NOVA course - 2025

Feed production, 24/6-2024.

from Liv Torunn Mydland

Sergio Rocha 19.6.2025

NMBU: we have our own Centre for Feed Technology

Photo: Ingvar S. Olsen

Photo: Dejan Miladinovic

Optimal nutritional composition of a fish feed depends on e.g.:

- Fish specie
- Production phase (Larvae? Fry? Smolt/Transfer? Grower?Broodstock?)
- Fish size
- The expected/«wanted» growth (FCR, TGC, SGR…)
- Season – water temperature
- System (open/closed/semi-closed cages, RAS?)
- Health-related stressors, etc

Primary reasons for feed processing

- Alter physical form
- Alter particle size
- Prevent spoilage
- Improve palatability
- Inactivate toxins/anti-nutritional factors
- Ease of handling
- Increase digestibility

- Improve intake of nutrients
- Increase surface area of particles
- More surface area for chemical and enzymatic reactions
- Change molecular structure
- Denaturing, cooking starch, creating biological polymers

Salmon feed vs farm animal feed

(or other herbivores)

A lot of protein and fat!

Contain much more
carbohydrates – and less protein
and fat !

Cold-pelleting vs extrusion

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MIXING SHEET

Inclusion (g/kg)	Ingredient	%	% adjusted for water
260,0	FM	0,26	0,1872
245,0	SPC	0,245	0,1764
100,0	WGM	0,1	0,072
116,7	GPS	0,1167	0,084024
190,0	FO	0,19	0,1368
15,0	MCP	0,015	0,0108
5,0	PREMIX	0,005	0,0036
60,0	GELATIN	0,06	0,0432
4,0	L-Lysine	0,004	0,00288
1,5	DL-Methionine	0,0015	0,00108
1,3	Iron	0,0013	0,000936
1,5	Choline chloride	0,0015	0,00108
1000,0	Water	0,28	0,28
			1,0000
		Amount of feed TOTAL WET (kg)	
Ingredient	**kg**	**9**	**Half for paddle mixer**
FM	0,1872	1684,8	842,40
SPC	0,1764	1587,6	793,80
WGM	0,072	648	324,00
GPS	0,084024	756,216	378,11
FO	0,1368	1231,2	
MCP	0,0108	97,200	48,60
PREMIX	0,0036	32,400	16,20
GELATIN	0,0432	388,8	
L-Lysine	0,00288	25,920	12,96
DL-Methionine	0,00108	9,720	4,86
Iron	0,000936	8,424	
Choline chloride	0,00108	9,720	4,86
Water	0,28	2520	
Total amount	**1**	**9000**	
Dry ingredients		6480	
SUM dry ingredients (pellets)		**6480**	
Dry minus gelatin + oil		4860	2425,788
		CHECK	**2430**

Cold-pelleting

Extrusion

COLD-PELLETING

Cold-pelleting

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Cold-pelleting

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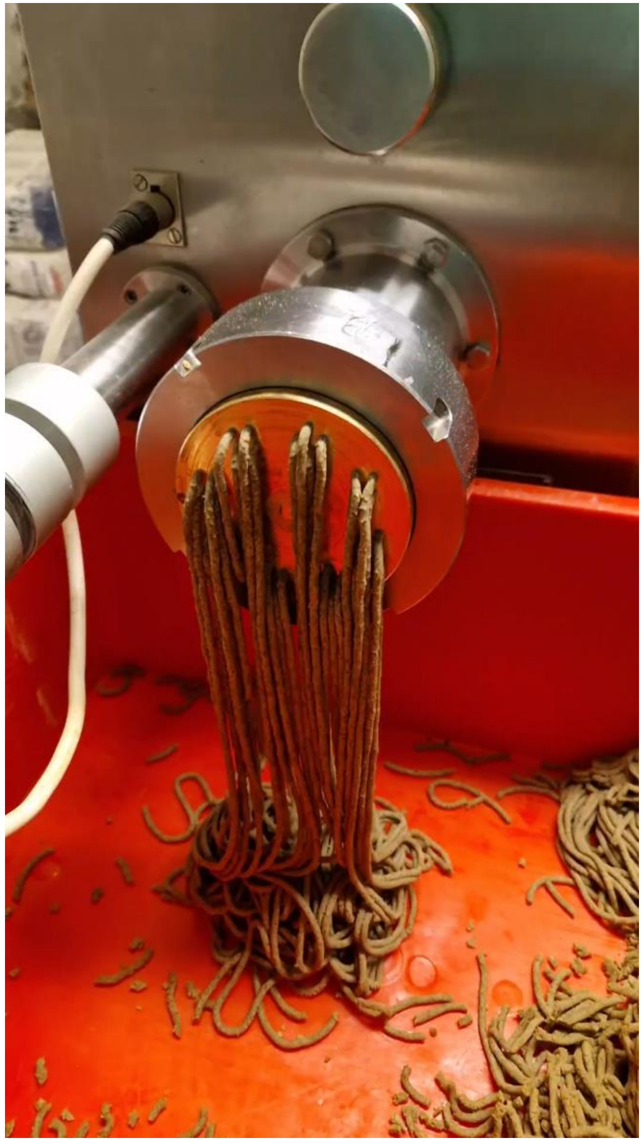
P35A

Pasta machine (Pasta extruder)

Cold-pelleting



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Cold-pelleting

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EXTRUSION

Mini-Extruder at MNBU

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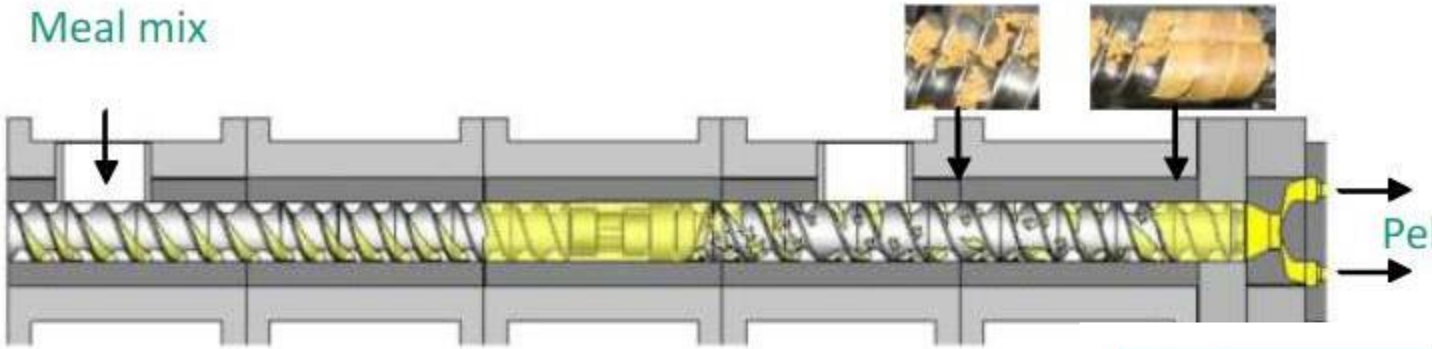
ThermoFisher
Process 16
Parallel Twin-Screw Extruders

25 – 35% moist (H_2O)
Temp: 110 – 130 °C
Pressure: 5 – 25 bar (or much more)



Pellet properties	Raw material properties	Molecule/	Raw material, example	Process-properties
No not crack	Elastic-	Gluten	Wheat	110 – 130 °C
Do not create dust/loose small particles	High binding («glue»)	Gluten (G), starch (S)	**G**: Wheat. **S**: grain; rice, tapioca, corn	110 – 130 °C
Ensure space for oil	Expansion	Starch	Grain, rice, tapioca, corn	Pressure difference out of extruder (ΔP > ~5 bar)
Do not leak oil	Ensure small pores (not a few large ones)	Starch	Grain, rice, tapioca, corn	Not too high pressure difference out of extruder (ΔP < ~30 bar)
Each pellet should have same size & properties	Narrow particle size distrubution			Thorough milling

EXTRUSION:
- Take only ca 30 seconds
- 25 – 35% moist ($H2O$)
- T: 110 – 130 °C
- Pressure: 5 – 25 bar

Extruders are also used for cheese doodles, corn flakes etc)

MORE than enough expansion!

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2mm

Moist and expansion

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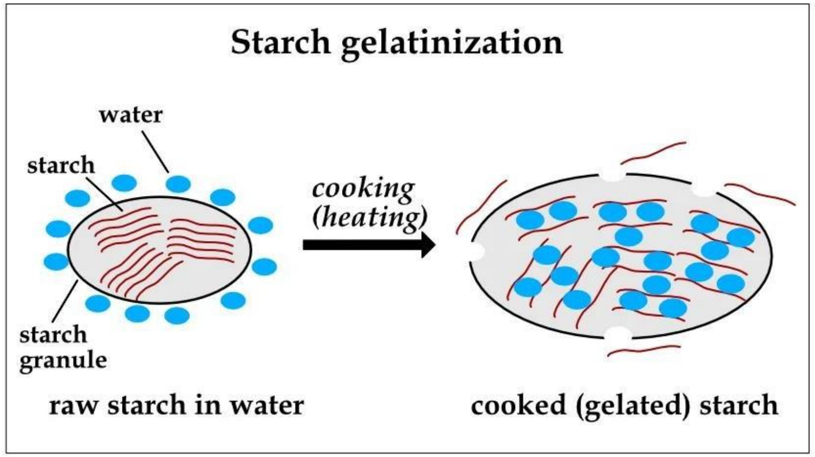
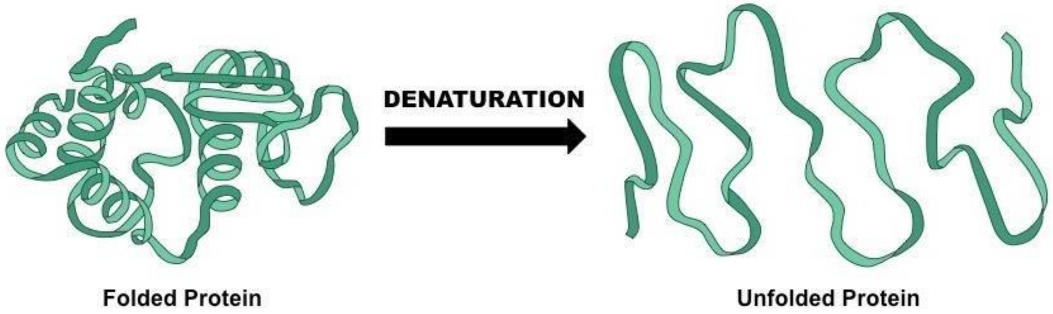
Cold-pelleting vs extrusion

	PROS	CONS
Cold-pelleting	- Ideal for small/pilot trials - Requires less material & less waste - Optimal to sensitive ingredients - Less technical	- Requires pre-gelatinized starch - Less water stability - Not used by fish industry - More chances to spoil
Extrusion	- More water stability - Increase digestibility - Industry-like - Longer shelf-life	- Requires larger amounts of ingredients - Temperature- and pressure-sensitive ingredients are added in additional steps - More technical

Advantages of extrusion – compared to pelleting

- increased temperature (90°C to 160°C)
- increased fat addition (30% or more)
- gelatinization of starch (70% to 95%)
- pasteurized/sterilized feed (90°C to 160°C)
- improved denaturation of protein
- increased production capacity (up to 50%)
- improved pellet durability (up to 20%)
- lower dust formation
- a more flexible process





How to make good pellets?

(in theory…)

What is a good pellets for aquaculture

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1. Control of floating/sinking properties
2. Pellet durability for handling/transportation
3. Attractive pellet appearance (shape and size)
4. Proper fat absorption characteristics
5. Rapid water absorption while maintaining integrity
6. Fish nutrition & health

Sinking speed is species-specific

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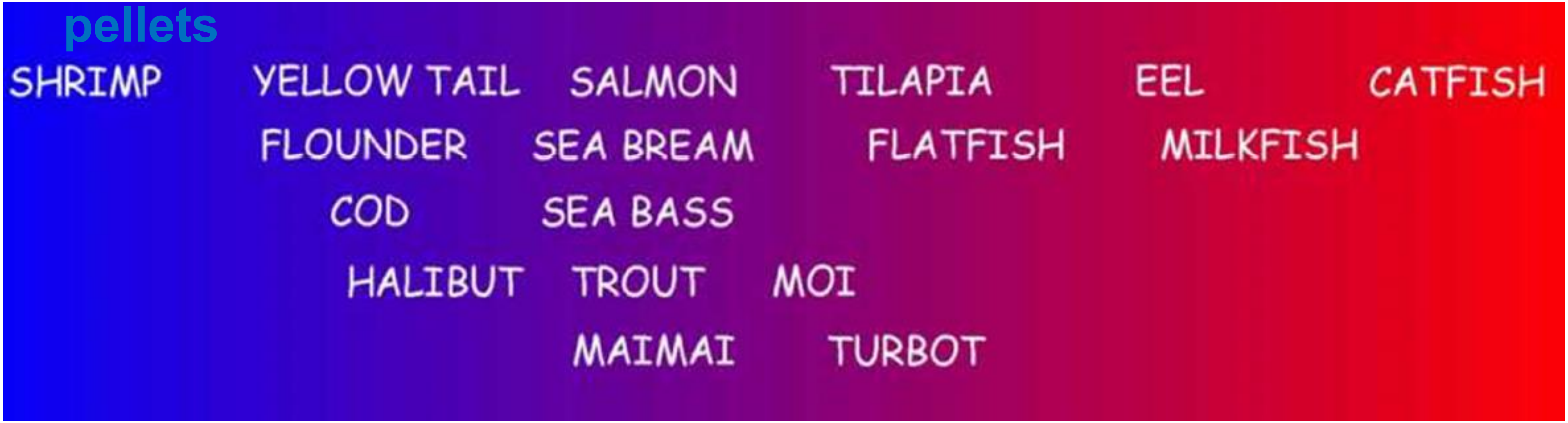
Fast sinking pellets

Slow sinking pellets

Neutral Bouyance

Floating pellets



Sinking speed and Bulk Density

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Product Bulk Density Correlation with Buoyance

Pellet Characteristic	In sea water @ 20℃ (3% salinity)	In fresh water @ 20℃
Fast sinking	> 640 g/l	> 600 g/l
Slow sinking	580-600 g/l	540-560 g/l
Neutral buoyancy	520-540 g/l	480-520 g/l
Floating	< 480 g/l	< 440 g/l

How to control sinking velocity?

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Ingredients + Extrusion (physics) = Bulk density

Wheat Flower
Wheat Gluten Meal

Starch assists expansion, binding, viscosity, pellet durability and oil retention **[11-15%]**

Gluten promotes elasticity and binding **[7-9%]**

Input mix (kg/h)
Input water (L/h)
Temperature (in diff. sections)
Screw configuration rotation (Rpm)

Pressure: affected by viscosity and all the parameters above.

After expansion, pellets should have a low density (floaitng).

Once coated, density will increase and they should sink slowly.

NB! But we only know AFTER finishing all the process! = tests!

How to control sinking velocity?

Extruded Floating and Sinking Diets Containing High Levels of Vegetable Protein

Made from base recipe containing 70% soybean meal, 20% wheat flour, and 10% fish meal.

After coating, these products contained 22% fat and 35.5% protein

494 g/l product density

750 g/l product density

Die and pressure

A diet composition and physical conditions that work well with a specific die will not work to a die with a different diameter!

How to control sinking velocity?

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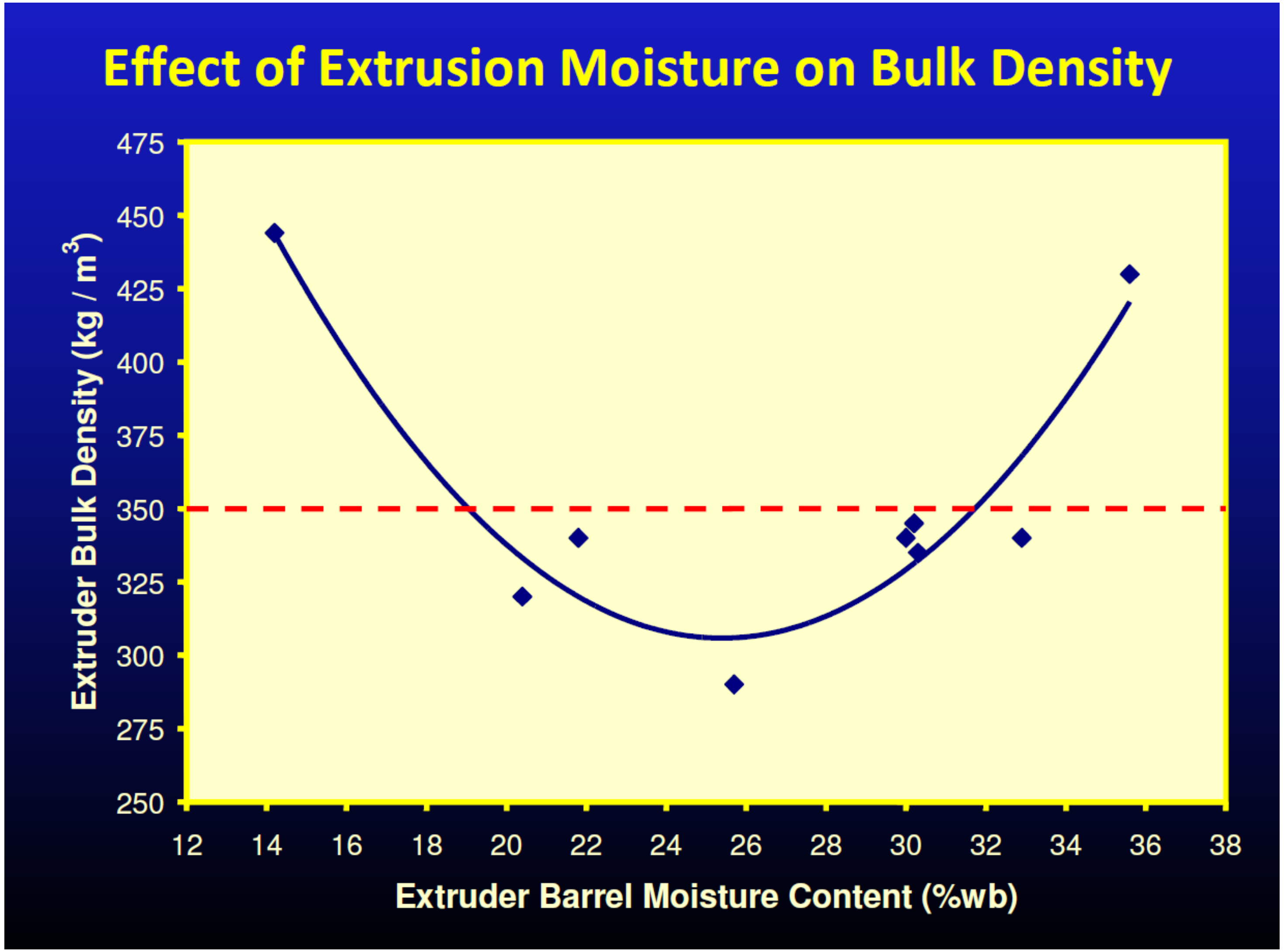
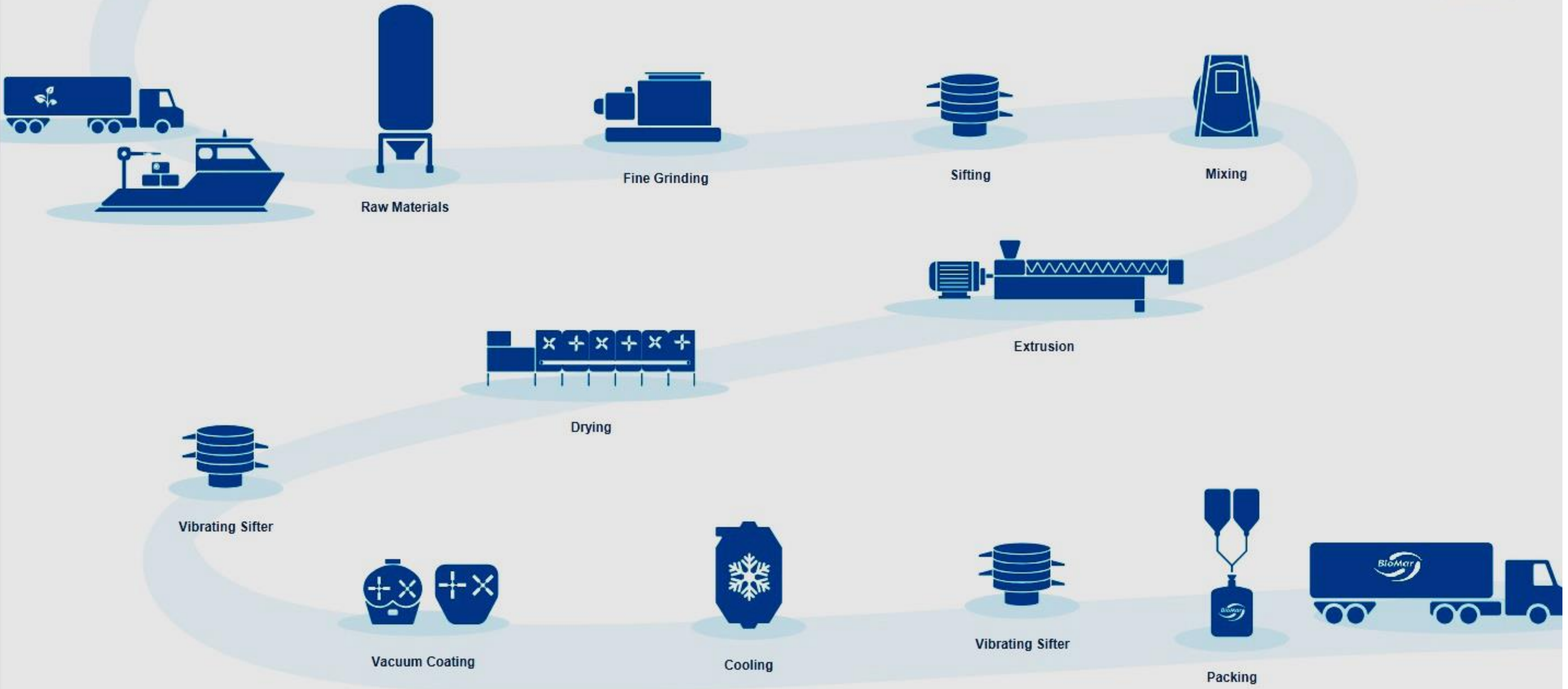


Drying and vacuum coating

Diet	Final Moist %	Weight before coating	Oils to add	**Final weight pellets (kg)**
1	9,65 % (35min)	5,82 kg	1,278 L	**6,98**
2	8,54 % (40min)	5,70 kg	1,251 L	**6,92**
3	8,80 % (45min)	5,64 kg	1,238 L	**6,86**

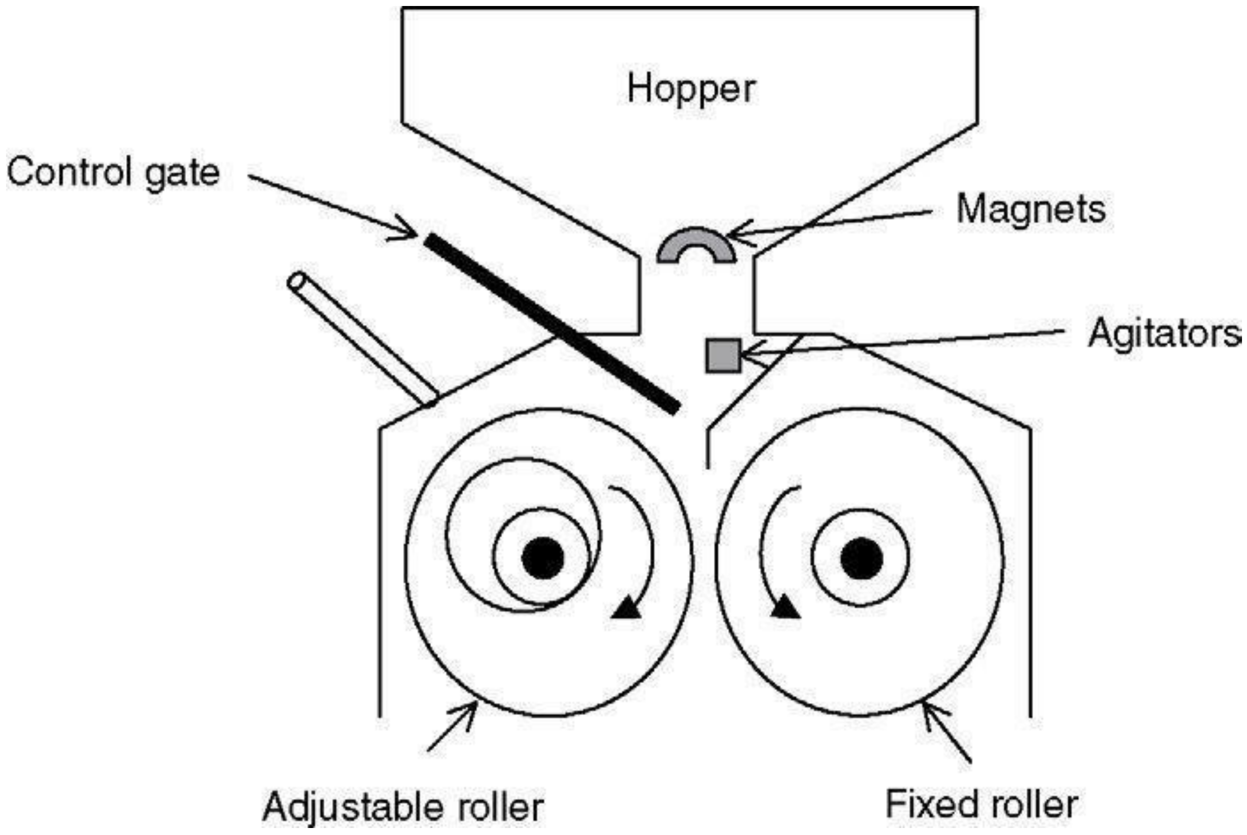
At industrial scale

Manufacturing Process

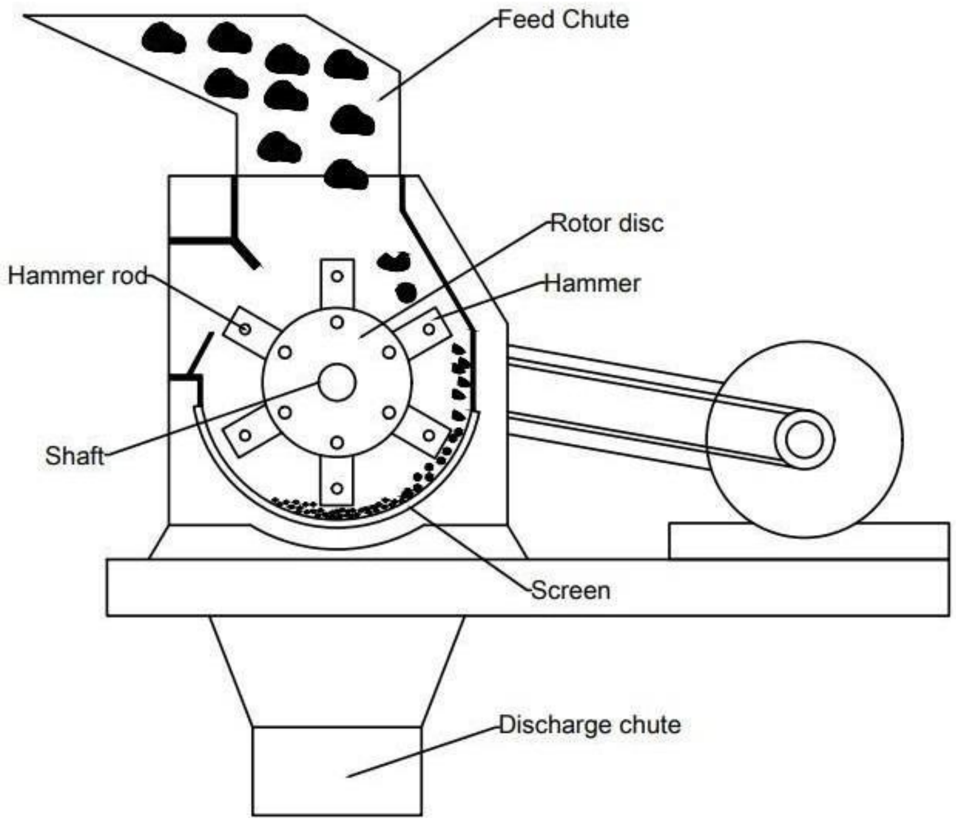


Grinding

Roller mill



Hammer mill

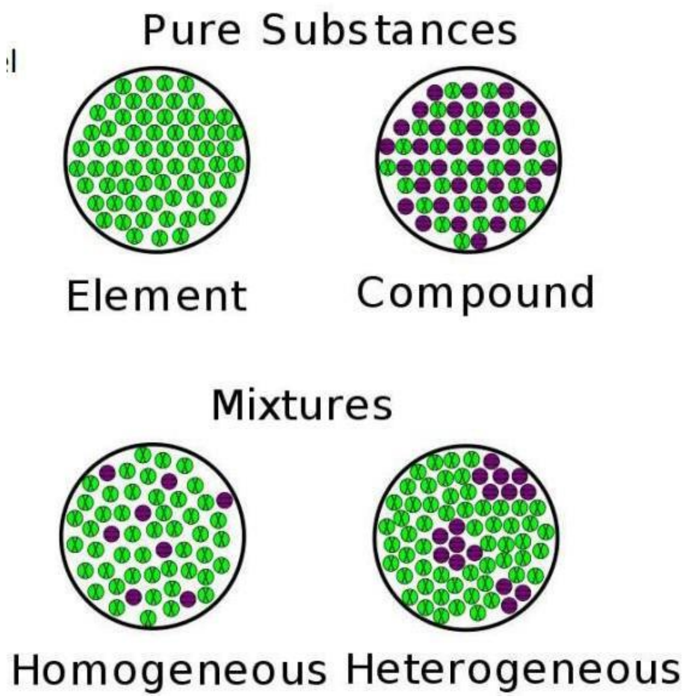


Weighing/dosing - mixing

- The objective of the mixing process is to produce feed in which all nutrients are uniformly distributed.

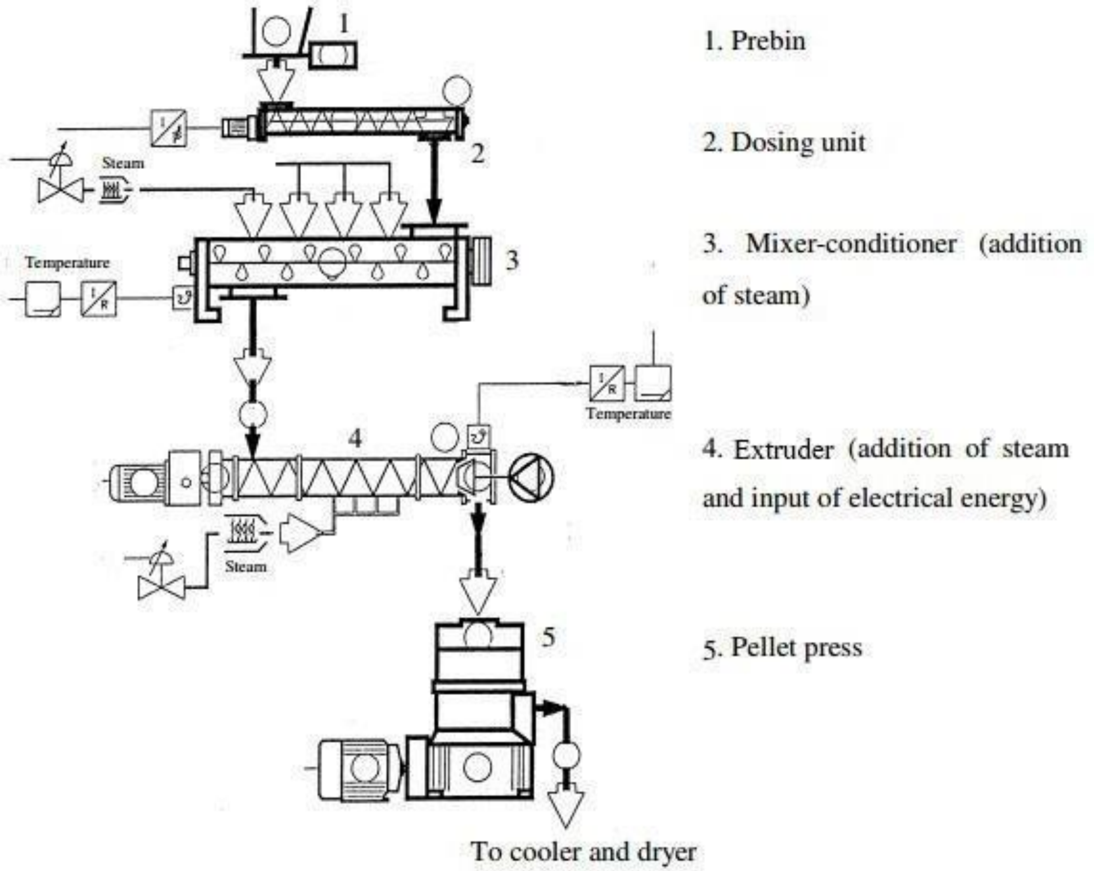
- Type of material?
  - Powder vs Liquids

- **Factors that determine mixer performance:**
  - Physical properties (particle size and shape, density, electric charge)
  - Sequence of ingredient addition
  - Build up of material / overfilling or underfilling
  - Mixing time



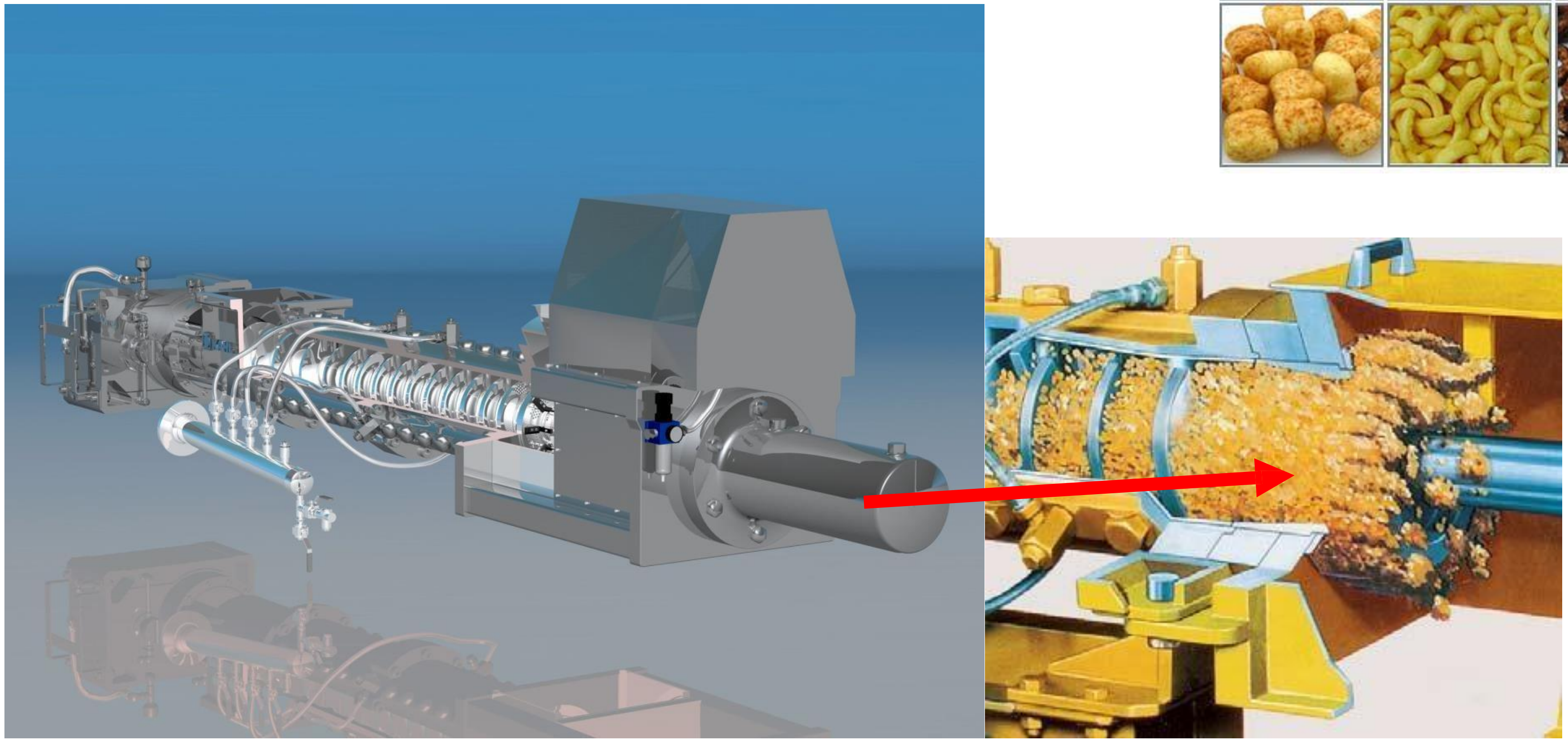
Steam is important!

- High energy - in a small volume
- Easy to transport (pumps are normally not necessary)
- Cheap and usable
- Intrinsically safe medium
- Temperature is related to the pressure
- Gives the heat to everything with lower temperature immediately
- Condense back to water immediately after the heat has been “handed ove” to the other ingredients in the mix

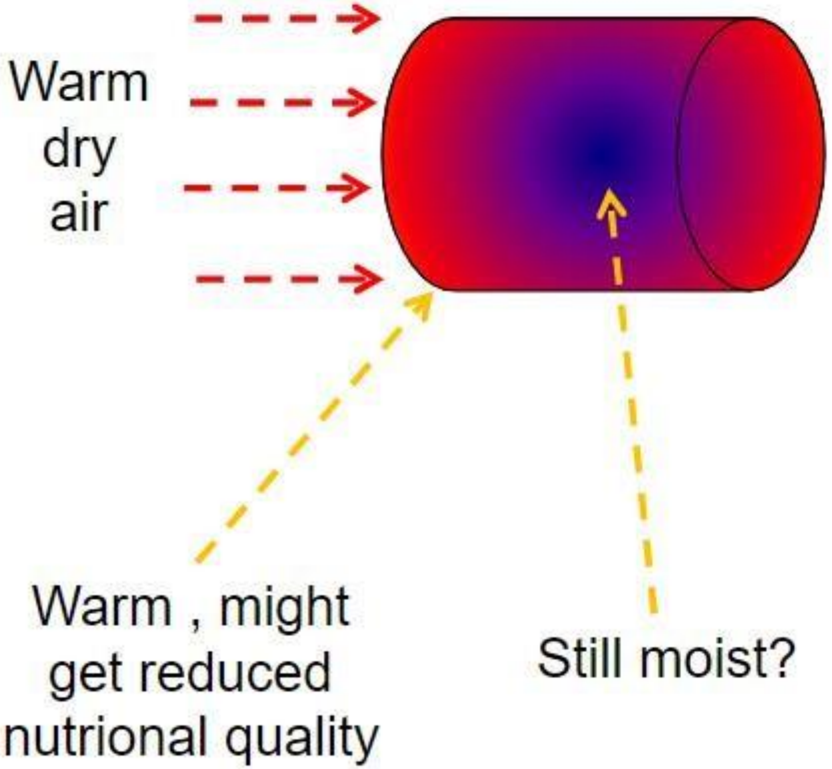


The Extrusion Processing Line

Extrusion - expansion

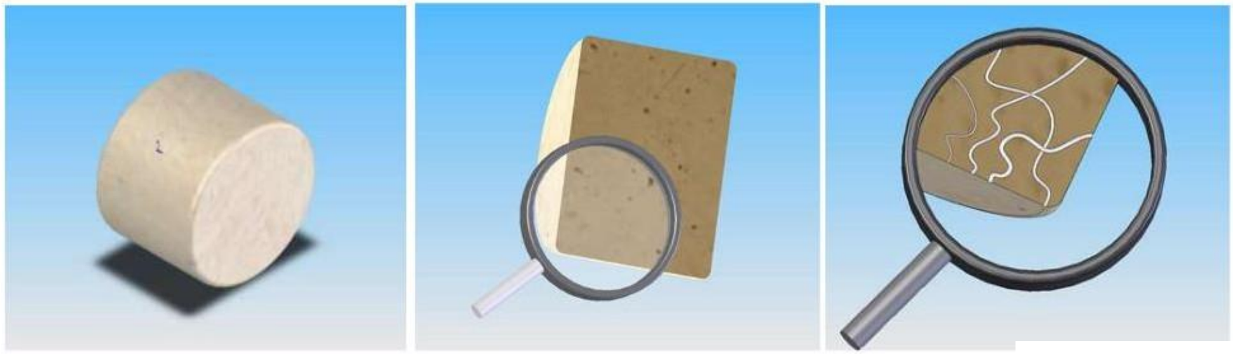


Drying

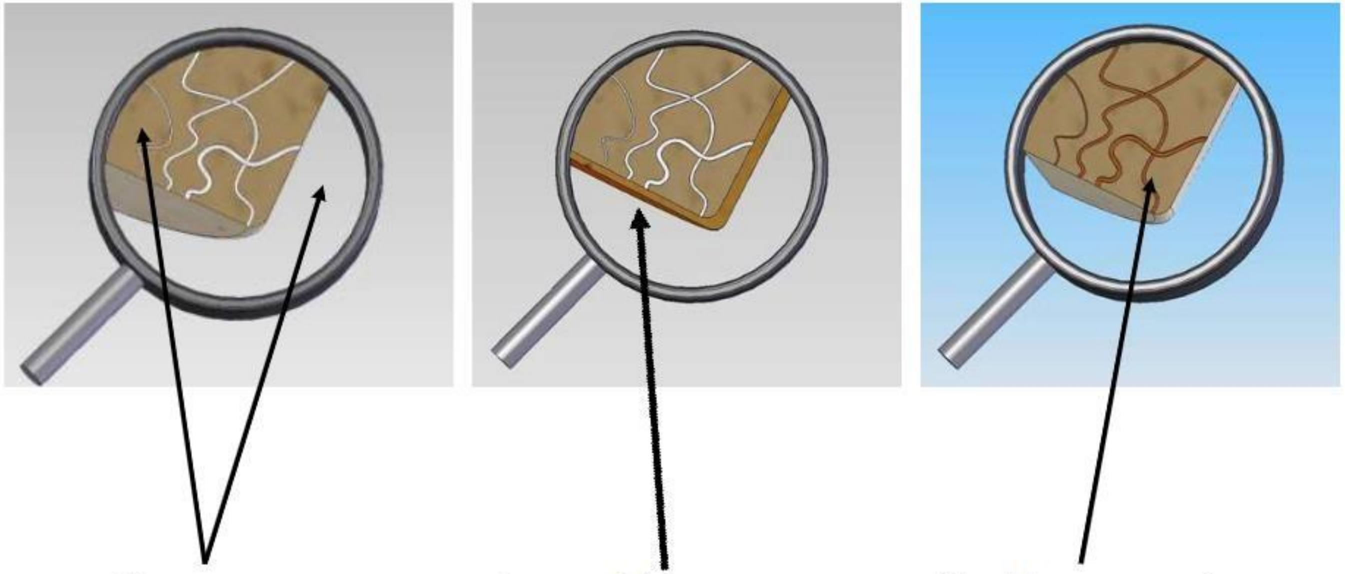

Warm
dry
air
Warm , might
get reduced
nutrional quality
Still moist?


BÜHLER

Vacuum coating



Extruded pellet – no oil added



Vacuum
around and inside
of the pellet

Layer of fat or any
other liquid (vitamin
color, aroma...) blinded
by capillary forces

Liquid component
in the pellet cavities
sealed by atmospheric
pressure

Vacuum infusion (fill the pellet with oil)

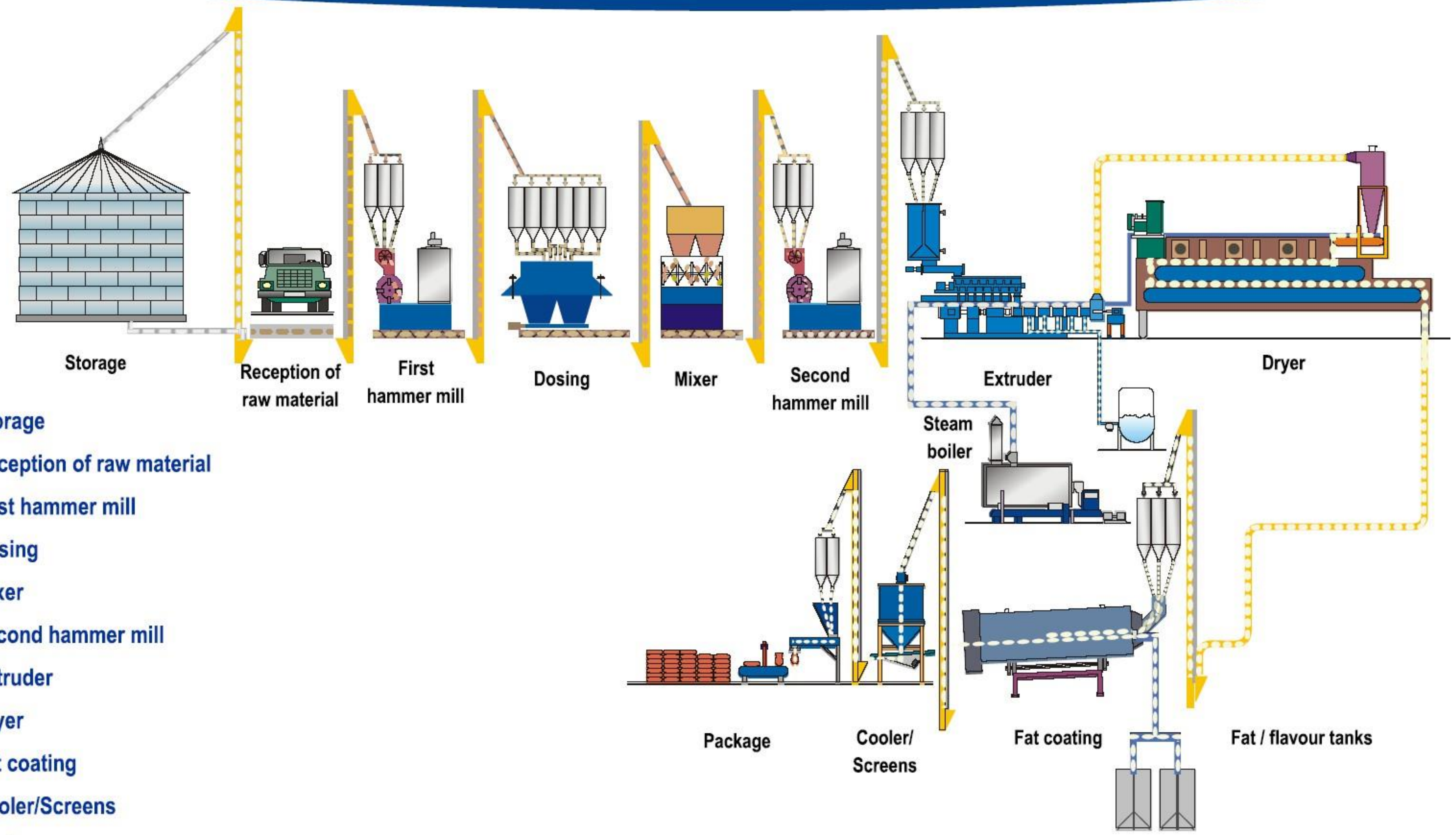
No oil added

10-15% oil

More than 30% oil

Source: Olav Fjeld Kraugerud

Extruded Feed Production Flow



Storage

Reception of raw material

First hammer mill

Dosing

Mixer

Second hammer mill

Extruder

Dryer

Fat coating

Cooler/Screens

Package

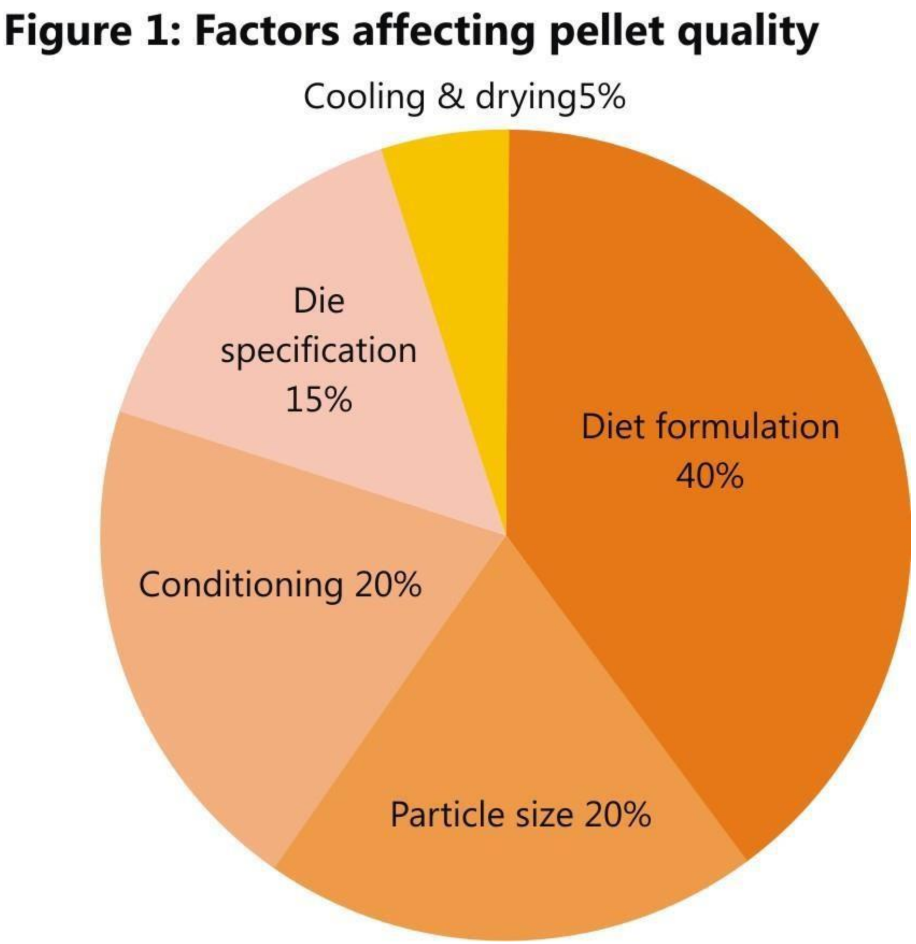
Salmon pellets must:

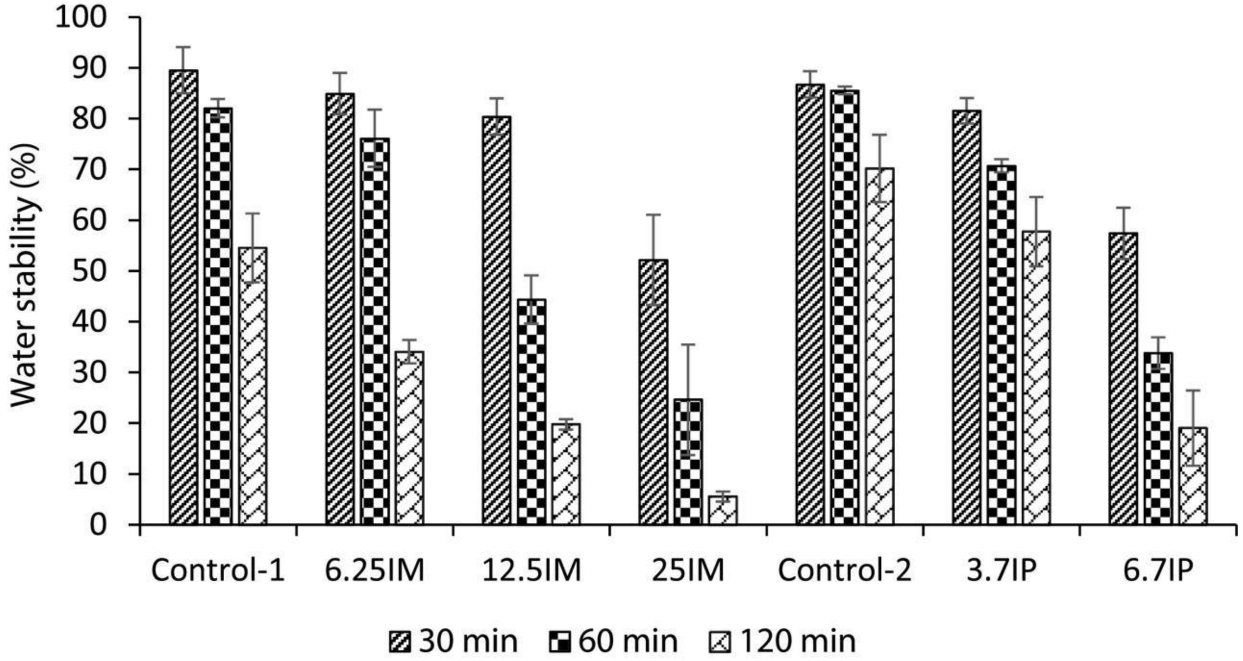
- A salmon pellet must contain correct amount of ALL nutrients, including all additives (e.g., astaxantin), and many of the antinutrients should be destroyed (or limited).

- Other important qualities – when being pumped into the cages:
  - Must be stable in water
  - Correct sinking velocity
  - Must be hard – (must not break into dust/loose smaller pieces) – but must not be too hard (digestibility can be affected…)
  - Must not leak fat !

  (more about pellet quality tomorrow ☺)

Pellet quality

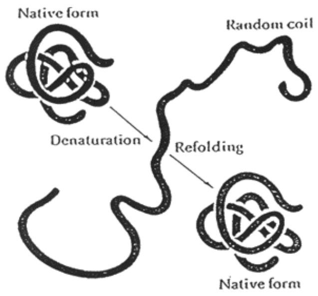




- Water stability (dry matter retention %) of pellets with increased inclusion of black soldier fly larvae (BSFL) meal and paste after 30, 60 and 120 min.
- IM= insect meal / IP = insect paste
- (Weththasinghe et al. 2021)

Reactions during feed processing (and storage)

- The effects of heat treatment on protein in feeds depend on many factors:

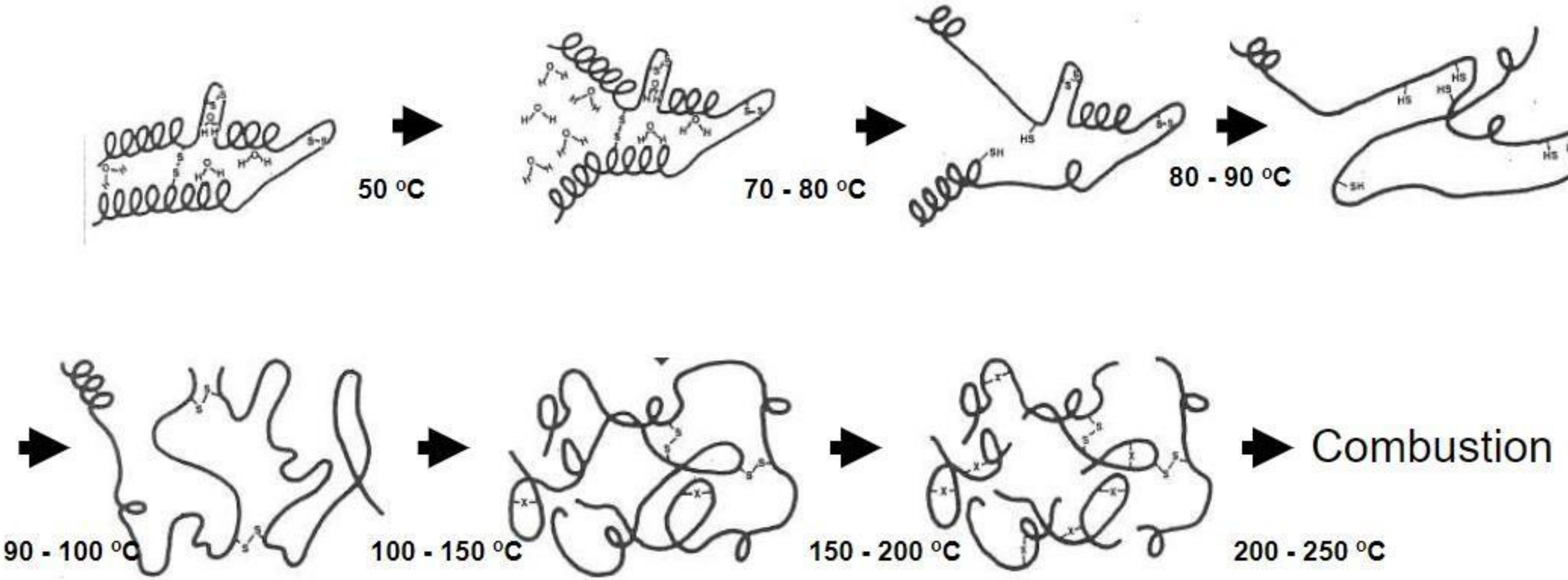


* moisture level * solubIe CHO

* maximum temperature * time x temperature effects

- <u>Heat-induced denaturation of proteins can make the protein susceptible to </u>e.g.:
- Hydrolysis of peptide bonds * Deamidation / imide formation
- Racemization / isomerization * Disulfide scission/reduction/formation
- Oxidation * Non-covalent changes (denaturation, misfolding, adsorption, aggregation or precipitation)
- Chemical reactions: Maillard reactions

Changes in proteins by heating

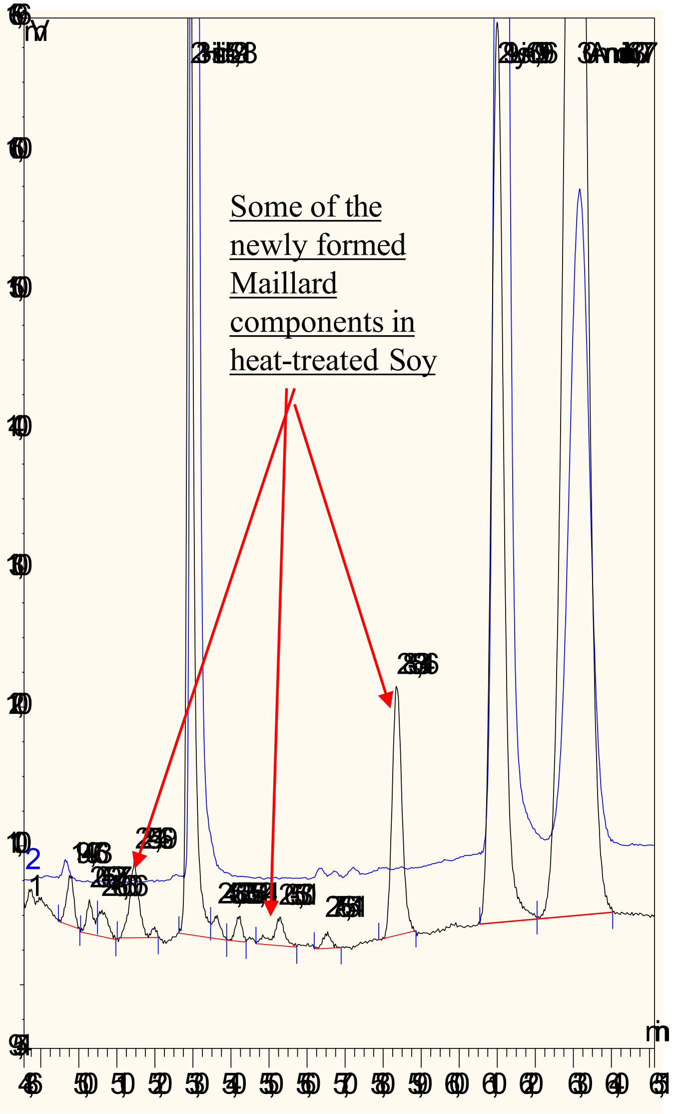


Finley. 1989

Maillard – nonenzymatic browning

- MR: a chemical reaction between an amino acid and a reducing sugar (e.g., glucose, lactose, arabinose, maltose, xylose). E.g., caramellization, the brown crust on your bread, the dark colour in beer….
- Amino acid analyses – Some of these browning products are favourable: they give both colour and flavour to the food & feed. However: several MRPs are toxic, neurotoxic, genome-affecting, and carcinogenic compounds (e.g., acrylamide).
- We can usually detect small reductions in specific AAs (e.g., Cys, Lys, Ser, Arg, Thr)

Also; racemization (heat-induced reaction in feed – converts L-AAs into D-AAs).



"Available Amino Acids"

- When formulating diets – we assume that all the analyzed AA's in our feed ingredients are available for digestion.
- Heat damaged AA's are often difficult to detect – as the AA-analysis methods include both oxidation step (Cys / Met) and acid hydrolysis step.

- A nutrient is only bioavailable if it can be used for normal metabolic functions in the animal.
- Overheating of protein will not affect the amount of protein in the feed but will damage its nutritional quality – thus we then need to analyze the "**bioavailability**" of the AA's.
- Lost protein value = lost profit

(we do not often see very heat damaged protein in salmon diets)

Storage of feed – affects the AA availability

Different meals and pelleted diets were stored for 1 week at 28°C (warm) or 4 °C (cold). Storage of the diets for 1 weekk at approx. 28°C resulted in reduced lysine bioavailability:

Chick bioassay:

Dietary treatment[b]	Weight gain, g	Feed intake, g	Gain:feed, g/kg
1. Basal diet (lysine deficient)	155[t]	350[x]	445[u]
2. As 1 + .08% Lys from L-Lys HCl	207[u]	429[y]	485[v]
3. As 1 + .16% Lys from L-Lys HCl	255[v]	468[yz]	545[w]
4. As 1 + .70% Lys from L-Lys HCl	314[w]	493[z]	637[x]
5. As 4 + .14% Lys from meal/cool diet[c]	338[x]	503[z]	673[y]
6. As 1 + .14% Lys from meal/cool diet[c]	236[yz]	430[y]	552[w]
7. As 1 + .14% Lys from meal/warm diet[c]	229[y]	430[y]	532[wz]
8. As 1 + .14% Lys from pellet/cool diet[c]	253[vz]	474[yz]	534[wz]
9. As 1 + .14% Lys from pellet/warm diet[c]	238[vyz]	466[yz]	510[vz]

Dietary treatment[c]	Analyzed lysine, %		Supplemental lysine intake, mg/chick		Relative bioavailability, %[f]
	Before treatment	After treatment	Total[d]	Bioavailable[e]	
6. Basal + .14% Lys from meal/cool diet	1.40	1.40	601	585	97
7. Basal + .14% Lys from meal/warm diet	1.40	1.33	602	534	88
8. Basal + .14% Lys from pellet/cool diet	1.40	1.41	663	711	107
9. Basal + .14% Lys from pellet/warm diet	1.40	1.38	653	602	92

Mavromichalis and Baker, 2000

Racemization

Table 2 D-Asp content (D/D + L%) in different commercial fish meals (mean of duplicate analyses) (Luzzana *et al.* 1996a)

	SFM*	LC†	LD1‡	LD2‡	HP§	HC1¶	HC2¶	HC3¶	HD1**	HD2**	HD3**	HD4**
DAsp	0.7^{a}	0.5^{a}	0.6^{a}	0.6^{a}	3.0^{b}	2.8^{b}	2.0^{b}	4.9^{b}	4.4^{b}	5.8^{b}	3.7^{b}	3.5^{b}

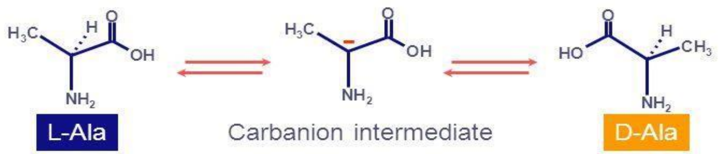
Values in the same row not sharing the same superscript letters differ significantly ($P < 0.05$). Reprinted with permission. Published 1996 by Blackwell Science Ltd.
*SFM, standard fish meal from Sigma Chemical Co. (St. Louis, MO, USA).
†LC, lowtemperature fish meal from Chile.
‡LD 1–2, low-temperature fish meals from Denmark.
§HP, high-temperature fish meal from Peru.
¶HC 1–3, high-temperature fish meal from Chile.
**HD 1–4, high-temperature fish meal from Denmark.

Table 1 Rate of racemization of aspartic acid (K_{Asp}) in whole herring (*Clupea harengus* L.) treated under different conditions (Luzzana *et al.* 1999). Reprinted with permission. Published 1999 by the American Chemical Society

Temperature (°C)	Moisture (%)	pH	K_{Asp} (10^{-3} min^{-1})
95	80	7.0	0.46
120	80	7.0	3.39
95	15	7.0	0.06
95	80	7.0	0.43
95	80	4.0	0.37

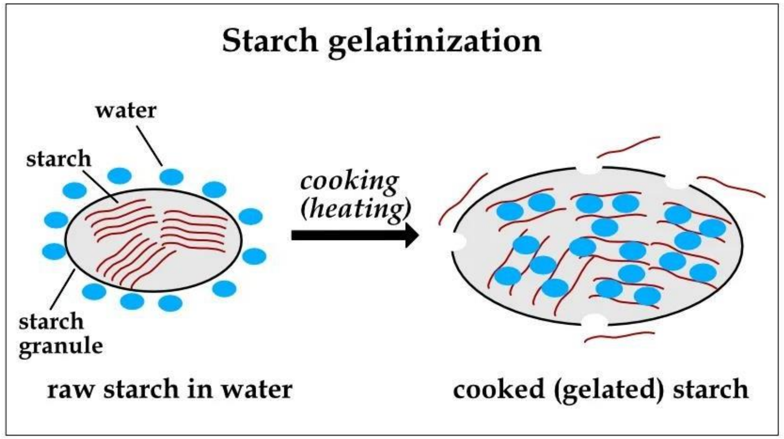
Racemization pathways

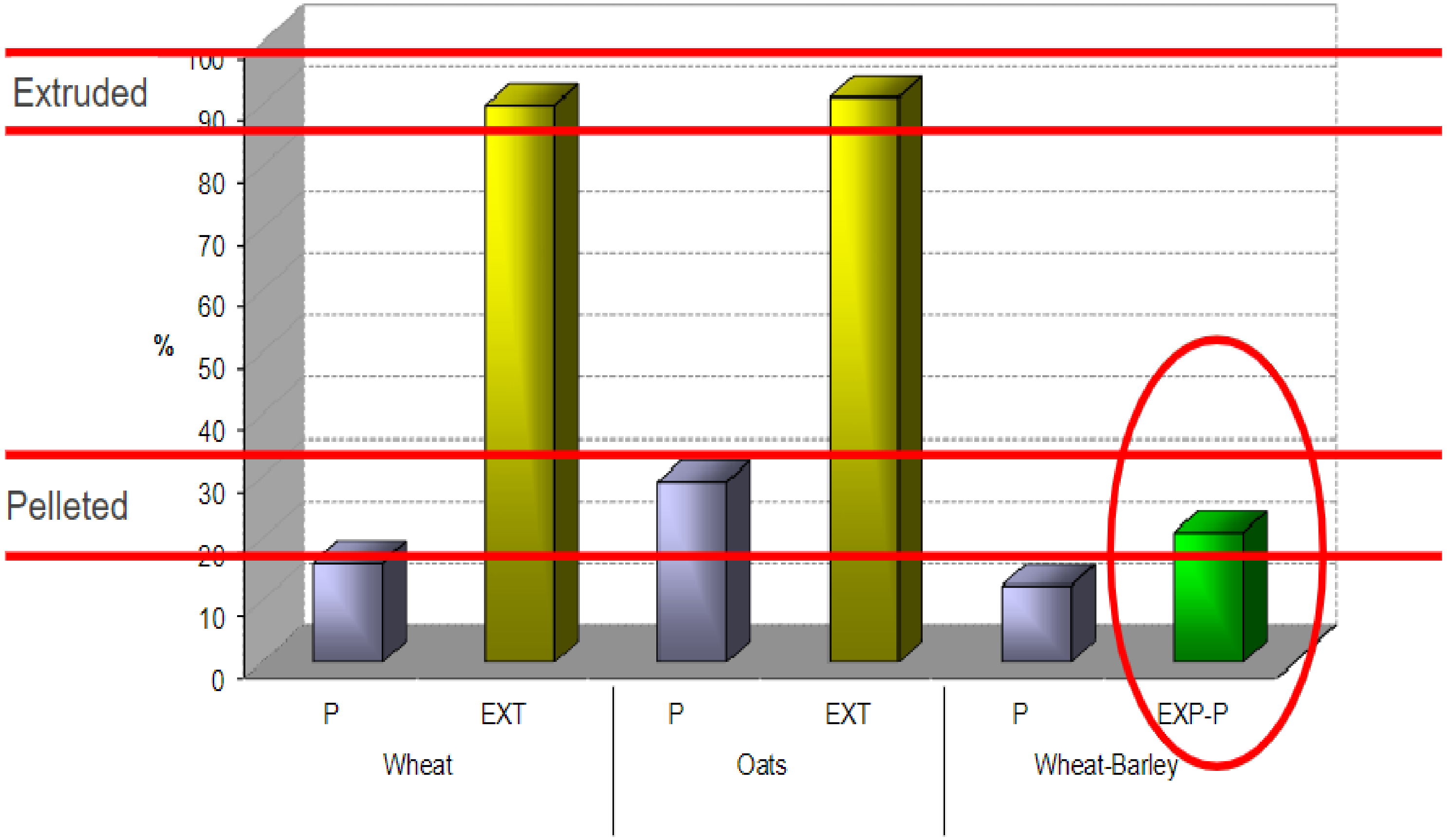
1. Free amino acid racemization



Universal mechanism; both in free and peptide-bound amino acids
Widely used in kinetic studies

Gelatinization





P: Pelleted; EXT: Extruded; EXP-P: Expanded & pelleted (Zimonja, 2008)

Pellet properties	Raw material properties	Molecule/	Raw material, example	Process-properties
No not crack	Elastic-	Gluten	Wheat	110 – 130 °C
Do not create dust/loose small particles	High binding («glue»)	Gluten (G), starch (S)	**G**: Wheat. **S**: grain; rice, tapioca, corn	110 – 130 °C
Ensure space for oil	Expansion	Starch	Grain, rice, tapioca, corn	Pressure difference out of extruder (ΔP > ~5 bar)
Do not leak oil	Ensure small pores (not a few large ones)	Starch	Grain, rice, tapioca, corn	Not too high pressure difference out of extruder (ΔP < ~30 bar)
Each pellet should have same size & properties	Narrow particle size distrubution			Thorough milling

Example from the Bühler Group:
Aquafeed processing at Marine Harvest, Norway
https://www.youtube.com/watch?v=xpVEvPVtO0Y

The most relevant plant antinutrients

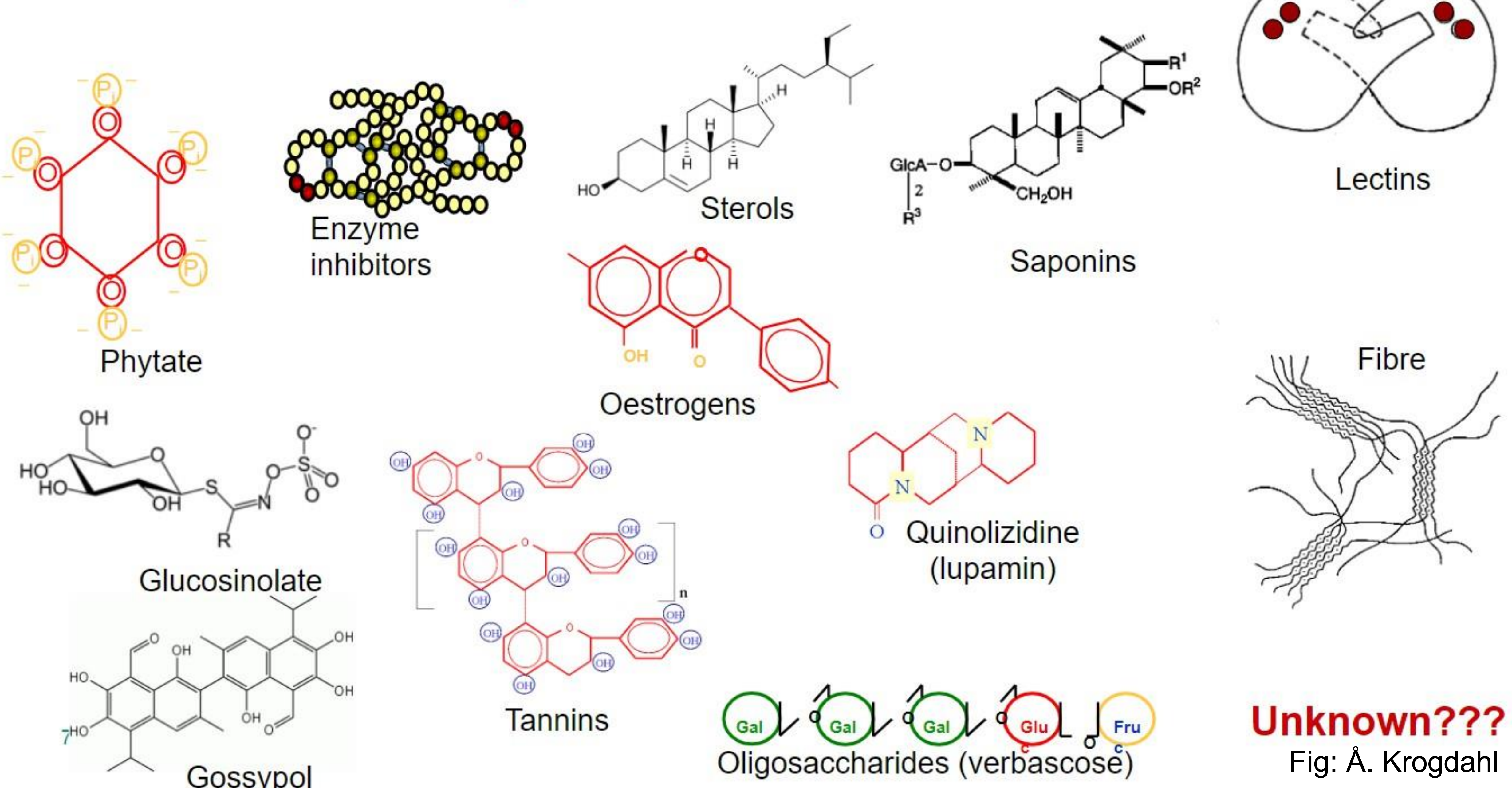


Fig: Å. Krogdahl

ANF’s – possible treatment methods

Antinutrient	Sources	Type of treatment
Proteinase inhibitors	Legumes	Heat, enzyme
Amylase inhibitors	Peas	Heat, enzyme
Lipase inhibitor	Beans	Heat, enzyme
Lectins	All plants seeds	Heat, enzyme,
Phytic acid	All plants	Enzyme
Fibre	All plants	Enzyme, dehulling
Tannins	Rape seed, beans	Dehulling
Saponins	Legumes	Alcohol extraction,
Sterols	Legumes	Alcohol/non-polar extraction,
Oestrogens	Beans	Alcohol/non-polar extraction
Gossypol	Cotton seed	Non-polar extraction,
Oligosaccharides	Legumes	Aqueous extraction
Quinolozidine alkaloids	Lupins	Aqueous extraction
Goitrogens	Rape seed	

Other methods: fermentation, selective breeding, gene modification

Making a diet…various constraints:

- **NUTRIENT REQUIREMENTS MUST BE MET** → min / max values of energy /DE, protein /DP, DP/DE ratio, amino acids, fatty acids, vitamins, minerals etc.

- **LIMITS ON THE USE OF RAW MATERIALS**
  - Min use of specific raw materials (‘force in’) e.g.:
    - Fish meal at particular level etc., fixed levels of vitamins-minerals premixes etc.
    - Availability for production
  - Max use of RM (limitation) e.g. due to:
    - Antinutritional factors, other characteristics or effects (e.g. dietary corn levels can affect fish pigmentation), availability for production

Making a diet…various constraints – cont.:

- **FEED PHYSICAL PROPERTIES**
  - RM and nutrients can affect the physical properties of the pellet (e.g., starch level can affect pellet structure and hence absorption and/or retention of oil, floating characteristics etc.)
  - Different specifications may be needed depending on the technology of production (pelleting, extrusion → single or twin screw etc.)
- **PRODUCTION / MANUFACTURING / TECHNICAL**
  (e.g., max oil that the factory can handle)
- **LEGISLATION**
  (e.g., max level of vitamin D, Se, Zn etc & use of specific raw materials such as LAP)
- **SPECIAL PRODUCT SPECIFICATIONS** (use or exclusion of specific RM, pigments, EPA+DHA levels etc can be adjusted according to market/customer requirements)

Raw material categories

Marine Raw Materials

- Marine Proteins
- Marine Oils
- Krill Meal

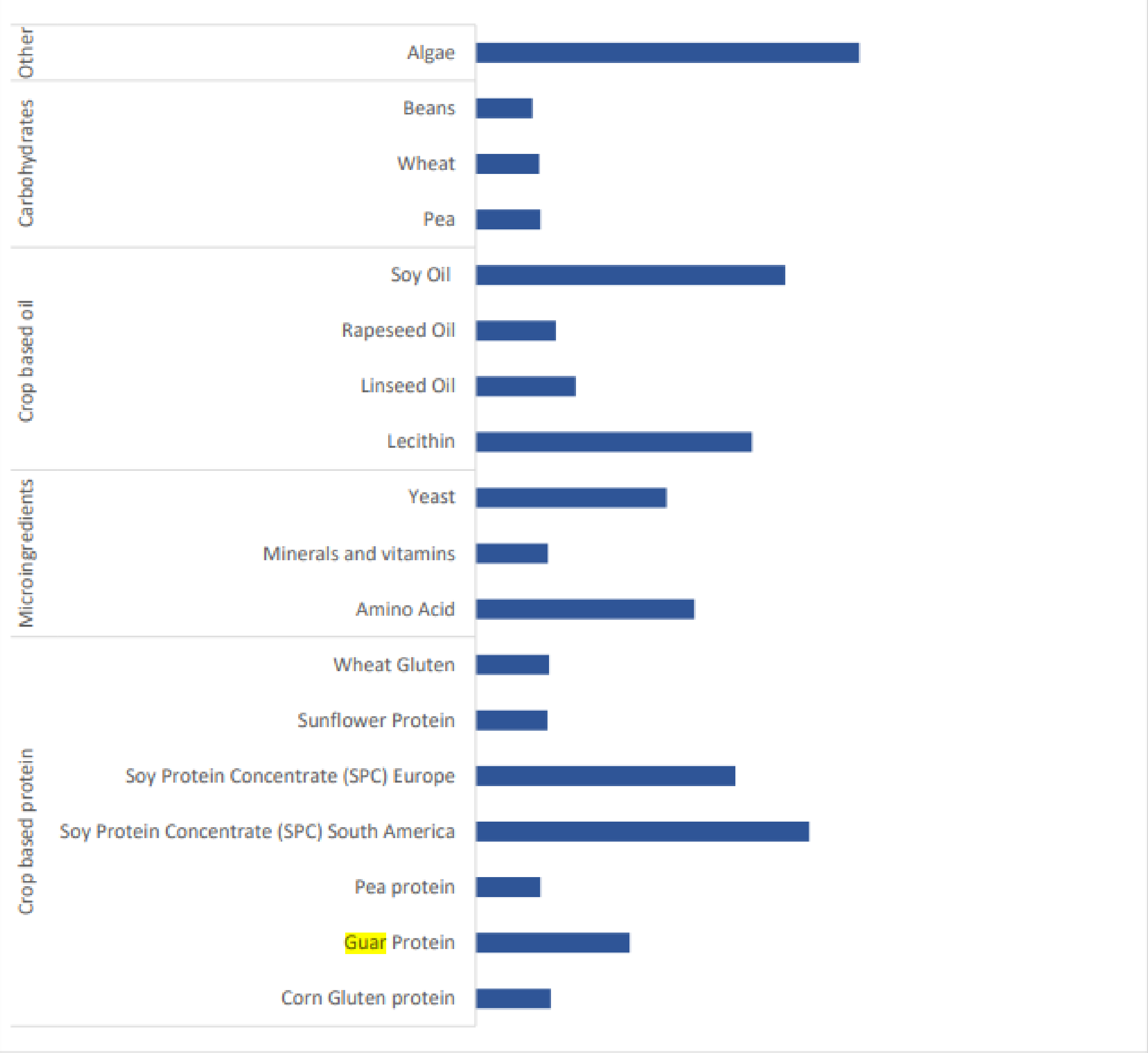
Vegetable Raw Materials

- Soy
- Wheat
- Rapeseed
- Corn
- Peas & Beans
- Sunflower
- Algae
- Palm
- Guar

Other Ingredients & Local Raw Materials

- Vitamins & Minerals
- Amino Acids
- Pigment
- Land Animal Proteins

Relative GHG emissions per tonne feed ingredient (tonnes CO_2/tonne feed ingredient at feed mill entry)



Sintef report, 2022:01198

BioMar will use soy varieties developed by St Louis-based Benson Hill. Sourcing protein from the plants should lower the environmental impact of BioMar's feeds. Photo: BioMar

BioMar to use high-tech soy to reduce footprint of feed

Growing protein-rich varieties requires less water and generates less CO2e than production of soy protein concentrate

Editorial team

PUBLISHED Thursday 26. January 2023 - 16:53 LAST UPDATED Friday 27. January 2023 - 12:49

Salmon feed producer BioMar has announced a strategic collaboration with United States feed technology company Benson Hill to advance its responsible sourcing programme.

The Danish company will use Benson Hill's high protein, lower carbon, US-grown soy for consecutive seasons.

St Louis-based Benson Hill uses a combination of machine learning and genetic selection to produce a range of soy varieties with different characteristics. It also uses gene editing for research and development, but not for commercial products. It has a segregated value chain for its non-GMO soy which has ProTerra Certification.

(fishfarmingexpert.com)

Certifications

Fig: Biomar

Examples of certification of sustainability:

- MSC (Marine Stewardship Councils)
- MarinTrust (Global Standard for Responsible Supply (IFFO RS)
- Aquaculture Stewardship Council (ASC)
- Sustainable Fisheries Partnership (SFP)
- The North Atlantic Pelagic Advocacy Group (NAPA)
- Global Salmon Initiative (GSI)
- SeaBOS (Seafood Business for Ocean Stewardship)
- Global Aquaculture Alliance (GAA)
- GLOBALG.A.P
- The ProTerra Foundation
- The Round Table on Responsible Soy (RTRS)
- New York Declaration on Forests
- Cerrado Manifesto Statement of Support Group
- UN Global Compact

EFSA - European Food Safety Authority

efsa
European Food Safety Authority

EFSA Journal 2011;9(5):2137

SCIENTIFIC OPINION

Scientific Opinion on the safety of 'yeast *beta*-glucans' as a Novel Food ingredient[1]

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA)[2, 3]

SCIENTIFIC OPINION

EFSA Journal

ADOPTED: 13 November 2019

doi: 10.2903/j.efsa.2019.5920

Safety and efficacy of astaxanthin-dimethyldisuccinate (Carophyll® Stay-Pink 10%-CWS) for salmonids, crustaceans and other fish

EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP),

SCIENTIFIC OPINION

EFSA Journal

ADOPTED: 21 October 2015 PUBLISHED: 20 November 2015

doi:10.2903/j.efsa.2015.4272

Safety and efficacy of ethoxyquin (6-ethoxy-1,2-dihydro-2,2,4-trimethylquinoline) for all animal species

EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP)

SCIENTIFIC OPINION

EFSA Journal

ADOPTED: 21 March 2017

doi: 10.2903/j.efsa.2017.4763

Safety and efficacy of OPTIPHOS® (6-phytase) as a feed additive for finfish

EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP),

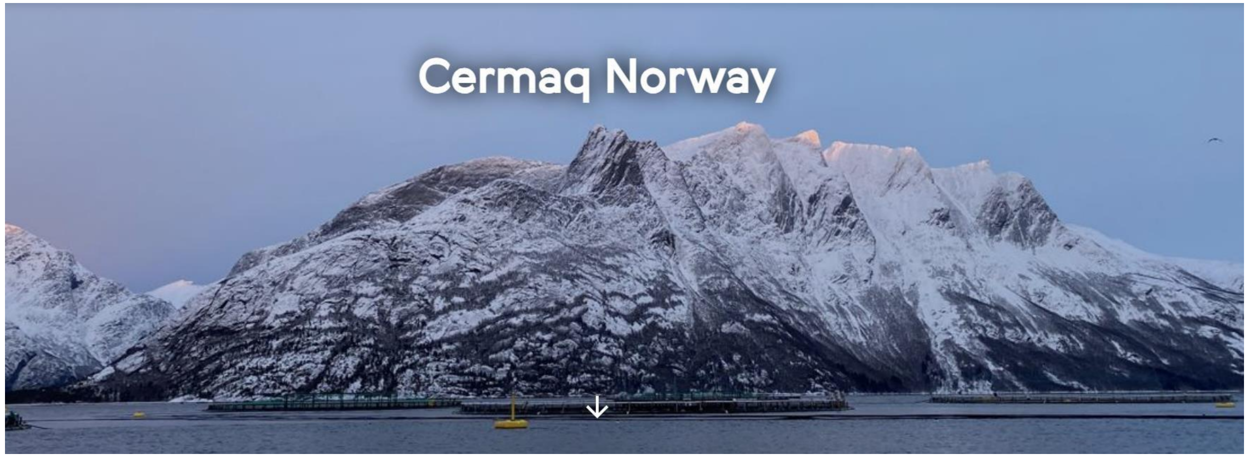
Certifications – fish farms

Every certification is a promise

We back up our commitment to sustainability, quality and safety by making ourselves openly accountable to the most stringent third-party standards in the industry. With these certifications as an independent, unbiased guide, our customers can be confident that Cermaq products are safe and sustainable, from a socially responsible company.

- GlobalG.A.P - English +
- ASC (Aquaculture Stewardship Council) - English +
- ISO 22000 - English +
- ISO 9001 - English +

https://www.cermaq.no/v%C3%A5r-produksjon/certifications



Links to our certificates:

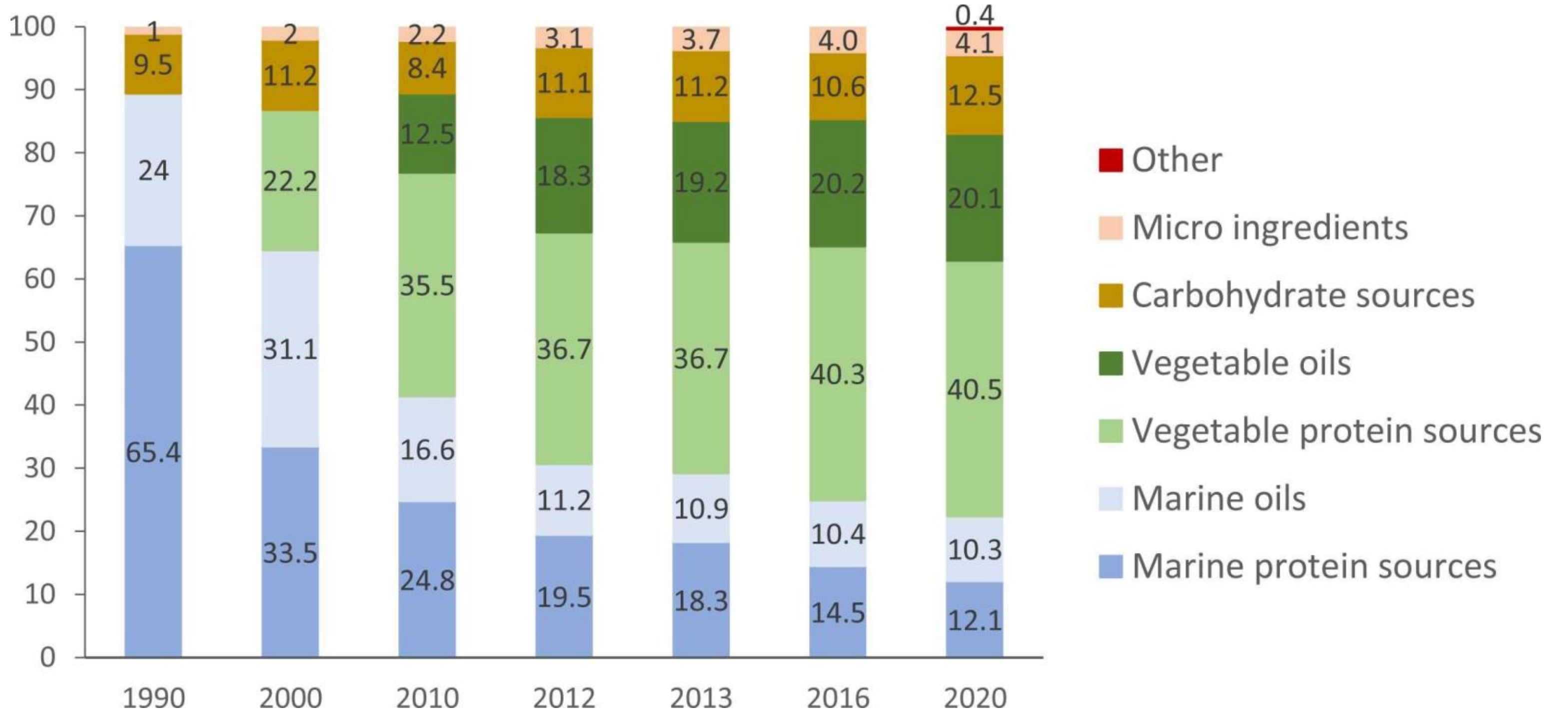
- ISO 9001 certificate
- ISO 22000 certificate
- ASC Chain of Custody Certificate - Steigen processing plant (N-2284)
- ASC Chain of Custody Certificate - Rypefjord processing plant (F-430)
- 2023 HACCP statement F430
- 2023 HACCP statement N2284
- Global GAP certificate

Monitoring program for both fish feed & fish in Norway

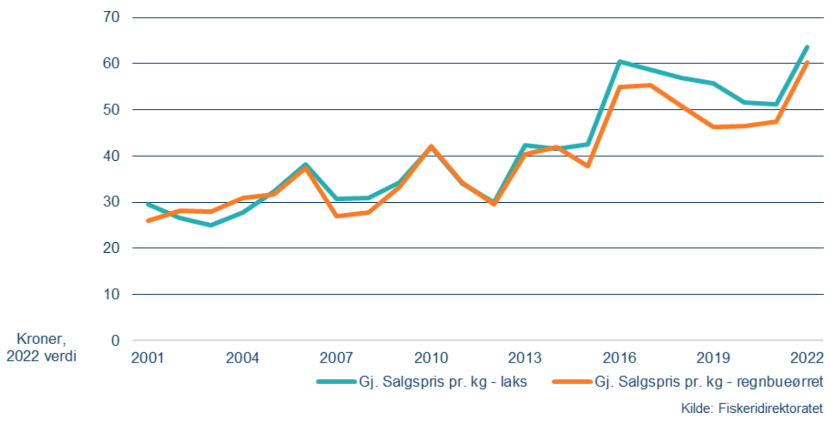
- In 2021, a total of 14135 fish were sampled – analyses of e.g., illegal substances, pharmaceuticals and contaminants:
  - No environmental contaminants were found above the EU maximum level (ML).
  - Residues of anti-sealice agents (cypermethrin, emamectin and lufenuron) were found, but all concentrations below the respective MRLs (Maximum Residue Limits).
  - Other veterinary drugs, like antibiotics or drugs used against internal parasites were not found.
  - Residues of crystal violet (forbidden to use) in 2 samples (but further investigation concluded with the cause likely being a contamination of the samples during sample taking). No other residues of illegal compounds were found.

https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2022-22
https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-en-2022-26

Average cost per kg fish produced (2022-values).

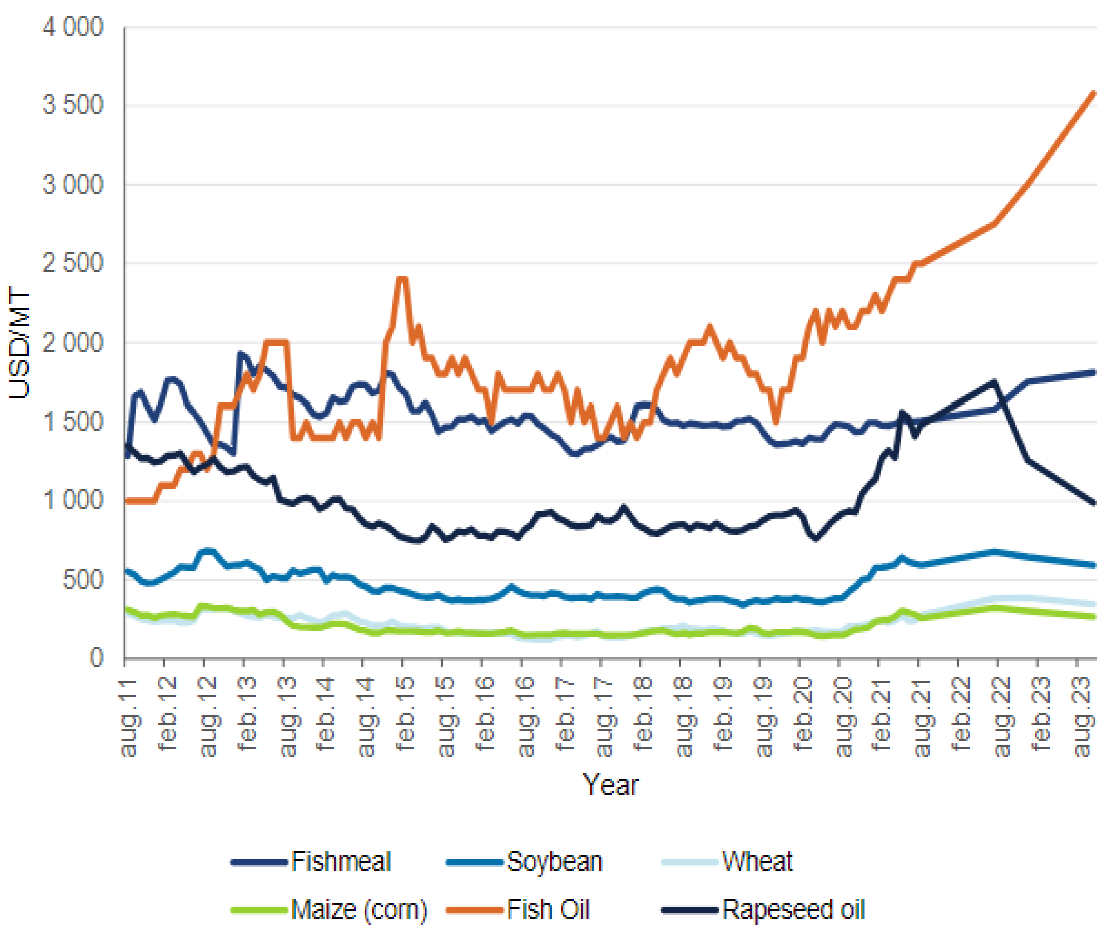


Average price per kg sold fish (2022-values)

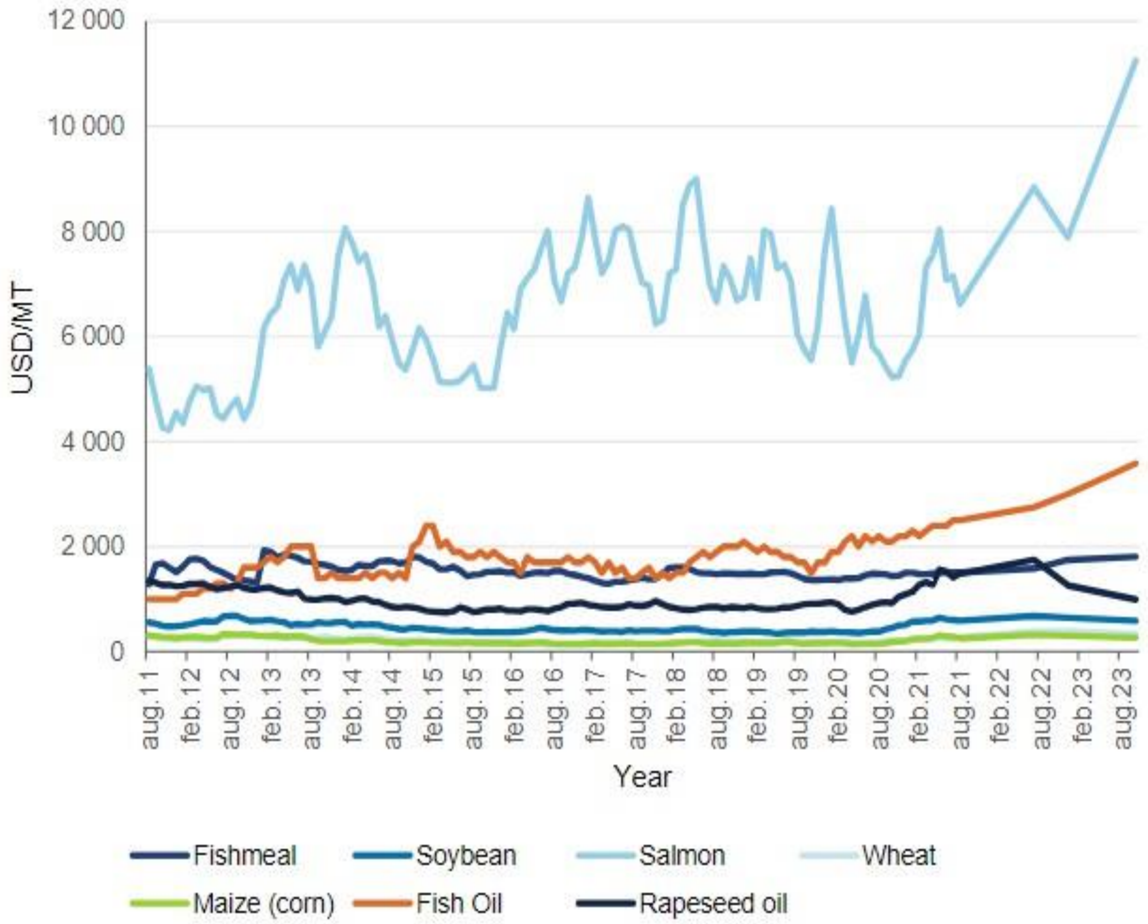


https://www.fiskeridir.no/Akvakultur/Nyheter/2023/lonnsomhetsundersokelse-for-laks-og-regnbueorret

Raw material cost (USD/MT)

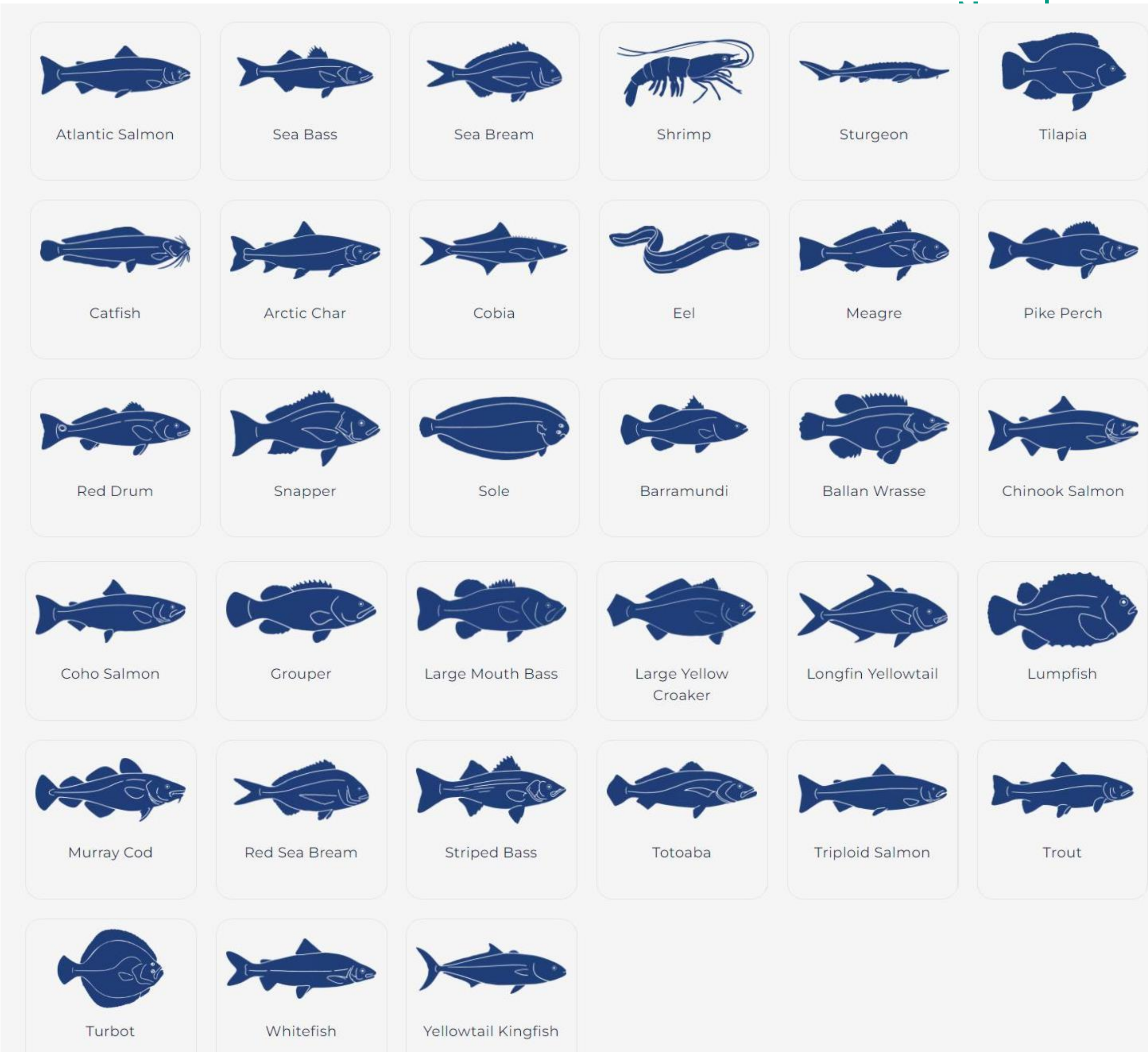


Salmon cost (USD/MT)



Source: IndexMundi

Examples of diets for different species can be found here:



https://www.skretting.com/en/species/

https://www.biomar.com/feed-and-services

- Questions?

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