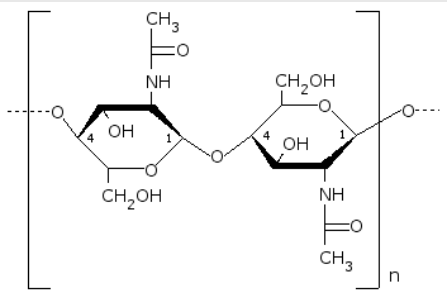
Amylose
Amylopectin
Glycogen —α-Amylase→ **Ogliosaccharide** —Maltase / Isomaltase→ **Glucose**

Chitin —Chitinase→ **Chitobiose** —Chitobiase→ **N-acetyl-glucosamine**

Sucrose —Sucrase→ **Glucose** + **Fructose**



Chitin

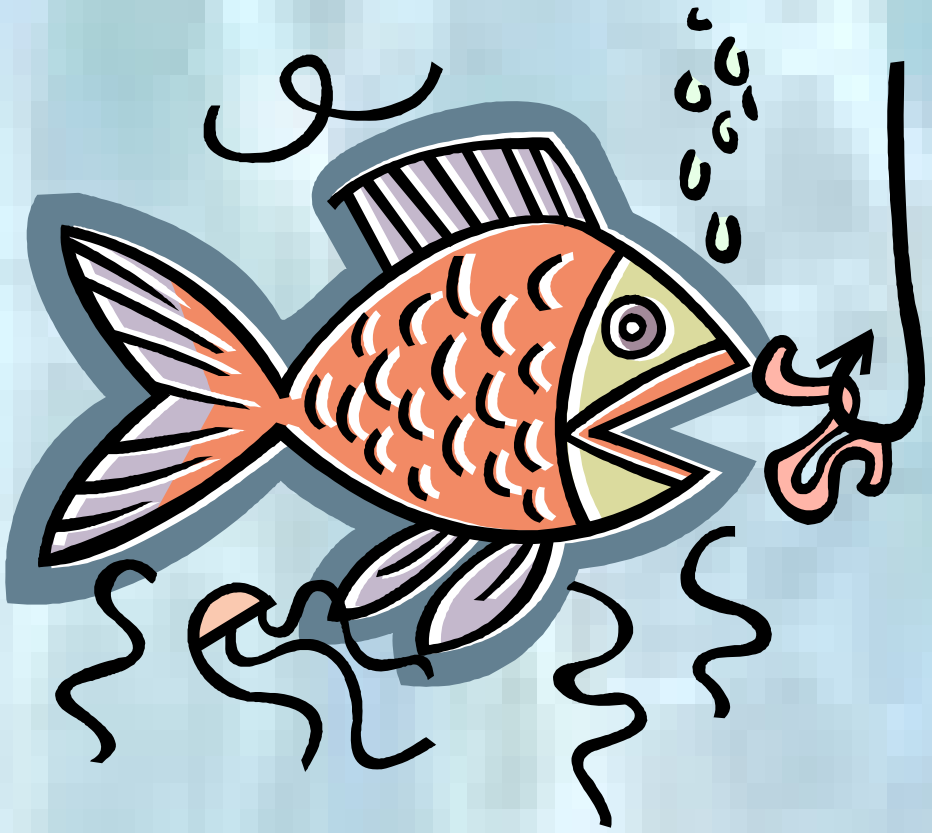


- Chitin is a structural polysaccharide found in:
  - Cell walls of bacteria
  - Fungi
  - Many invertebrates
- It consists of ß-1.4-linked N-acetyl-D-glucosamine
- Chitinase is absent from the digestive tract of fish that lack a stomach and pyloric Ceca
- Chitinase is found in the gastric mucosa of many fish
- Fish that ingest their prey whole have high chitinolytic enzyme activity
- Fish that are able to disrupt the chitin envelope of the prey have low chitinolytic activity

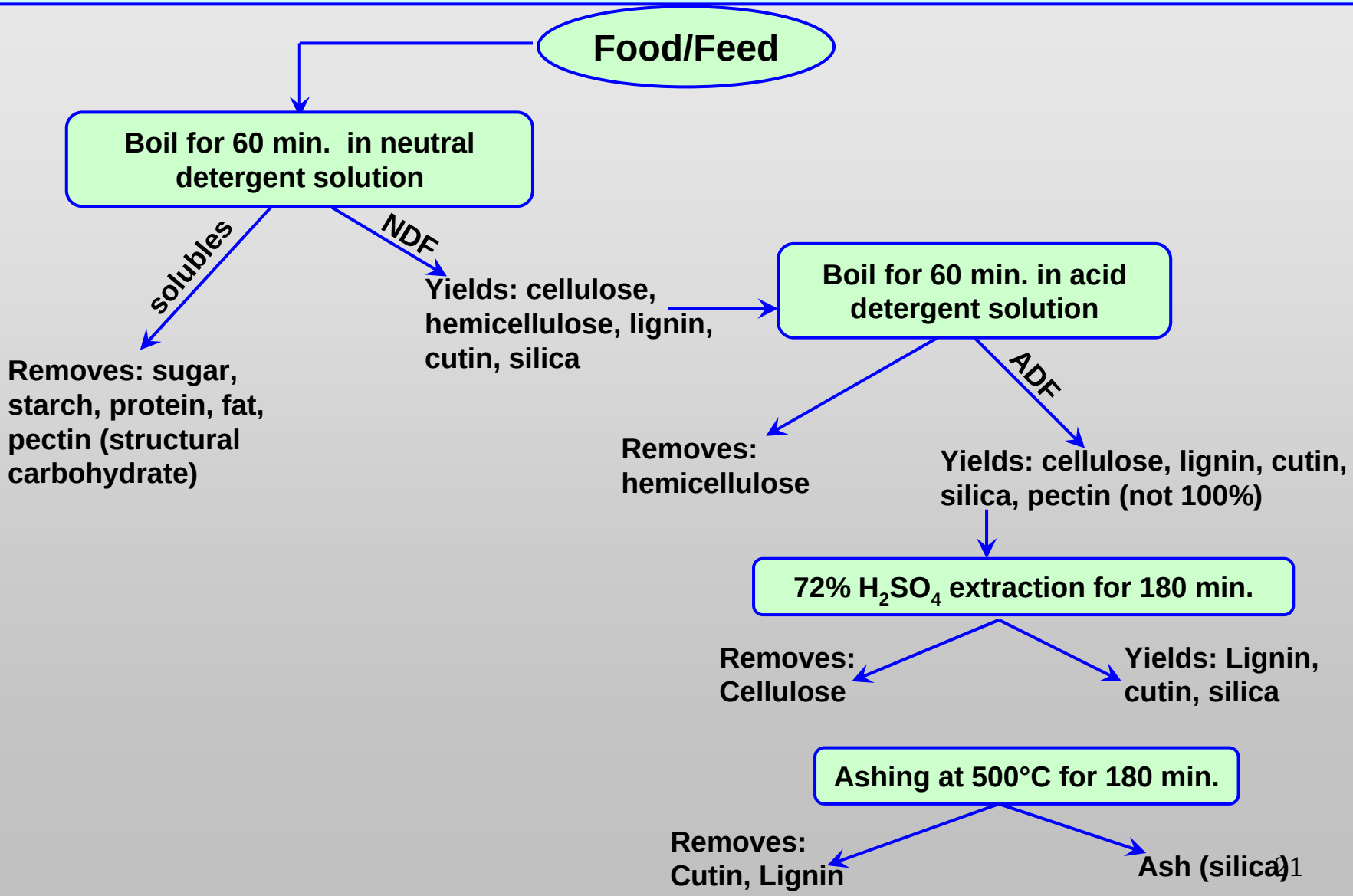
Localisation of the digestive enzymes of the fish gut, their substrates and the products resulting from their digestive actions

Source site of secretion	Enzyme	Site of action	Substrate	Product
Stomach	Pepsins	Stomach	Protein	Peptides
Pancreas	Trypsin	Intestine	Protein/peptides	Peptides
Pancreas	Chrymotrypsin	Intestine	Protein/peptides	Peptides
Pancreas	Carboxypeptidase	Intestine	Protein/peptides	Amino acids, Peptides
Intestine	Aminopeptidase	Intestine	Protein/peptides	Amino acids, Peptides
Instestine	Di-/tripeptidases	Intestine	Di-/tripeptides	Amino acids
Pancreas	Lipase	Intestine	Triacylglycerols	Fatty acids, Monoacylglycerols
	Esterases	Intestine	Esters	Alcohols, Fatty acids
Pancreas	Amylase	Intestine	Starches	Disaccharides
Intestine	Disaccharides	Intestine	Disaccharides	Monosaccharides
Pancreas and gut microflora	Chitinases	Intestine	Chitin	N-acetyl-glucosamine
Gut microflora	Cellulase	Intestine	Cellulose	Saccharides

III Feed quality and its determination



The detergent system – Van Soest analysis – for determining the chemical composition of plant derived feeds

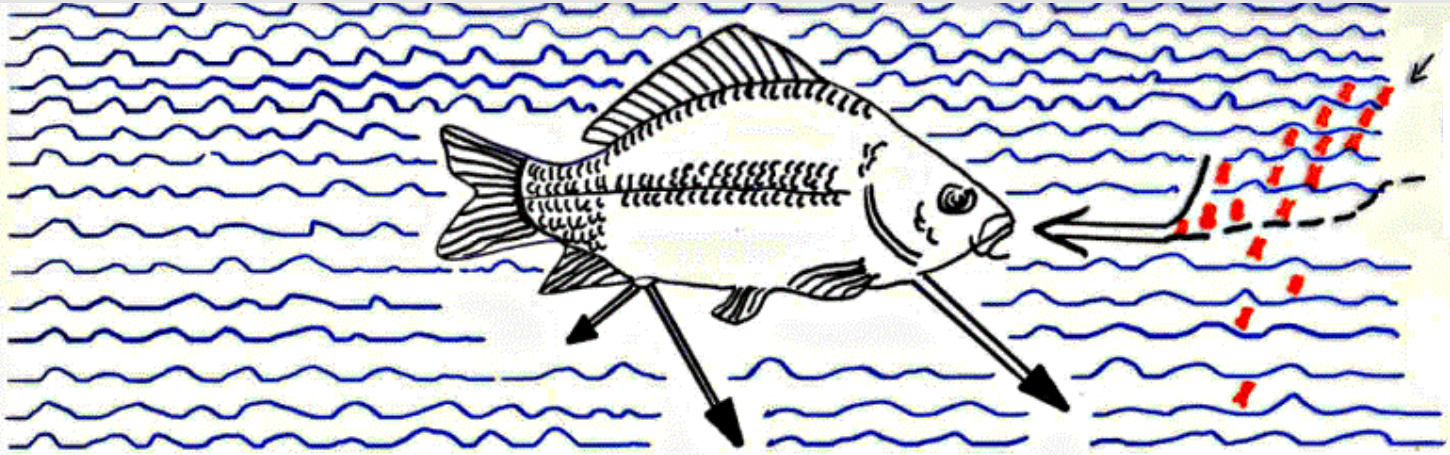


Cell walls (neutral detergent fibre) Fraction A			Cell contents (neutral detergent solubles) Fraction B
Non-nutritive matter	Partially nutritive matter		Nutritive matter
Lignin and acid insoluble ash	Cellulose	Hemi-cellulose	Soluble carbohydrate Protein Ether extract Soluble ash

Van Soest detergent system for partitioning the dry matter of food/feed

(Harris, 1970 - taken from Javier, 1975)

Feed energy



Nutrients
Energy
Active substances

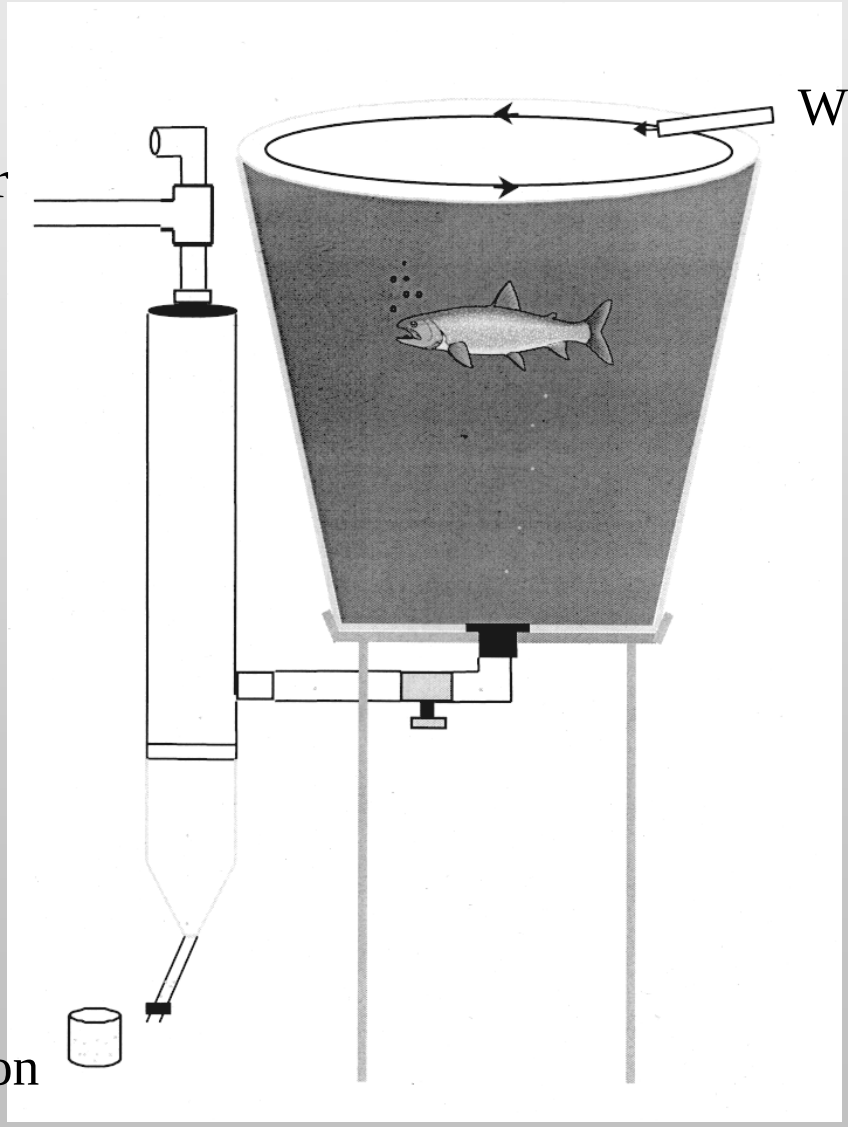
-Urea – N
-Creatin Creatinin-N
-Trimethylamin – N
-Amino acids?

Undigested feed particles and endogenous substances

XP, XL, XF, XX, XA

Gills – N
- Ammonia, NH_3
- Amonium, NH_4
- Amino acids?
- Urea?

Feacal collection by sedimentation



Digestibility of feed/food is generally thought to depend mainly on the NATURE of feed/food ingested.

It is generally assumed that digestibilities are almost constant.

In salmonids digestibility of carbohydrate may be substantially affected by the level of intake

Calculation of apparent and true digestibility of nitrogen

$$\text{APPARENT protein (N) digestibility (\%)} = \frac{I - F}{I} \times 100$$

$$\text{TRUE protein (N) digestibility (\%)} = \frac{I - (F - FK)}{I} \times 100$$

where: I = N intake
F = faecal-N output on the the test diet
F_K = faecal-N output on a non-protein diet

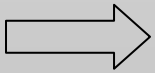
F_K = 12 mg N kg^{-1} d^{-1} on diets without excessive amounts of fibre

Calculation of apparent lipid digestibility

$$\text{Apparent lipid digestibility (\%)} = \frac{\text{(lipids in feed - lipids in faeces)}}{\text{lipids in feed}} \times 100$$

Example: feed consumed 15 g; feed CL 10%; apparent DM digestibility 80%; faeces CL 2%

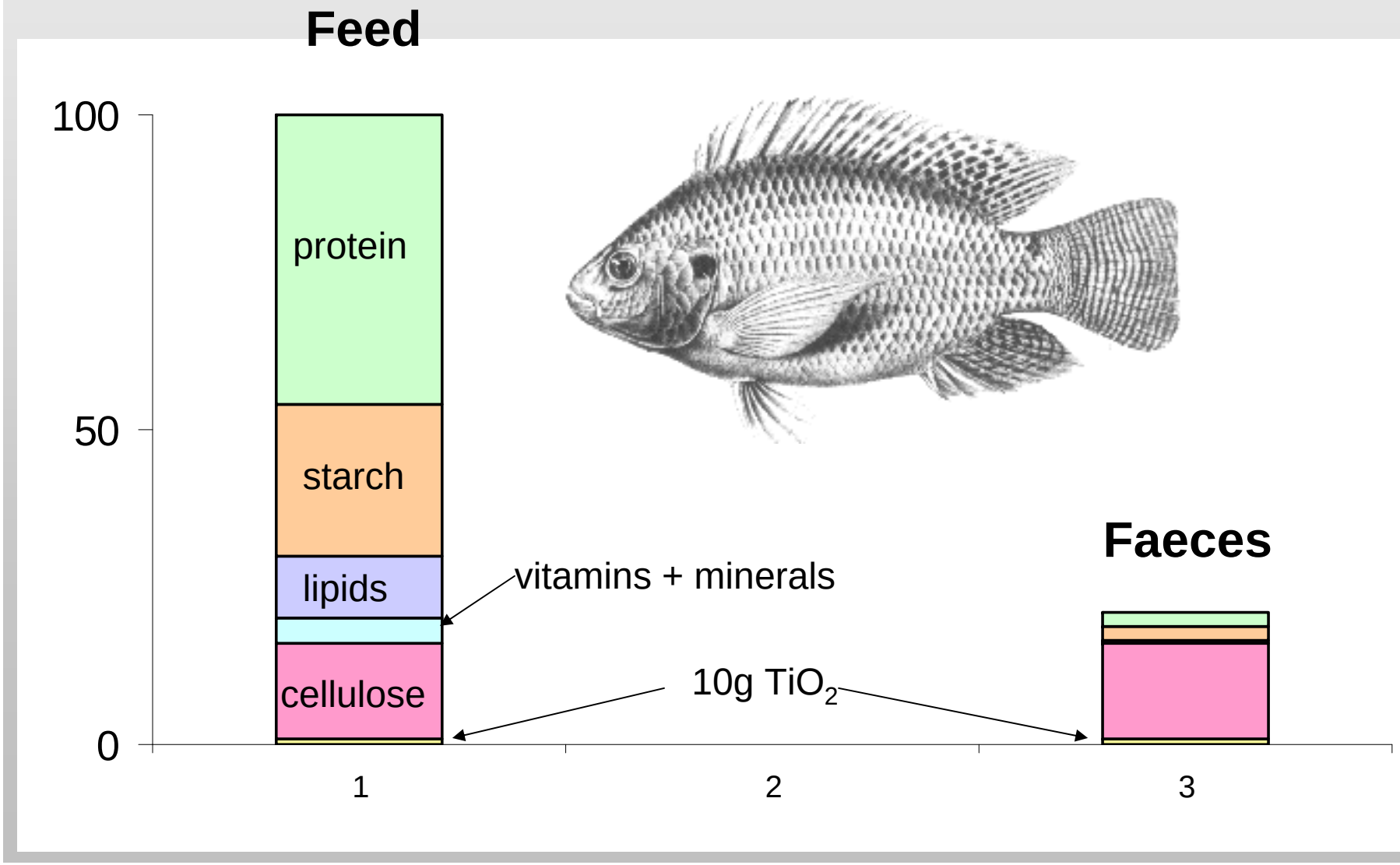
15 g feed
3 g faeces



1.5 g lipids in feed
0.06 g lipids in faeces

$$\text{Apparent lipid digestibility} = \frac{\text{(1.5 g - 0.06 g)}}{\text{1.5 g}} \times 100 = 96\%$$

Determination of the apparent feed digestibility using titanium dioxide (TiO_2) as marker



Calculation of the apparent digestibility

$$\text{Apparent digestibility (\%)} = \left(1 - \frac{(\%\ TiO_2\ \text{feed})}{(\%\ TiO_2\ \text{faeces / recovery})}\right) \times 100$$

Example: TiO_2 feed = 1%; TiO_2 faeces = 4.5%; recovery = 90%

$$\text{Apparent digestibility (\%)} = \left(1 - \frac{1}{4.5/0.9}\right) \times 100 = 80\%$$

Digestibility of crude protein and content of digestible energy in common protein sources of fish feeds

Feed	Digestibility (%)	DE (MJ/kg DM)
Fishmeal	86	21,2
Soybean, extruded	75	19,4
Fababean, autoclaved	87	11,8
Peas, autoclaved	90	11,3
Soybean, powdered	94	14,4
Corn gluten	87	18,3
Wheat gluten	97	19,6

Digestibility of isolated lipids in fish

Lipid source	Digestibility (%)
Herring oil	99
Sunflower oil	99
Soya oil	99
Flax oil	99

Rectification of essential amino acid deficient plant derived proteins by synthetic amino acid supplements

Effectiveness of supplementation strategies

Excellent or good response

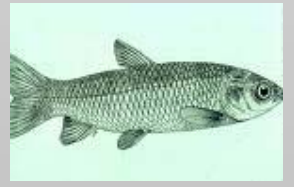
- Salmon

- Trout

- Tilapia

No or very poor response

- Chinese carps

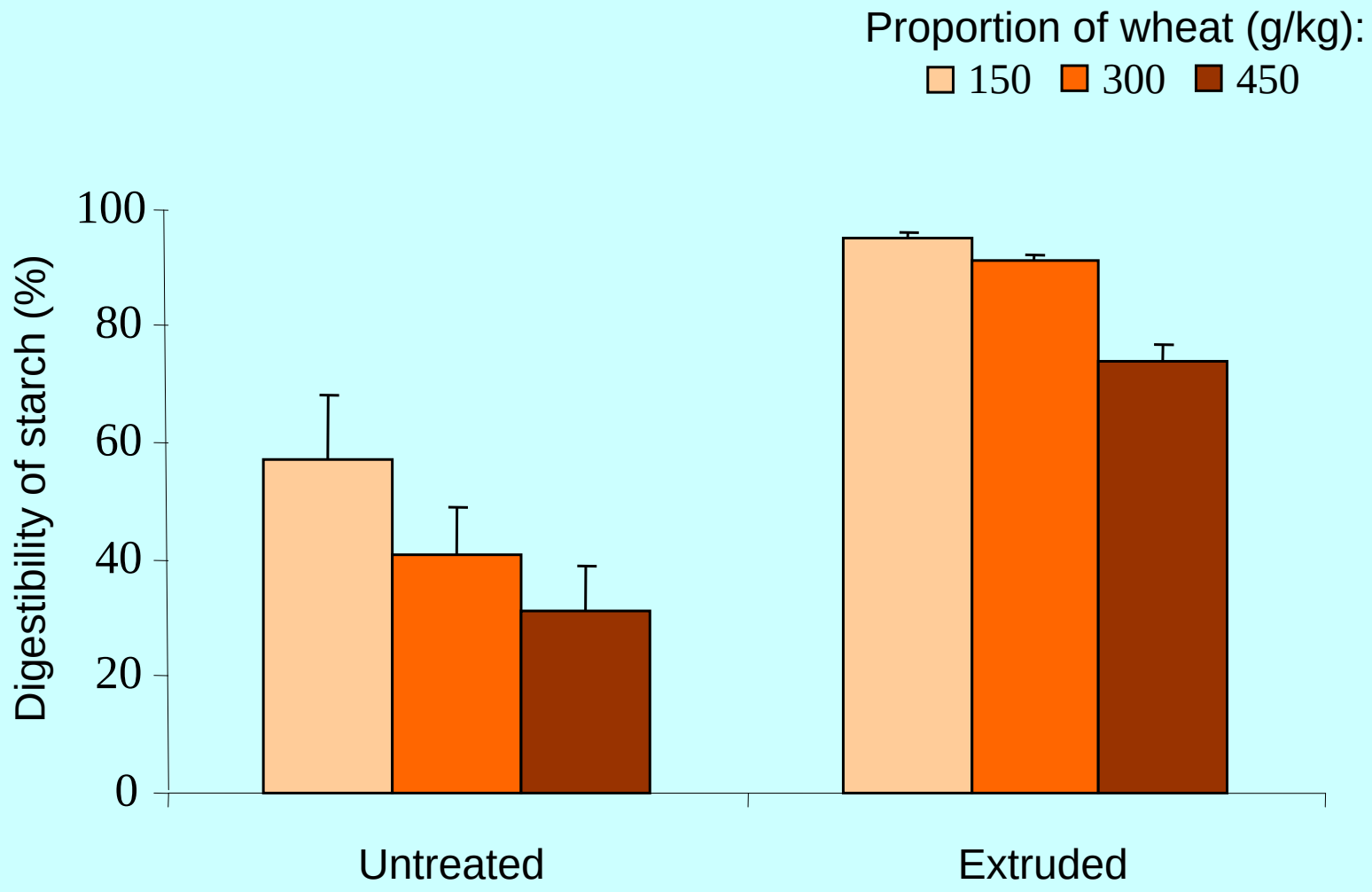


- Major Indian carps

- Catfish??

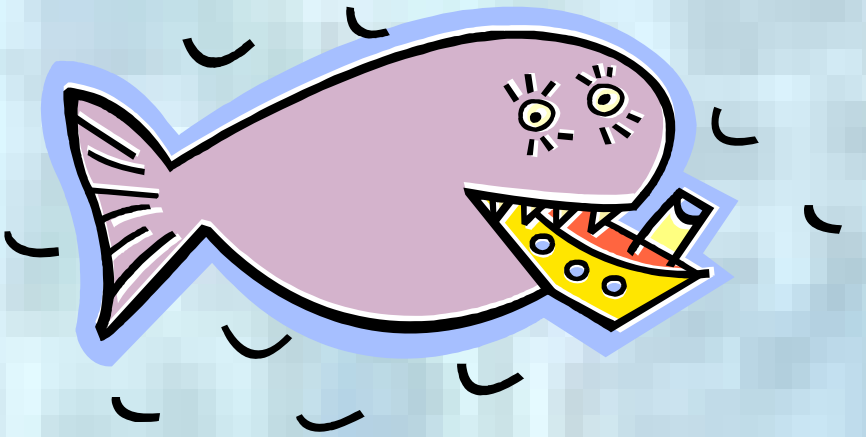
Effect of replacement of casein with synthetic amino acids in fattening diets of carp (Becker, 1985)

Proportion Casein/AA	Days on trial	Protein content of diet	Fish mass (g)		Protein and Energy intake	
			initial	final	Protein	Energy
		% DM			g $kg^{-0.8}$ d^{-1}	kJ $kg^{-0.8}$ d^{-1}
100 : 0	81	34.2	64.7	381	4.9	299
50 : 50	81	33.4	64.6	366	5.0	294
0 : 100	35	32.4	64.9	62.9	4.7	293
25 : 75	46	33.2	62.9	146	5.1	331



Digestibility of starch from untreated and extruded wheat if present in varying proportions in fish feed (n=4)

IV Feed Evaluation



Nutrient requirement, feed efficiency and feeding systems

Derivation of energy and nutrient requirement: The factorial approach.

The pathways of food/feed energy through animal and human body.

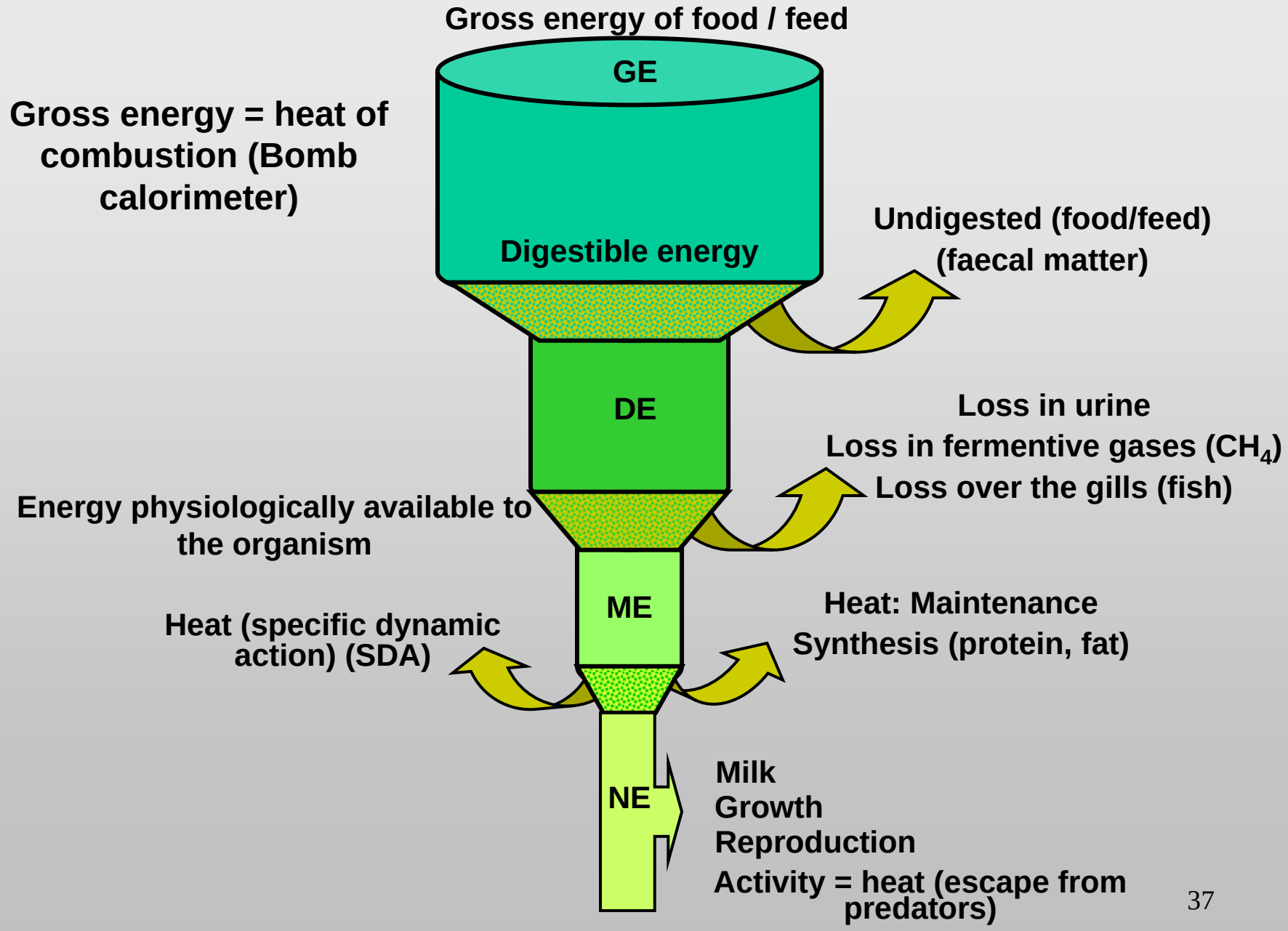
Protein quality and growth performance.

Energy and nutrient availability: Practical example from feeding experiments.

Important criteria with reference to results from feeding experiments.

Feeding techniques and efficiency of growth.

Energy cascade in humans and animals

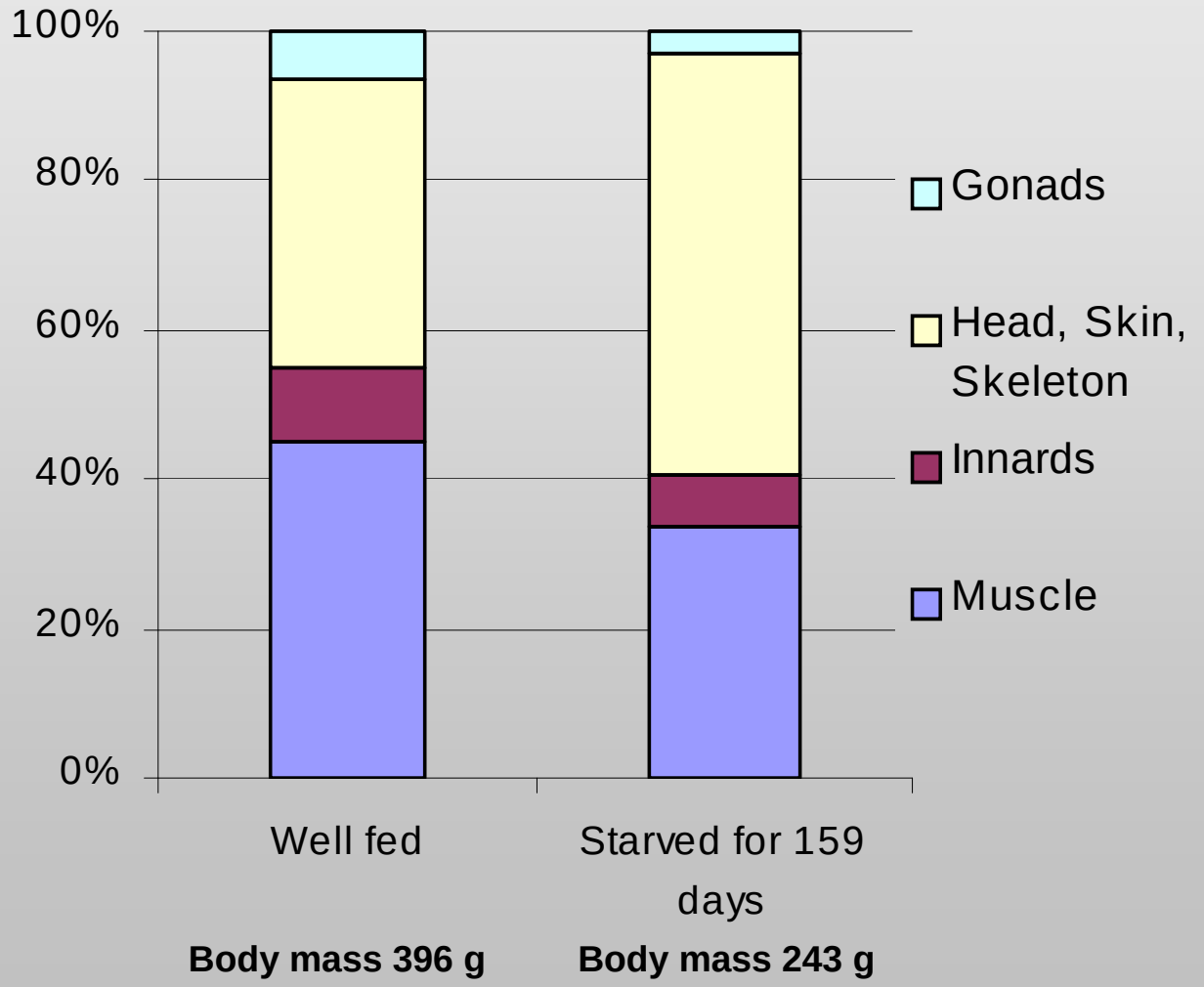


Comparison of proximate composition, energy and mineral content in some fish species with other foodstuffs (related to fresh weight of edible part)

Species	Proximate composition		Energy MJ/kg^{-1}	Minerals g kg^{-1}	
	Protein %	Fat %		Ca	P
Salmon	23.0	13	8.9	0.1	0.19
Cod	18.0	1	3.3	0.01	0.20
Carp	15.0	8	6.5	5.7	8.7*
Tilapia	15.5	6	6.9		*
Beef	16.0	34	15.9	-	0.14
Pork	17.0	25	12.5	-	0.20
Egg	13.0	12	6.8	-	-

*Whole body composition

Proportion (%) of body constituents in well fed and starved Fish *(Cyprinus carpio L.)*



Variation in fish flesh proportion (edible part) of various species

Portion destined for human consumption varies from 25% to 75% of total fish mass. These differences are largely associated with:

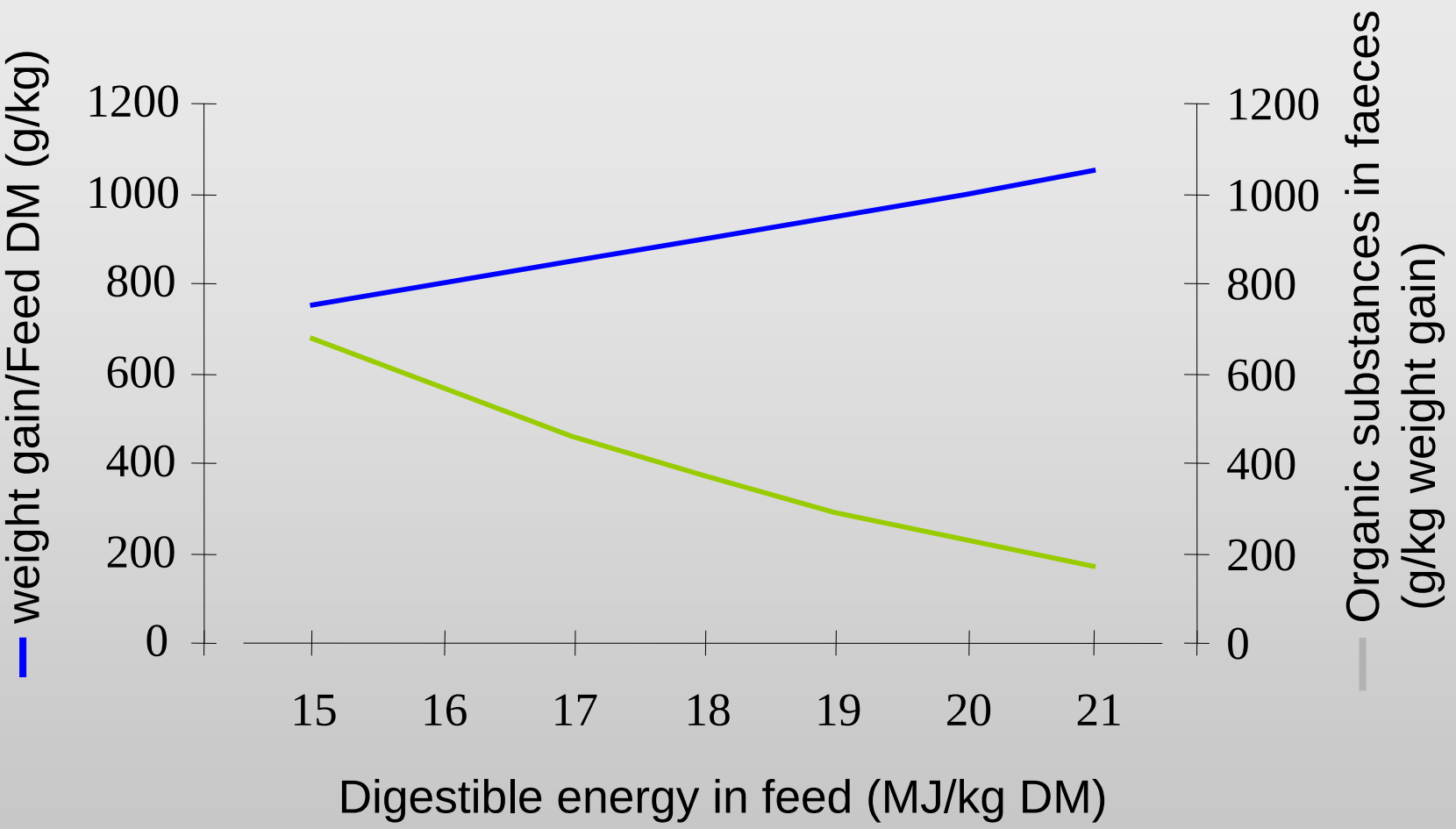
- Body shape
- Nutritional condition
- Skeletal characteristics
- Age

Proportion of edible part (%)			
50 – 70%	**30 – 40%**	**20 – 30%**	**15 – 25%**
Species with long trunks and small heads	Species with short trunks and large heads	Most popular carnivorous fish, have intermediate proportions	
• Tunas • Salmon • Carp • Cod • Herring	• Rock fish • Sculpins	• Basses • Perch • Grouper • Snapper	• Shrimps • Crabs • Lobster

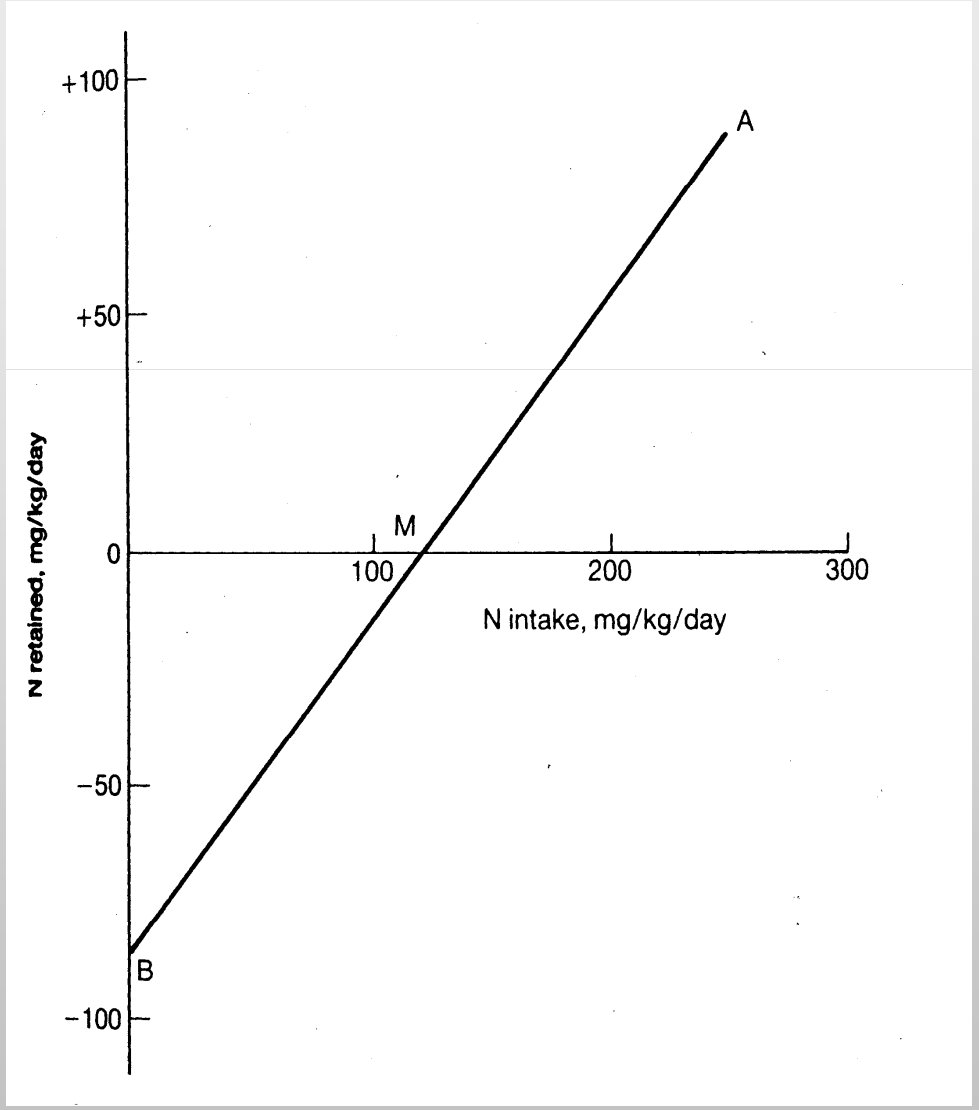
Essential amino acid (EAA) utilisation

- **Maximal utilisation (65-80 %) when 50-70 % of the maximum protein retention is achieved**

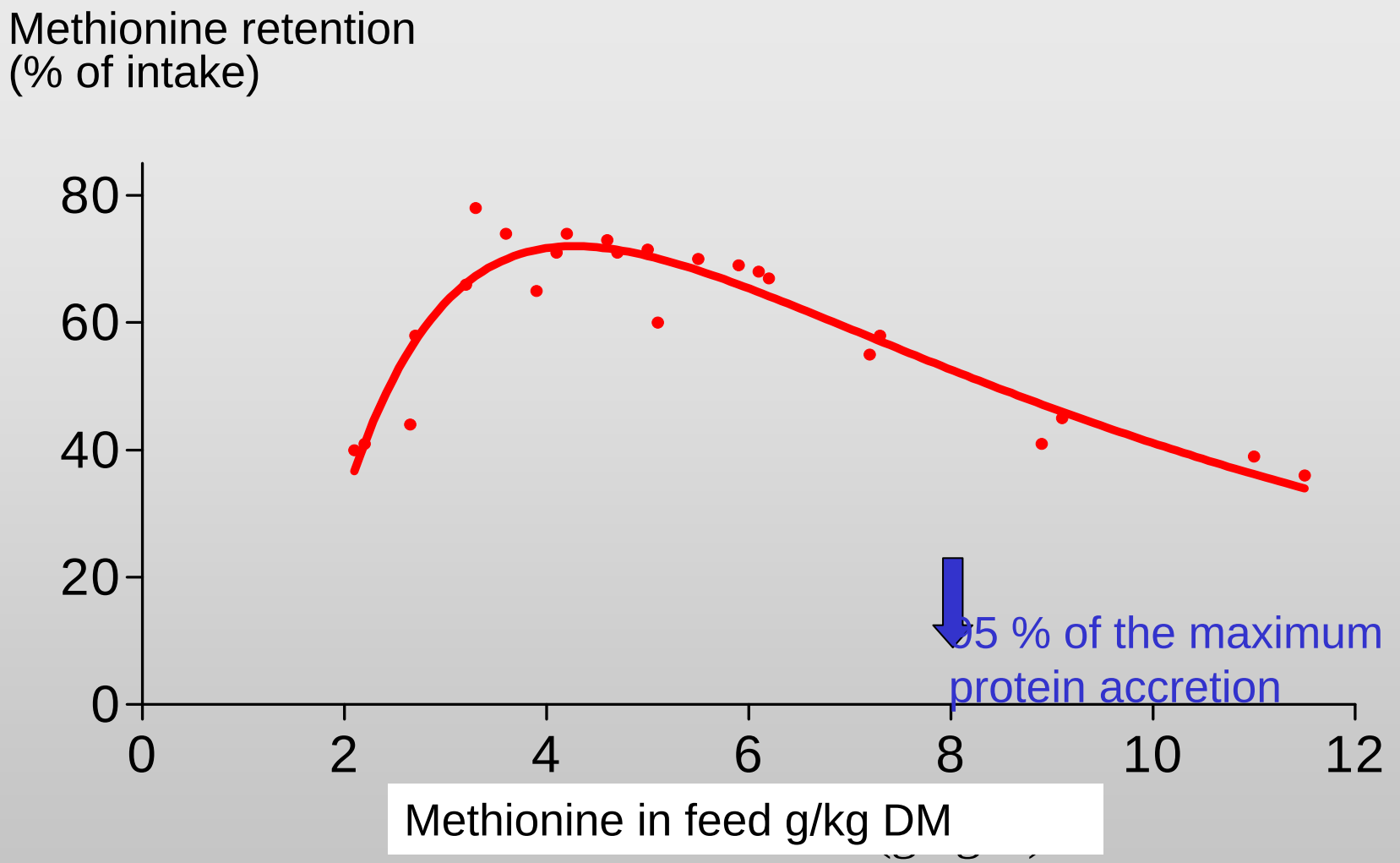
- **If maximal protein retention is the target, EAA utilisation drops to 40-60 %**



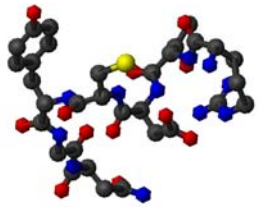
Feed conversion and feed lost in faeces depending on energy content of the feed



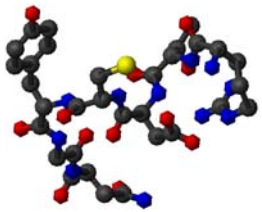
Requirement for Nitrogen



Utilisation of methionine by trout



Protein conversion parameters



- Protein Efficiency Ratio (PER)
- Productive Protein Value (PPV)

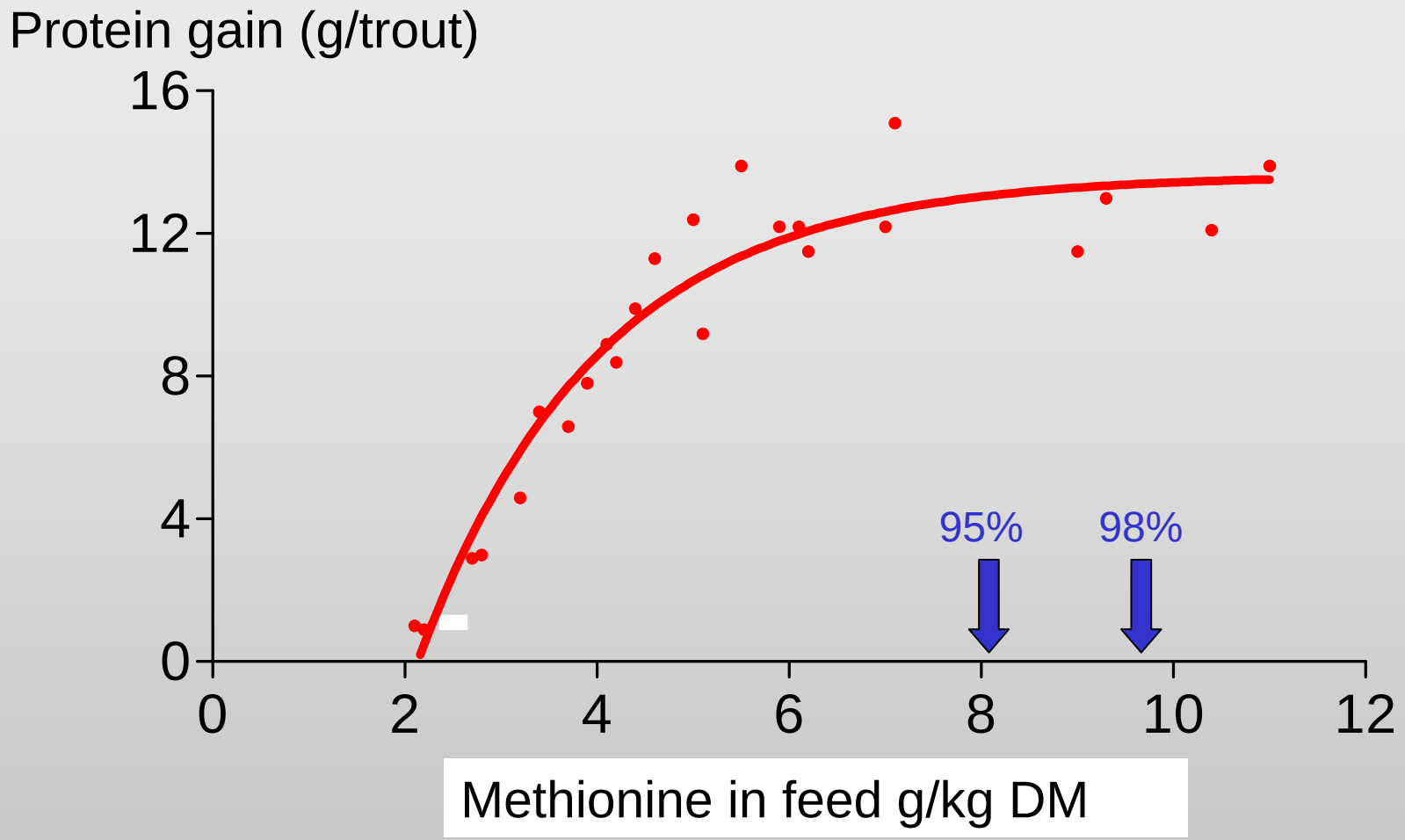
PPV and PER

Protein efficiency ratio (PER)

PER = weight gain (g) / protein intake (g)

Protein productive value (PPV)

PPV = [(final carcass protein – initial carcass protein) / protein feed] x 100



Protein gain of trout depending on methionine concentration in the diet

Protein and energy requirement currently recommended for growth in different fish species

Species	Digestible Protein (mg g^{-1} DM)	Digestible Energy (kJ g^{-1} DM)	Ratio DP/DE (mg Protein kJ^{-1} Energy)
Catfish	270 – 244	13.1 – 12.8	19 – 21
Trout	330 – 420	15.1 – 17.2	22 – 25
Common Carp	315	12.1	26
Tilapia	300	11.5	26

Fish generally digest proteins with (apparent) an efficiency exceeding 90%.

Proteins of animal origin are generally more digestible than those of plant origin.

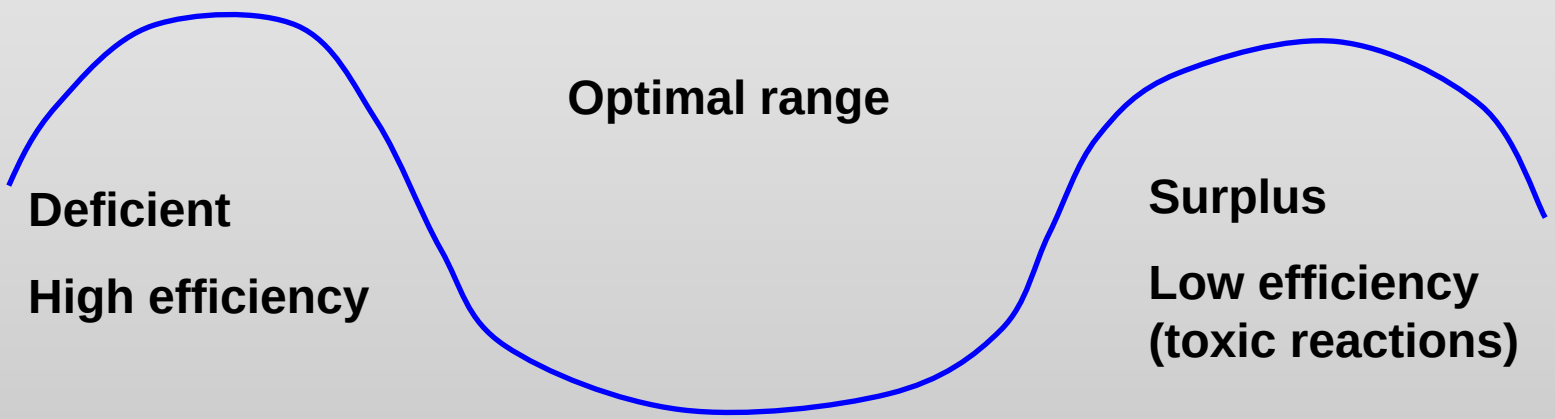
Processing of plant proteins brings about a marked increase in digestibility.

For example, cooking of whole soya bean leads to an increase from 70% to 85%.

Treatment effects are due to the destroying of antinutrients and changes in the carbohydrate moity of plant material.

Concentrations of digestible energy (DE) and digestible crude protein (DCP) in dry matter of various ingredients tested in trout (Pfeffer et al., 1995)

Feed	Proportion in diet	DE (MJ kg^{-1})	DCP (g kg^{-1})
Not influenced by dietary proportion			
Wheat gluten	924	21.6	818
Fish oil	210	39.0	
Poultry blood meal	500	20.6	780
Pressure cooked soya beans	500	19.4	362
Influenced by dietary proportion			
Poultry offal meal	250 500	18.3 18.3	513 507
Gelatinized corn starch	210 407	21.2 7.2	
Field beans: raw	250 500	7.9 5.9	214 197
Autoclaved	250 500	12.3 10.5	250 242
Field peas: raw	250 500	8.7 7.3	218 210
Autoclaved	250 500	21.1 7.4	230 218



Energy and nutrient availability and consequences for their use efficiency

(practical examples from feeding experiments; after Pfeffer, 2003)