Proteins

Biopolymers
CHEM-E2155

Michael Hummel

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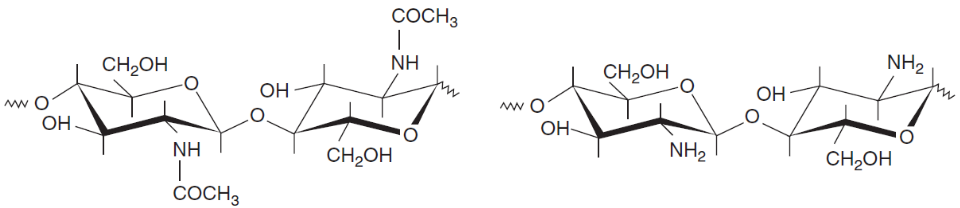
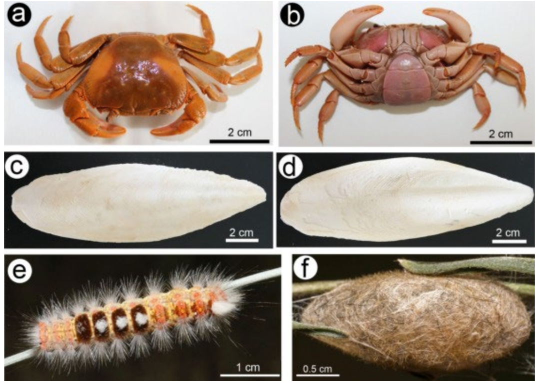
School of Chemical
Engineering

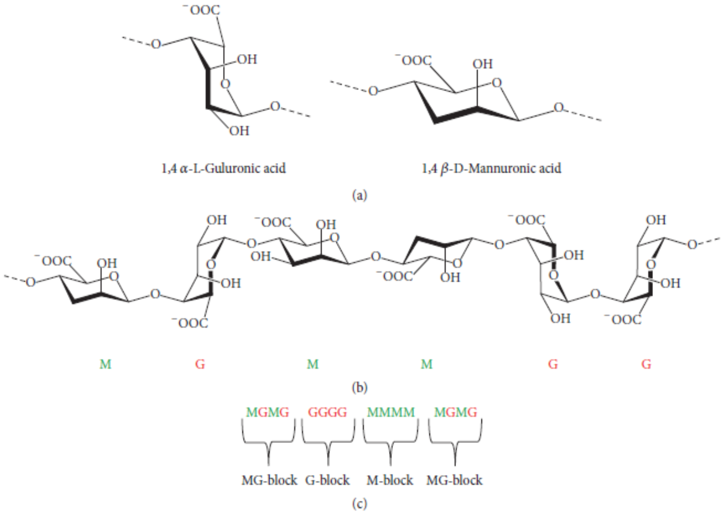
Previous lecture

Chitin/chitosan





Alginates



Schedule

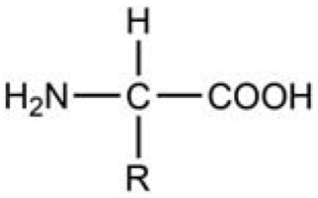
Day	Subject of lecture	Discussion part
08 January	Introduction to the course	
15 January	Biopolymers overview	Reading 1
22 January	Biopolymers for packaging	Reading 2
29 January	Discussion day	Reading 3 & Assignment 1
05 February	Biodegradation 1	Reading 4
12 February	Biodegradation 2	Reading 5
26 February	Discussion day	Reading 6 & Assignment 2
04 March	Chitin, alginates and others	Reading 7
11 March	Proteins	Reading 8
18 March	Discussion day	Reading 9 & Assignment 3
25 March	TBD	Reading 10

Learning Outcomes

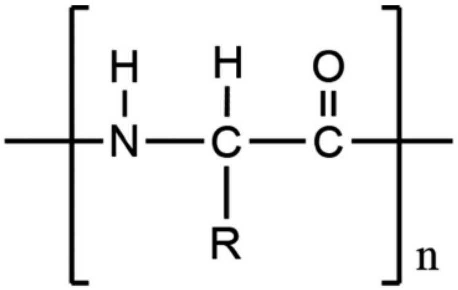
After today's course you

- know various relevant proteins
- understand the difference between wool and silk
- understand the environmental impact of soy protein

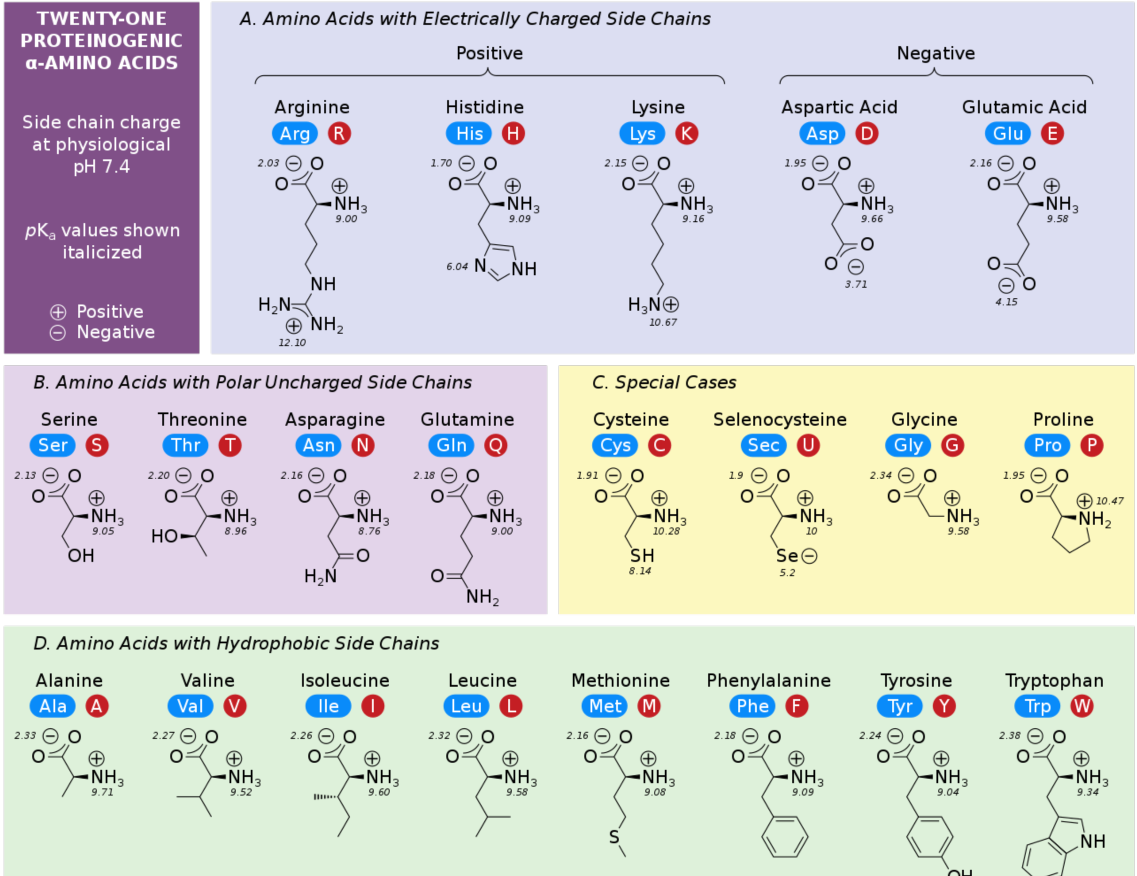
Proteins



Amnio acids



Peptide (amide) bonds



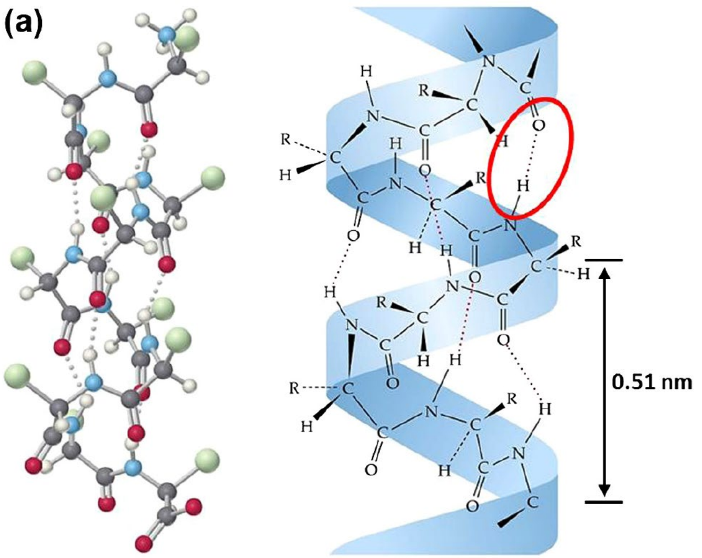
https://en.wikipedia.org/wiki/Amino_acid

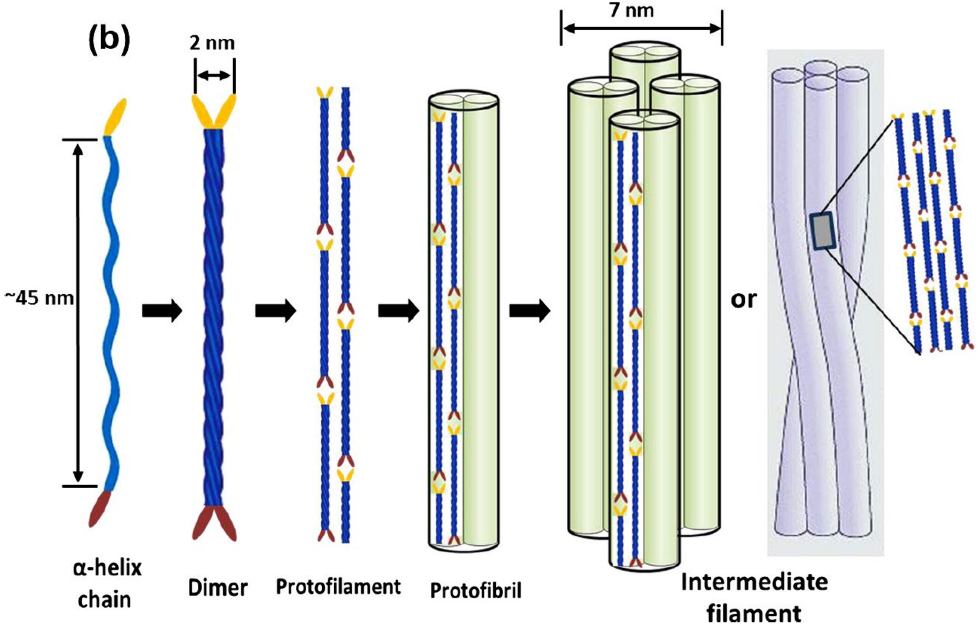
Keratin

Distribution of α- and β-keratin.

α-Keratin	**Wool**, hair, quills, fingernails, horns, hooves; stratum corneum
β-Keratin	**Feathers**, avian beaks and claws, reptilian claws and scales
α- and β-Keratin	Reptilian epidermis, pangolin scales

<u>**α-keratin structure**</u>





Wang et al. Progress in Materials Science 2016, 76, 229-318

Keratin

Distribution of α- and β-keratin.

α-Keratin	**Wool**, hair, quills, fingernails, horns, hooves; stratum corneum
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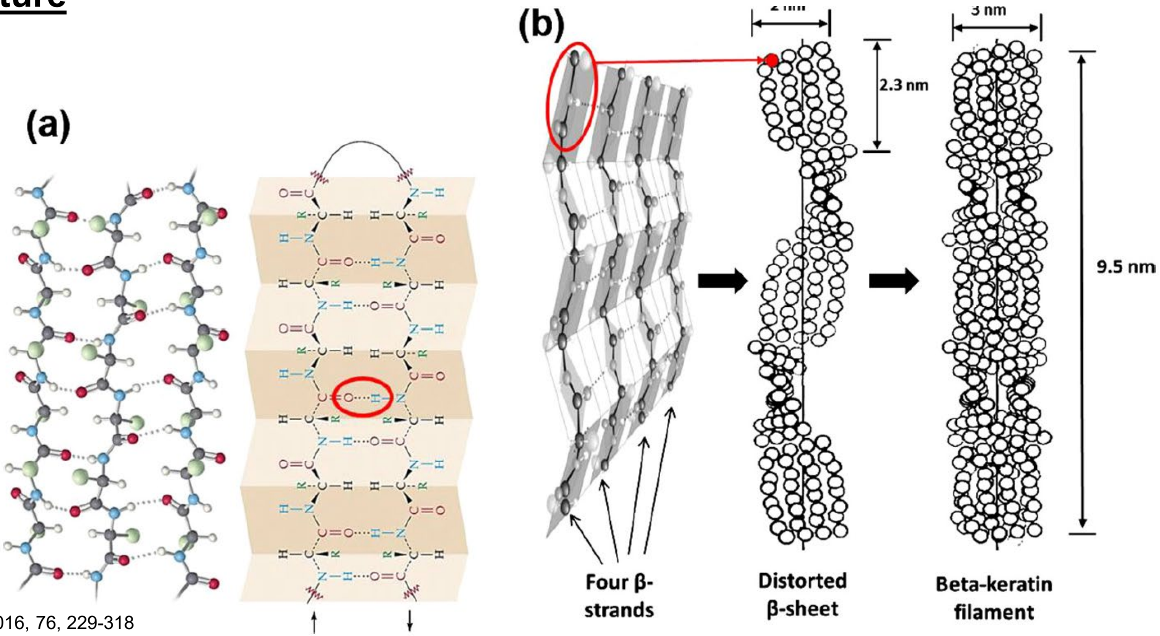
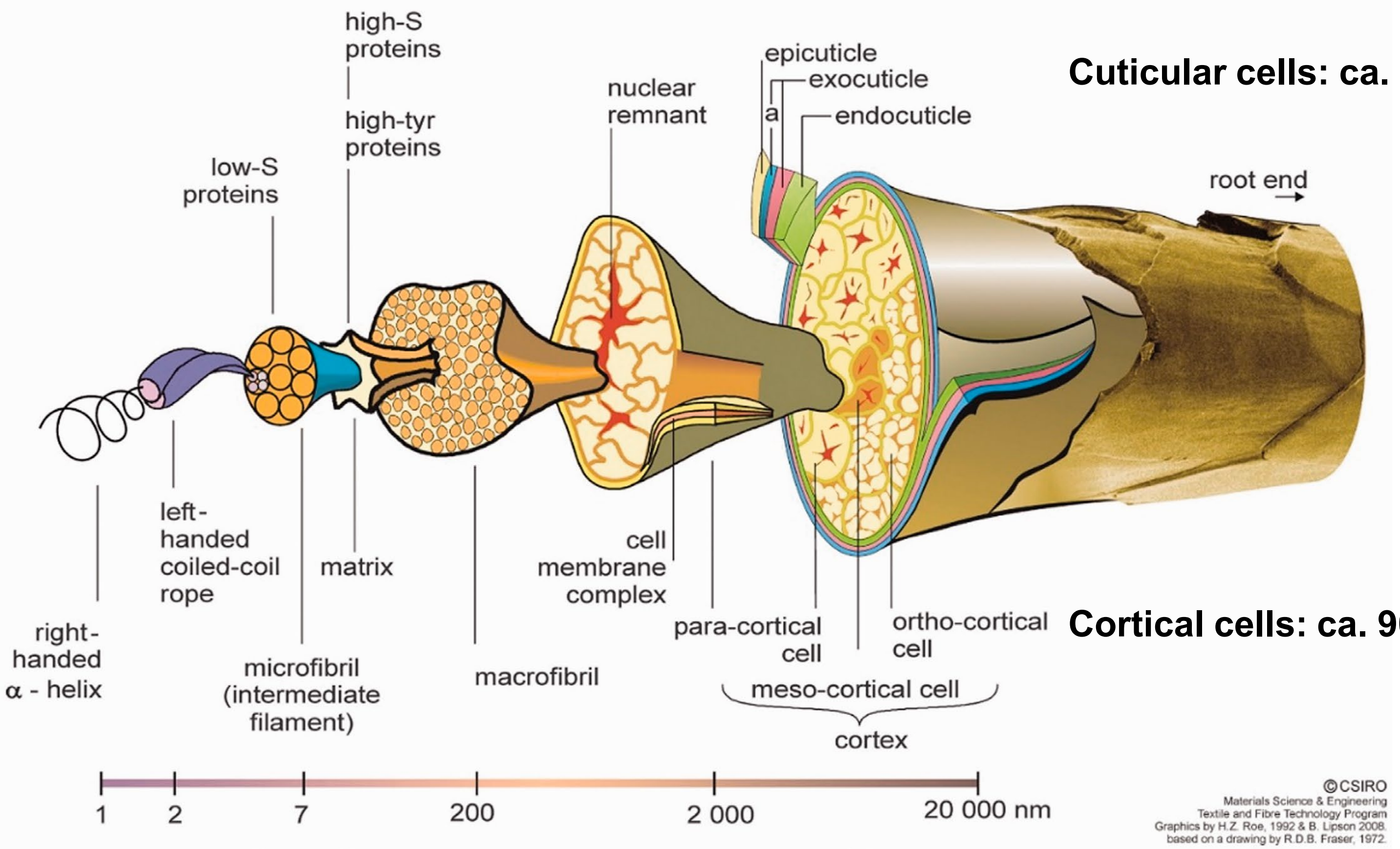
<u>β-keratin structure</u>



Wang et al. Progress in Materials Science 2016, 76, 229-318

Wool fibers



Cuticular cells: ca. 10%

Cortical cells: ca. 90%

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Caven et al. Textile Research Journal 2019, 89, 510-516.

Silk

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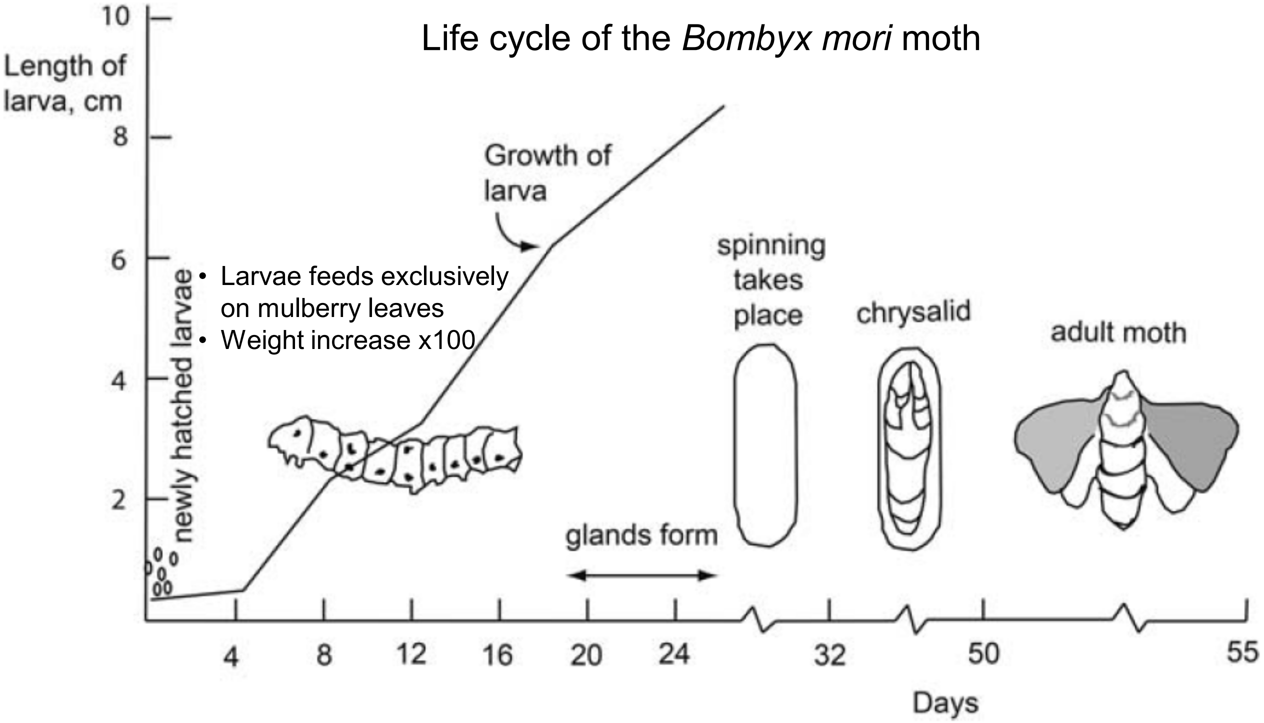
https://unsplash.com/s/photos/silk

Formation

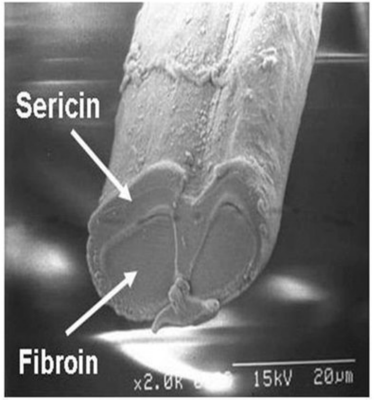
Domestic silk moth (*Bombyx mori*)
China, India, Korea, Nepal, Japan, “West”

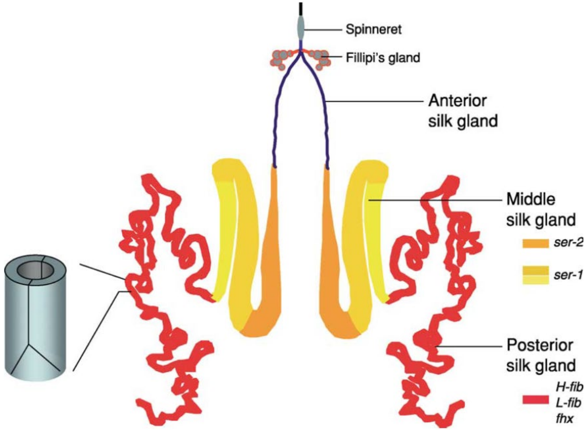
Chinese (oak) tussar moth (*Antheraea pernyi)*
China, subtropical and tropical Asia

Antheraea paphia, South India small tussore
(India, Sri Lanka)

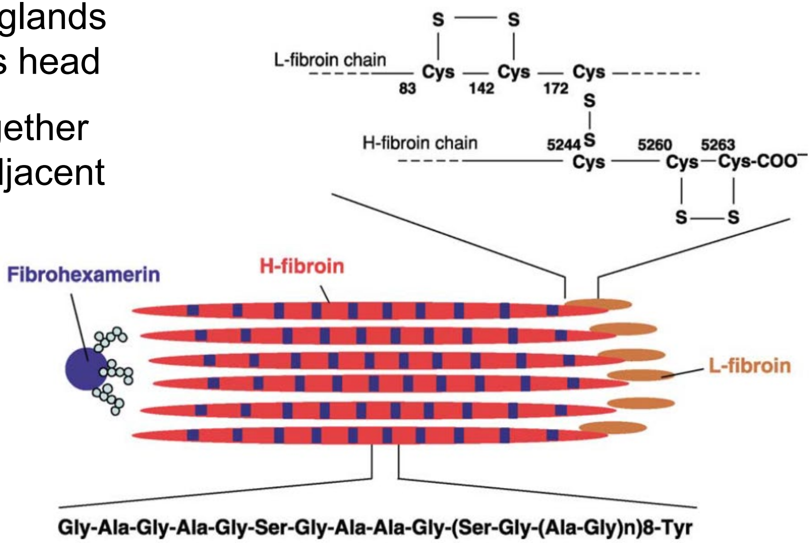


Formation



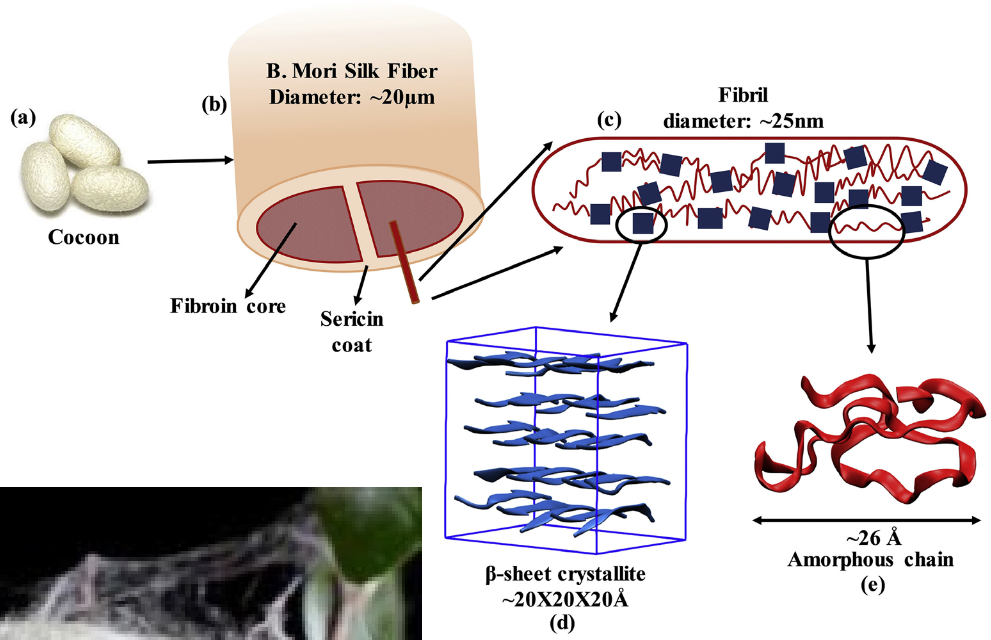


- larvae secretes fibroin (contained in two of the glands inside the silkworm) through two openings in its head
- two emerging filaments of fibroin are bound together by a protein gum, sericin (extruded from two adjacent glands



Formation

- single thread diameter 15–25 µm
- filaments up to 1-2 km
- cocoon is formed over a period of 3–6 days
- moth escapes from cocoon by secreting enzyme that damages silk filaments
- cocoons are “stifled”: hot air treatment (110 °C) to kill chrysalis

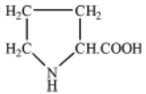
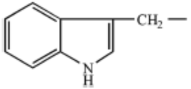
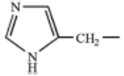


https://www.youtube.com/watch?v=VC0OgY8_eqk

Silk processing

- sericin removed via degumming process (e.g., treatment with soap solutions, enzymatic, hot water treatment, dilute alkali or acid solutions)
- bleaching with H_2O_2, sodium perborate ($NaBO_3$), sodium persulfate ($Na_2S_2O_8$), sodium dithionite ($Na_2S_2O_4$)

Table 3.6 Amino acids present in silk fibroin, mol%.

No.	Amino acid	Structure of side chain (R)	*Bombyx mori*	Tussah
1	Glycine	$H-$	44.6	26.5
2	Alanine	CH_3-	29.4	44.1
3	Phenylalanine	$C_6H_5-CH_2-$	0.6	0.6
4	Valine	$(H_3C)_2CH-$	2.2	0.7
5	Leucine	$(H_3C)_2CH-CH_2-$	0.5	0.8
6	Isoleucine	$(H_3C-H_2C)(H_3C)CH-$	0.7	0
7	Proline (complete formula)		0.4	0.3
8	Serine	$HO-CH_2-$	12.1	11.8
9	Threonine	$(H_3C)(HO)CH-$	0.9	0.1
10	Tyrosine	$HO-C_6H_4-CH_2-$	5.2	4.9
11	Methionine	$CH_3-S-CH_2-CH_2-$	0.1	0
12	½-cystine	$-CH_2-S-S-CH_2-$	0.2	0
13	Arginine	$H_2N-C(=NH)-NH-CH_2CH_2CH_2-$	0.5	2.6
14	Lysine	$H_2N-CH_2CH_2CH_2CH_2-$	0.3	0.1
15	Tryptophan		0.1	1.1
16	Histidine		0.1	0.8
17	Aspartic acid	$HOOC-CH_2-$	1.3	4.7
18	Glutamic acid	$HOOC-CH_2CH_2-$	1.0	0.8

Silk production

https://www.youtube.com/watch?v=77ktNSPFbwQ

Wheat proteins

Wheat protein

Wheat grain proteins

- **Non-gluten proteins** (15-20%)
  - **Albumins** (water soluble)
  - **Globulins** (water insoluble or soluble in salt solutions)
- **Gluten proteins** (80-85%)
  - **Monomeric gliadins** (soluble in alcohols MW 20-80 kDa)
  - **Polymeric glutenins** (MW 80-10^3 kDa)
    - High-molcular-weight glutenin subunits (HMW-GS)
    - Low-molcular-weight glutenin subunits (LMW-GS)

Mostly monomeric with MW<25 kDa

Wim S. Veraverbeke & Jan A. Delcour, Wheat Protein Composition and Properties of Wheat Glutenin in Relation to Breadmaking Functionality, Critical Reviews in Food Science and Nutrition, 2002, 42, 179-208.

Wheat protein

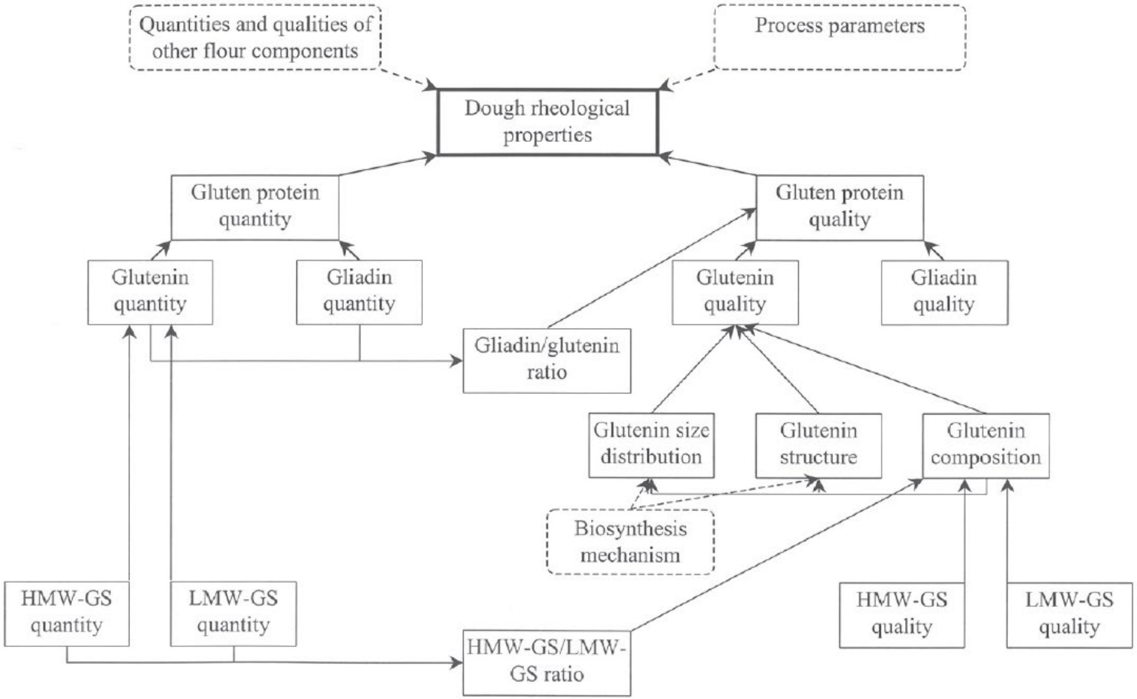
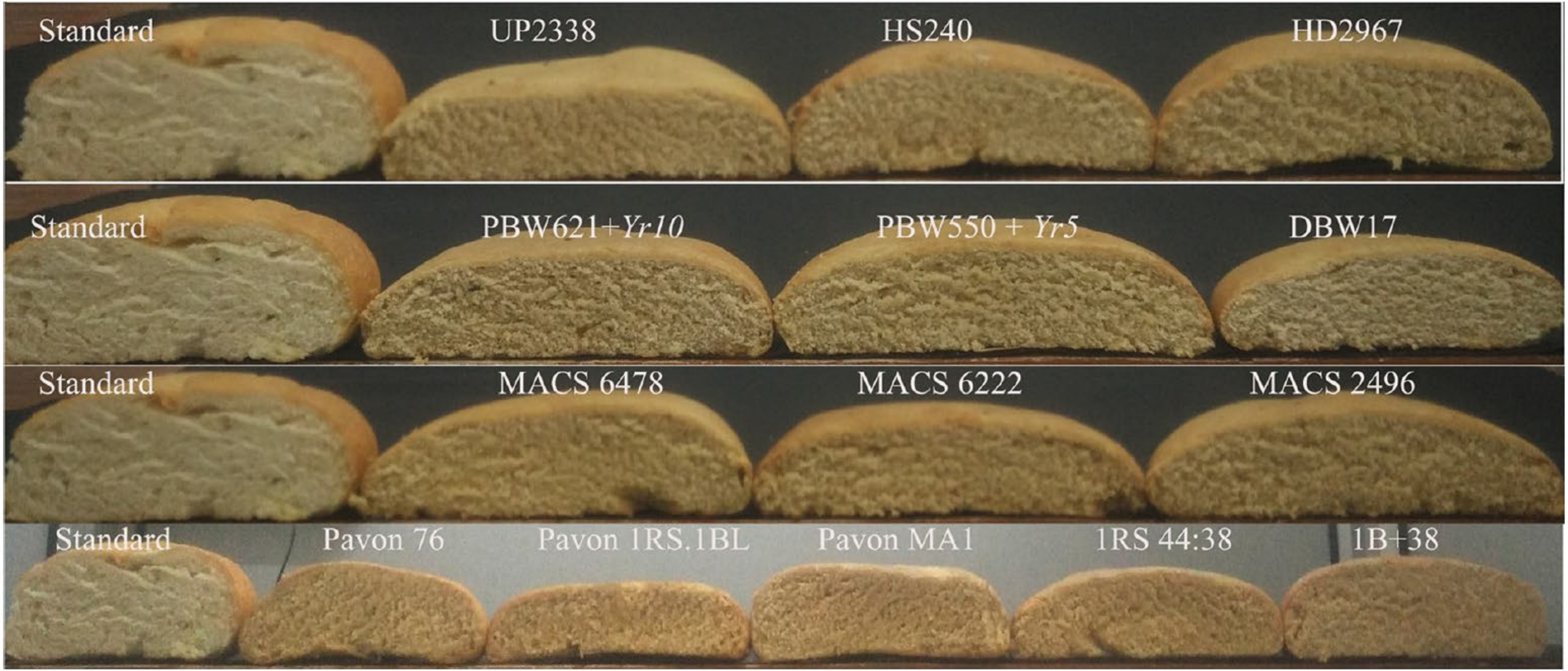


FIGURE 1. Factors governing wheat dough rheological properties.

Wim S. Veraverbeke & Jan A. Delcour, Wheat Protein Composition and Properties of Wheat Glutenin in Relation to Breadmaking Functionality, Critical Reviews in Food Science and Nutrition, 2002, 42, 179-208.

Wheat protein



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Ambika Sharma, Imran Sheikh, Rahul Kumar, Krishan Kumar, Pritesh Vyas & H. S. Dhaliwal, Evaluation of end use quality and root traits in wheat cultivars associated with 1RS.1BL translocation. Euphytica 2018, 214, Article number: 62

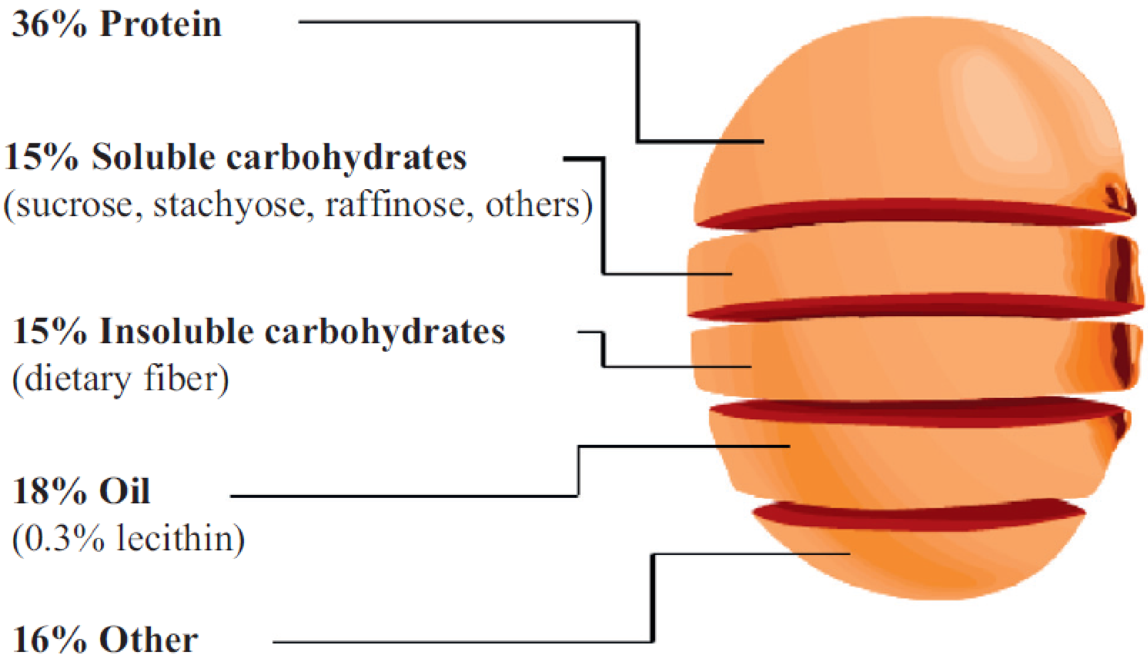
Soy proteins

Soy protein

<u>Soybean production in 2018</u>

Brazil	126 Mt
USA	124 Mt
Argentine	83 Mt

= 80% of global production

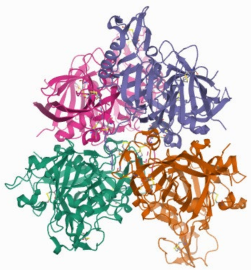


M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Soy proteins

7S globulin

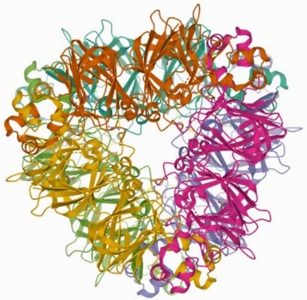
MW ≈ 150 kDa
pI ≈ 4.5



https://www.rcsb.org/structure/3aup

11S globulin

MW ≈ 3050 kDa
pI ≈ 4.5

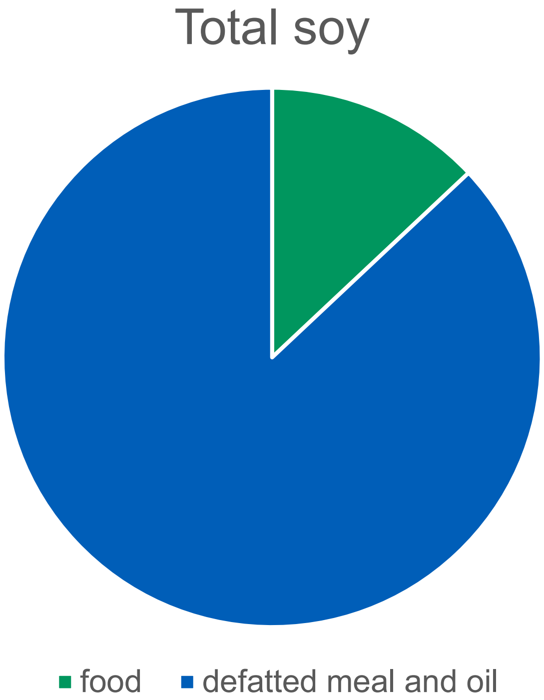


https://www.rcsb.org/structure/1OD5

- The term 11S refers to the sedimentation coefficient, with a range of 10.5–13 versus the 7S family with coefficients of 7.0–9.0
- The sedimentation coefficient (s) of a particle characterizes its sedimentation during centrifugation. It is defined as the ratio of a particle's sedimentation velocity to the applied acceleration causing the sedimentation.

Soy protein

- 13% of soybeans go directly into producing foods including soymilk, tofu, miso, and tempeh.
- 87% (278 million metric tons) of these beans are crushed into defatted soybean meal and oil.
  - 95% of the oil goes into the edible market.
  - Almost 98% of the meal is destined for animal feed, while the remaining 2% serves as raw material for human soy protein products.



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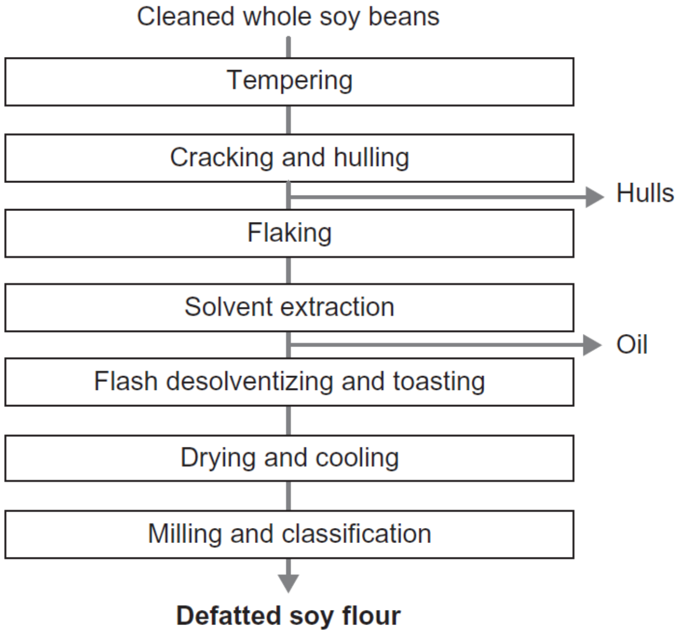
Soy protein



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Benefits of soybeans processing: how to get the soybean oil and soybean meal

Soy protein – LCA

Sustainability of isolated soy protein (ISP) was evaluated through a life cycle analysis (LCA)
LCA is a method of **quantifying the environmental impacts** associated with a given product. In LCA, researchers create an inventory of resources used and pollutants generated in product production and use. From this an impact assessment estimates the product's ultimate effects on human health, ecosystem function, and natural resource depletion.

LCA has been defined by the EPA as a way to "evaluate the environmental effects **associated with any given industrial activity** from the initial gathering of raw materials from the earth until the point at which all residuals are returned to the earth" or "cradle-to-grave." Several organizations have developed methods for LCA, each using a **different analytic approach** to this complex activity.

Soy protein – LCA

TABLE 2.1 Overview of Carbon, Water and Land Use Footprint for Different Protein Sources Based on Consequential and Attributional Modeling.[a] Results From Meta-Analysis Provide an Overview of the Variability in Results in All Included Studies[b] (Muñoz & Schmidt, 2015; Muñoz, 2015)

	Consequential Model (Substitution)			Attributional Model (Economic Allocation)			Range of Results According to Meta-Analysis		
	Carbon Footprint (kg CO_2e/ kg protein)	Blue Water Footprint (L water/kg protein)	Land Use Footprint (m^2 year/ kg protein)	Carbon Footprint (kg CO_2e/ kg protein)	Blue Water Footprint (L water/kg protein)	Land Use Footprint (m^2 year/ kg protein)	Carbon Footprint (kg CO_2e/kg protein)	Blue Water Footprint (L water/kg protein)	Land Use Footprint (m^2 year/kg protein)
Beef, suckler cows	178	1607	1311	184	1607	1310	45–643 ($n = 27$)	1548–6821 ($n = 9$)	75–2100 ($n = 14$)
Beef, dairy cows	n.a.	n.a.	n.a.	125	351	156	45–150 ($n = 5$)	95–607 ($n = 2$)	37–210 ($n = 3$)
Pork	24	1855	59	29	1855	55	22–53 ($n = 13$)	340–3225 ($n = 7$)	39–75 ($n = 8$)
Chicken	17	629	33	18	629	32	10–30 ($n = 6$)	195–1665 ($n = 7$)	23–40 ($n = 4$)
Skim milk powder, SMP	23	n.a.	n.a.	23	153	31	20–26 ($n = 3$)	0–398 ($n = 7$)	0–36 ($n = 4$)
Caseinate	26	n.a.	n.a.	19	170	12	19–30 ($n = 3$)	0–170 ($n = 3$)	0–12 ($n = 3$)
Whey protein, WPC	16	36	19	20	194	14	15–20 ($n = 3$)	32–203 ($n = 4$)	12–19 ($n = 4$)
Isolated soy protein (ISP)	2	38	8	6	205	6	1–7 ($n = 10$)	38–205 ($n = 2$)	6–8 ($n = 2$)

M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Soy protein – LCA

Carbon footprint

A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2-eq or CO_2e is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

For example, the GWP for methane is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tonnes of methane and nitrous oxide respectively is equivalent to emissions of 25 and 298 million metric tonnes of carbon dioxide.

https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent

Soy protein – LCA

Carbon footprint

In the fifth IPCC assessment report, the global warming potential of methane over a time horizon of 100 years was increased from previously 25 CO_2e per kg methane emission, to 28 and even 34 kg CO_2e per kg methane emission if climate carbon feedbacks are included (indirect effects). The result of applying the newer characterization factors would be that beef got an even higher carbon footprint than suggested in this analysis.

Soy protein – LCA

Attributional LCA:

LCA aiming to describe the environmentally relevant physical flows to and from a life cycle and its subsystems.

Attributional assessments, which give an estimate of what part of the global environmental burdens belongs to the study object.

Consequential (substitutional) LCA:

LCA aiming to describe how environmentally relevant flows will change in response to possible decisions.

Consequential assessments, which give an estimate of how the production and use of the study object affect the global environmental burdens.

Soy protein – LCA

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M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Soy protein – LCA

Another way to analyze the results is to calculate the amount of CO2e that is saved by replacing 1 kg animal-based protein with 1 kg proteins from soy (as ISP). In the case of consequential modeling, the savings are 14-176 kg CO_2e per kg replaced animal-based protein, and 12-178 kg CO_2e per kg replaced animal-based protein based on attributional modeling.

- No feed conversion loss
- No methane emissions from enteric fermentation
- Legumes, such as soy and peas, have the ability to fix nitrogen from the atmosphere, which reduces (or eliminates) the need for nitrogen fertilizers, that is, less emissions related to the production of fertilizers as well as less field emissions related to N surplus.

M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Soy protein – LCA

Energy use is usually included in the LCA models. For ISP there is a close relationship between the carbon footprint and energy use, mainly due to the significant energy use related to the separation and drying steps of the process. This is also the case for dairy proteins. This correlation is less pronounced for chicken and pork—and for beef in particular, the carbon footprint is not a good indicator for energy use, as it is mainly methane and nitrous oxide emissions that drive the carbon footprint.

M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Soy protein – LCA

Water use footprint

the blue water footprint for ISP is about 157-50 times lower than for the analyzed meat proteins

Land use footprint

the land use footprint of ISP is nearly 160 times (consequential) or 30-220 times (attributional) smaller than for beef; 2-9 times small than pork, chicken, whey protein

M. Thrane, P.V. Paulsen, M.W. Orcutt, T.M. Krieger, Chapter 2 - Soy Protein: Impacts, Production, and Applications, Sustainable Protein Sources, 2017, 23-45.

Summary questions

- What is the difference between attributional and consequential (substitutional) LCA?
- What are the two types of gluten proteins?
- What is the difference between wool and silk?

Reading 8 discussion

Title: The Myth of Cultured Meat: A Review
From: Chriki, S. and Hocquette, J.-F. *Frontiers in Nutrition* 2020

Discussion and summarize briefly:

- What did you know about cultured meat before you read this article?
- Who are Prof. Sghaier Chriki and Dr. Jean-François Hocquette?
- What are the main obstacles of cultured meat towards mass consumption?
- What is your opinion on cultured meat?

Instructions:
Write your names and summary of discussion in e.g. PowerPoint. Save the text as image file (.jpg) and upload it to the Padlet page:
https://padlet.com/michaelhummel/CHEME2155_2024