NewFoodSystems
Neue Lebensmittelsysteme

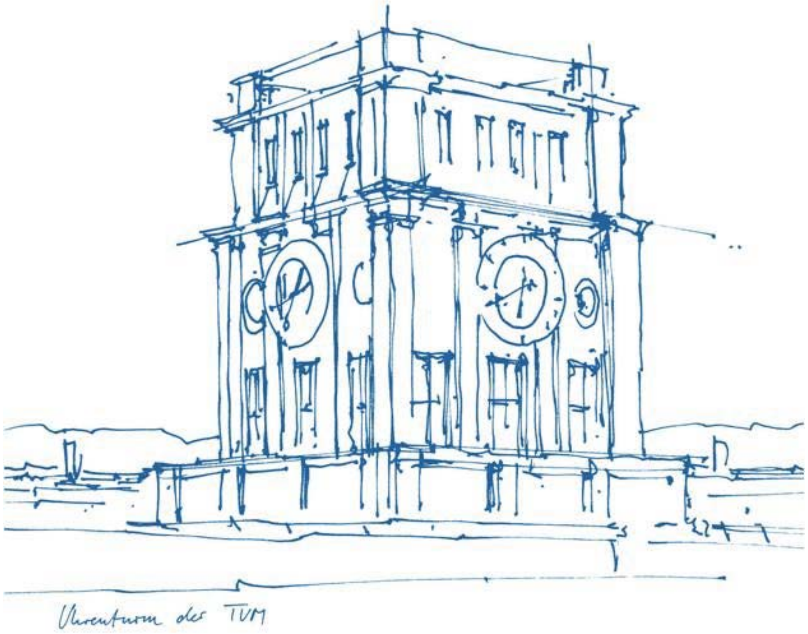
How Processing of Protein-Rich Plant Materials Affects Protein Ingredient Functionality

Ute Weisz and Hannelore Daniel

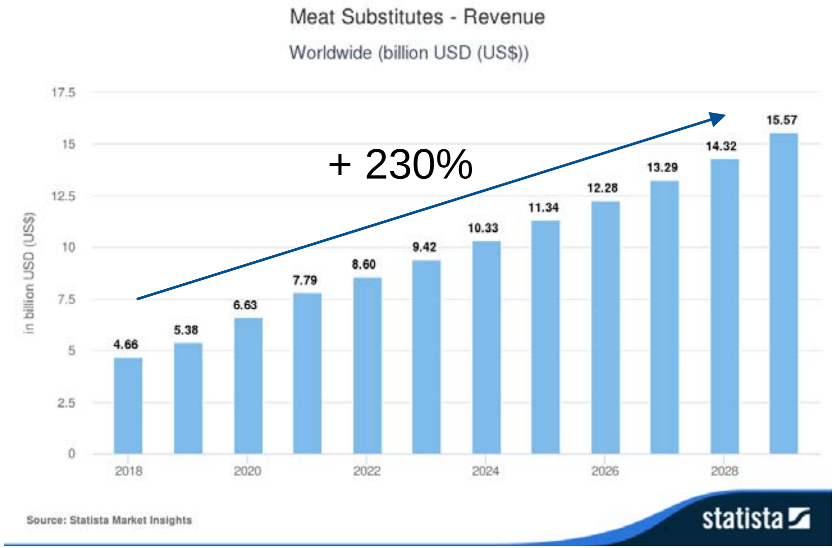
Technical University of Munich

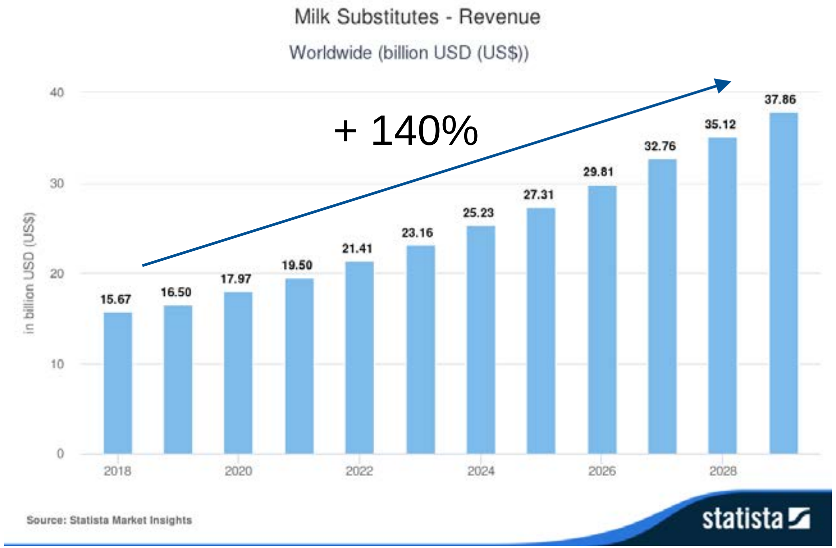
School of Life Sciences

Berlin, 04 December 2024



Market growth of plant-based product alternatives





Not only industry is interested in plant proteins

Innovative Food Science and Emerging Technologies

Dynamic in-vitro system indicates good digestibility characteristics for novel upcycled plant protein; correlation to techno-functional properties

frontiers | Frontiers in Soft Matter

Addressing the structural sophistication of meat via plant-based tissue engineering

Future Foods

Impact of short-term germination on dehulling efficiency, enzymatic activities, and chemical composition of mung bean seeds (*Vigna radiata* L.)

Food Chemistry

Review

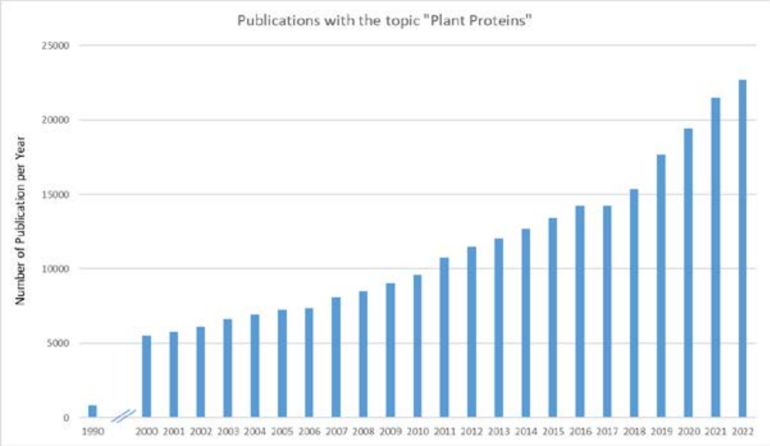
Structural, extraction and safety aspects of novel alternative proteins from different sources

npj | science of food

COMMENT OPEN

The sustainability paradox of processing plant proteins

Patricia Duque-Estrada and Iben Lykke Petersen



Source: Web of Science

Journal of Agriculture and Food Research

Plant-based protein modification strategies towards challenges

Food Hydrocolloids

Commercial plant protein isolates: The effect of insoluble particles on gelation properties

Review

Mung bean protein as an emerging source of plant protein: a review on production methods, functional properties, modifications and its potential applications

Powder Technology

Dry fractionation of chickpea flour: Impact of de-oiling and flow aids

Cellular Agriculture

Chapter 17 - Manufacture of Hybrid alternative protein food products using a combination of plant-based ingredients, fermentation-derived ingredients, and animal cells

REVIEW

Off-Flavors in Pulses and Grain Legumes and Processing Approaches for Controlling Flavor-Plant Protein Interaction: Application Prospects in Plant-Based Alternative Foods

npj | science of food — Review article

Current challenges of alternative proteins as future foods

REVIEW — Molecular Nutrition & Food Research

Opinion Piece: New Plant-Based Food Products Between Technology and Physiology

Ute Schweiggert-Weisz, Lara Eisbach, Susanne Gola, Sabine E. Kulling, Christina Diekmann, Sarah Egert, and Hannelore Daniel

Food Chemistry

Effects of plant polyphenols on lipid oxidation in pea and soy protein solutions

Vanessa Soendjaja, Andrey L. Girard

Which raw materials can be used for the production of plant-based proteins?

Oilseeds

Cereals

Leaves

Macroalgae

Microalgae

Pulses

Tubers and Roots

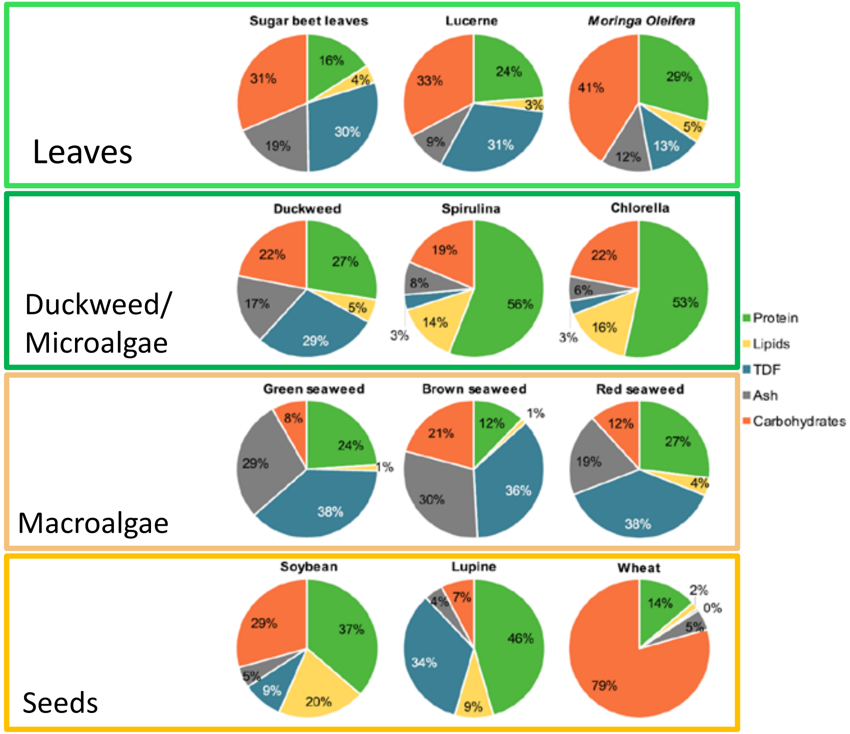
Duckweed

Parts of land plants

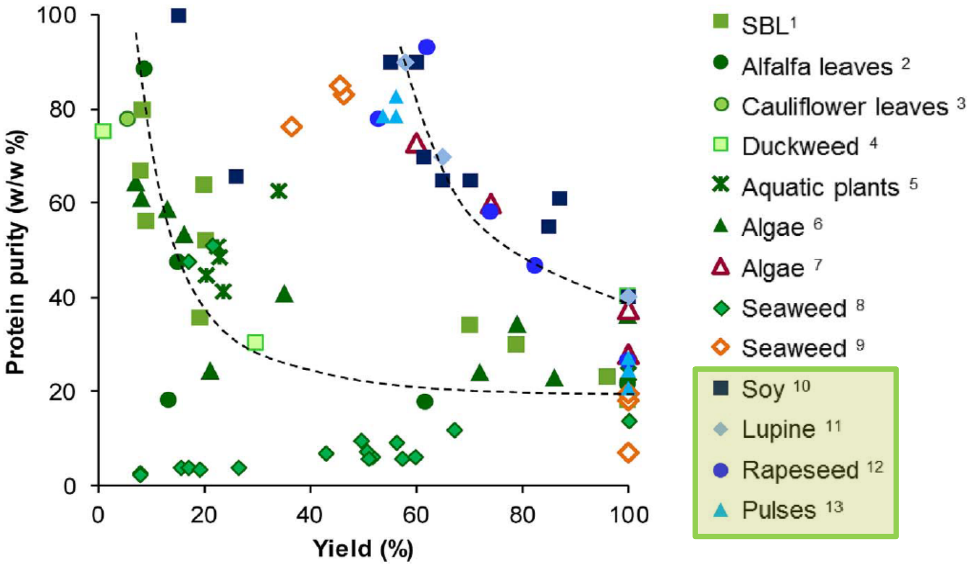
Raw materials from aquatic systems

Schweiggert-Weisz, U., Eisner, P., Bader-Mittermaier, S., Osen, R. (2020) Food proteins from plants and fungi. Curr. Opin. Food Sci., 32, 156-162; Amorim, M.L., Soares, J., Selia dos Resi Coimbra, J., de Olivieira Leite, M., Teixera Albine, L.F., Martins, M.M. (2021) Crit. Rev. Food Sci. Nutr., 61, 1976; Gordalina, M., Pinheiro, H.M., Mateus, M., da Fonseca, M., Cesario, M.T. (2021) Appl. Sci., 11, 7969, Muller, T., Bernier, M.E., Bazinet, L. (2024) Foods, 13, 1218

How do the raw materials differ in terms of composition and processability?

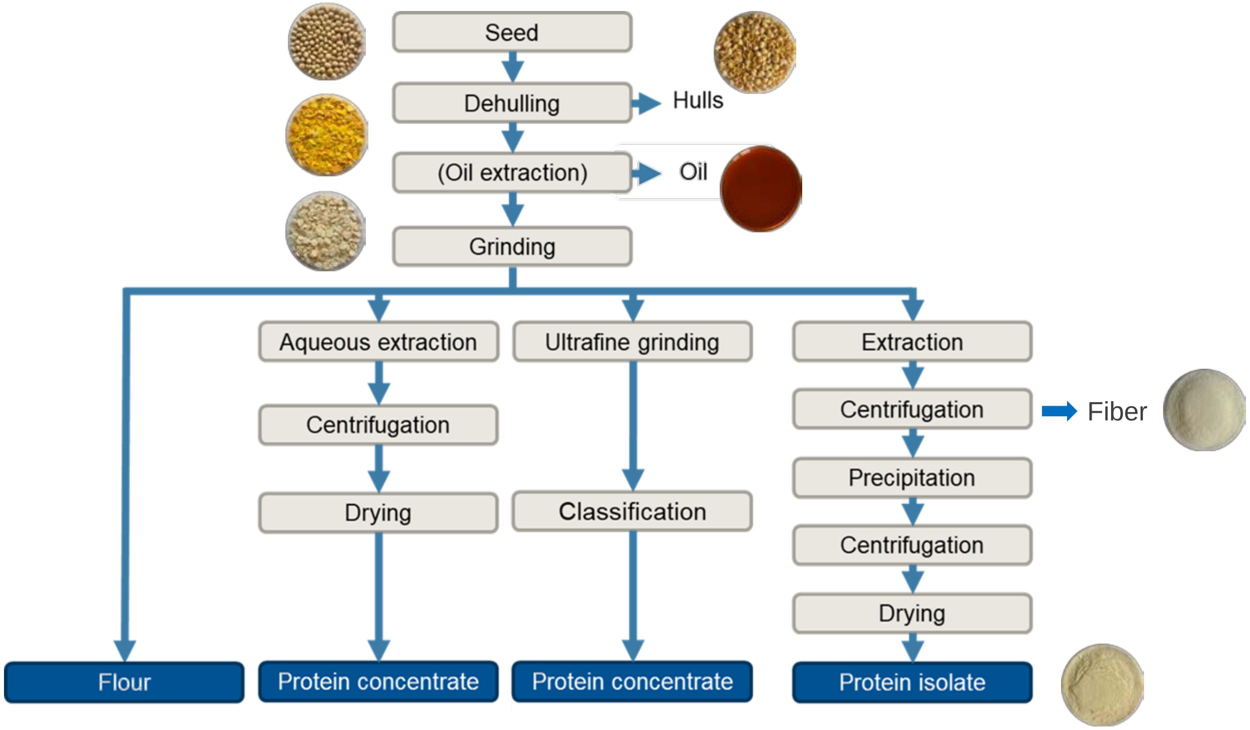


Tamayo Tenorio et al. (2018) Trends Food Sci Techn, 71, 235-245.



It is much easier (and therefore more economical) to isolate storage proteins, especially albumins and globulins.

How are protein ingredients produced?



Etzbach, L., Gola, S., Küllmer, F., Acir, I.-H. Wohlt, D., Ignatzy, L.M., Bader-Mittermaier, S., Schweiggert-Weisz, U. (2024) PNAS – Special Issue ´Sustainability of animal-sourced foods and plant-based alternatives´, in press; Loveday, S. (2020), Nutrition Bulletin, 45.3 (2020): 321-327.; Munialo, C. D. (2024) Int. J. Food Sci. Technol., 59, 462.

What is the difference between flours, concentrates and isolates?

Isolates (Protein content higher than 80%)

Chemical composition: Only traces of fibre, starch and secondary plant metabolites

Sensory properties: almost neutral

Technofunctionality properties: mainly determined by the proteins

Concentrates (Protein content: 50-80%)

Chemical composition: fibres still contained, secondary plant metabolites reduced or enriched (depending on substance and process)

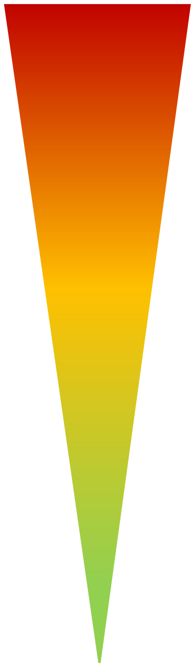
Sensory properites: Raw material-specific odour and taste still perceptible

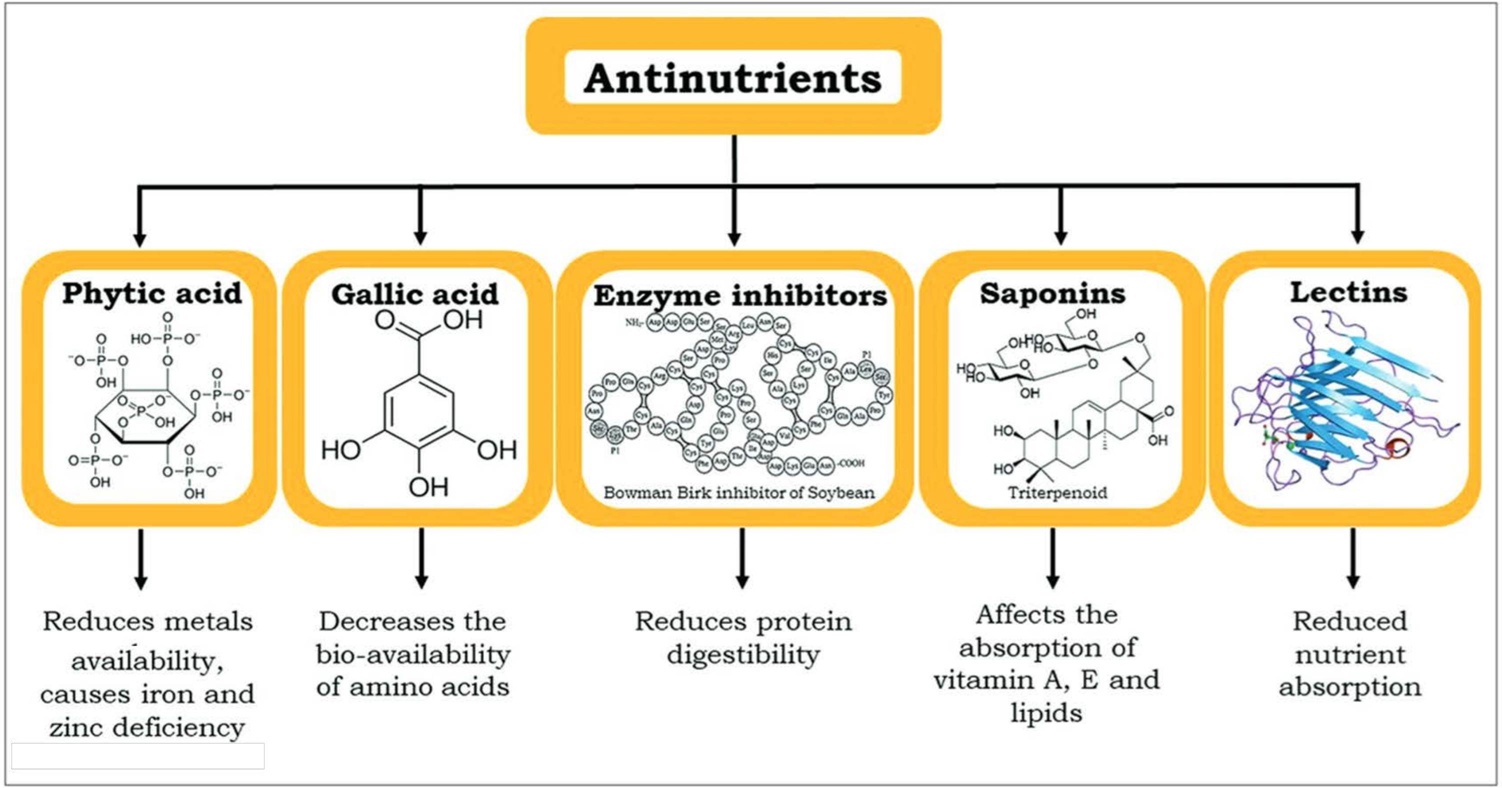
Technofunctional properties: varies and depends on the amount of fibres, starch and proteins

Flours (Protein content less than 50%)

Partly thermally treated to inactivate enzymes

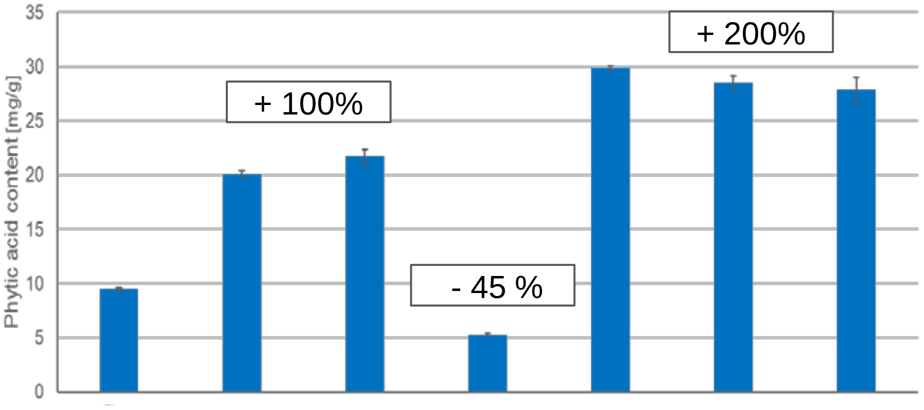
Sensory and technofunctional properties: comparable to that of the raw material




Antinutrients
Phytic acid
Gallic acid
Enzyme inhibitors
Bowman Birk inhibitor of Soybean
Saponins
Triterpenoid
Lectins
Reduces metals availability, causes iron and zinc deficiency
Decreases the bio-availability of amino acids
Reduces protein digestibility
Affects the absorption of vitamin A, E and lipids
Reduced nutrient absorption

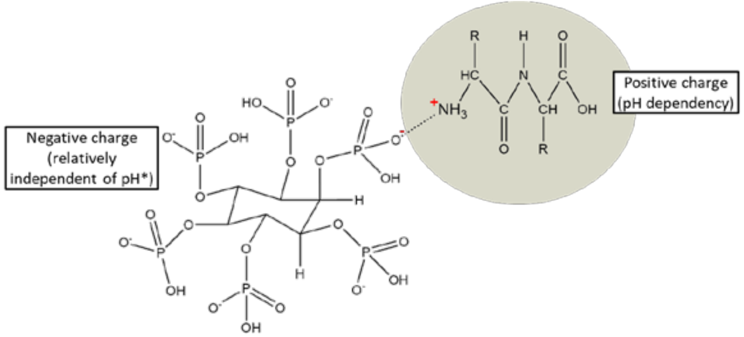
However … ?

… antinutritive compounds like phytic acid can also be enriched

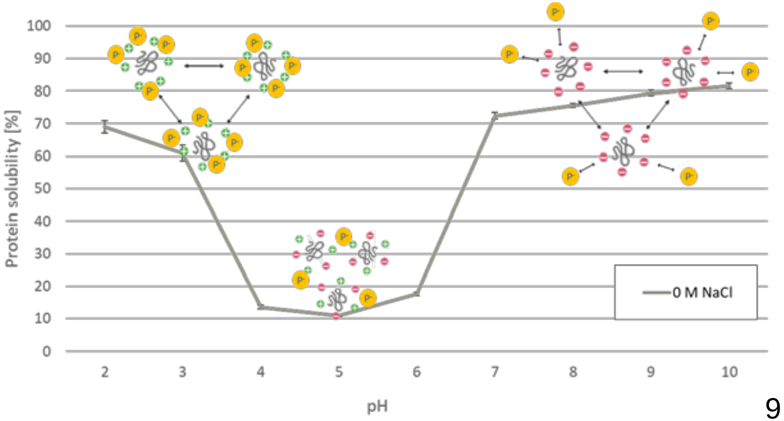


Flour Different processing procedures with different extraction pH and isolation pH

Different letters indicate significant differences (p ≤ 0.05). Values are mean ± standard deviation (n=3)

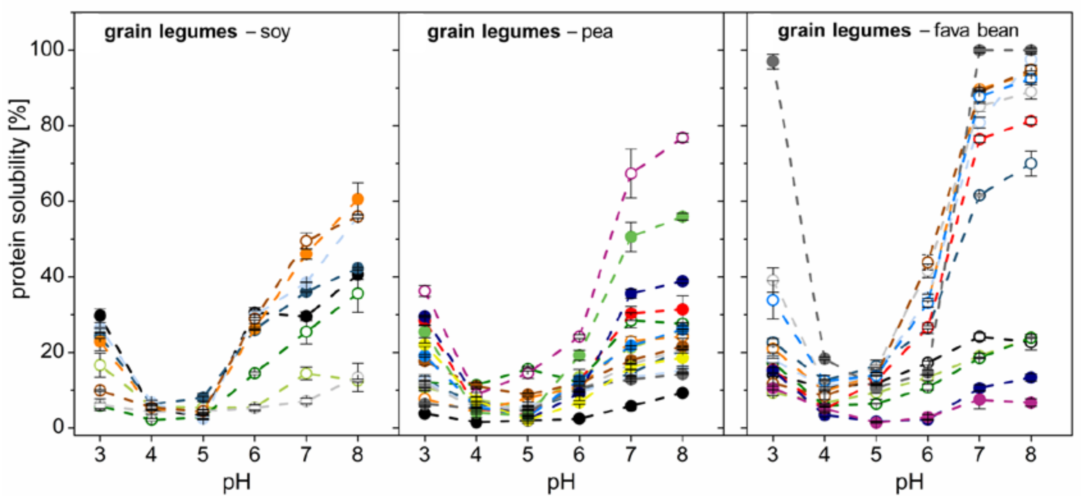


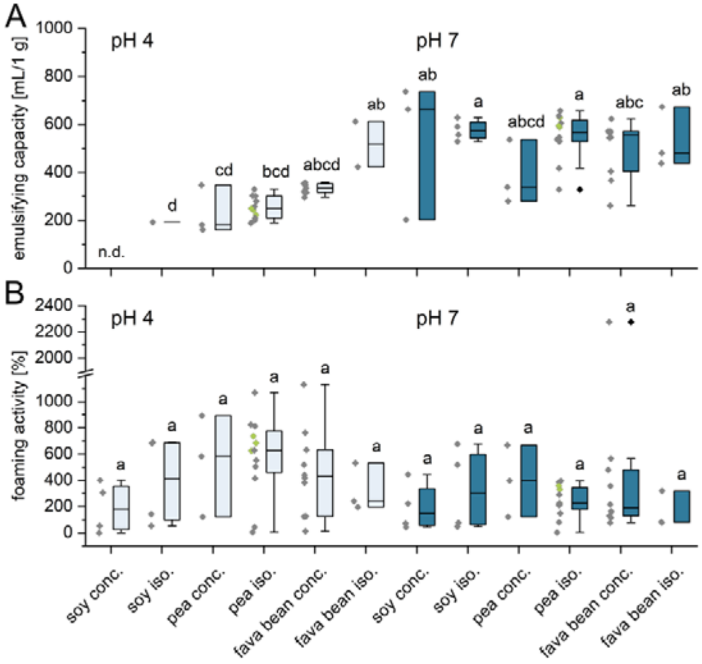
Modified according to Wang, R., & Guo, S. (2021). Compr. Rev. Food Sci. Food Saf, *20*(2), 2081-2105.
*pKs-values (phytic acid) in Humer, E., C. Schwarz, and K. Schedle (2015) *J. Anim. Physiol. Amin.* 99, 605.



Wintersohle, C., Kracke, I., Ignatzy, L.M., Etzbach, L., Schweiggert-Weisz, U. (2023) Curr. Res. Food Sci., 7, 100582

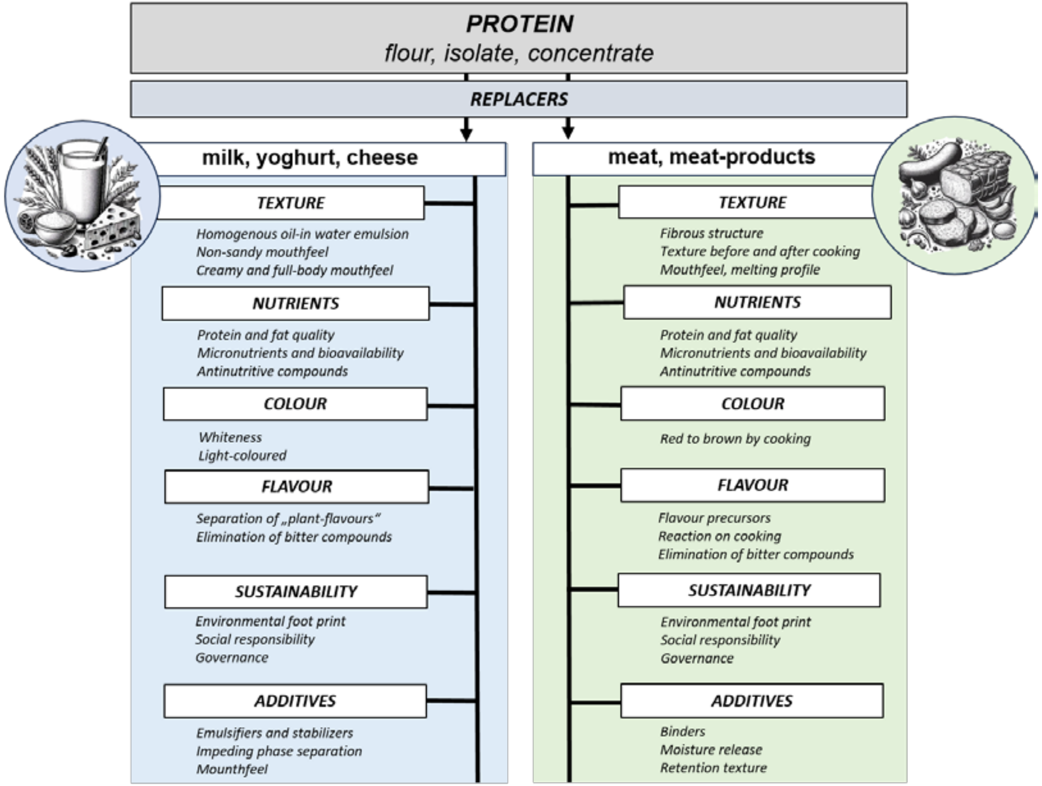
Physico-chemical and technofunctional properties of protein ingredients





Etzbach, L., Gola, S., Küllmer, F., Acir, I.H., Wohlt, D., Ignatzy, L.M., Bader-Mittermaier, S., Schweiggert-Weisz, U. (2024) Opportunities and Challenges of Plant Proteins as Functional Ingredients for Food Production. Proceedings of the National Academy of Sciences, release date: 02 December 2024

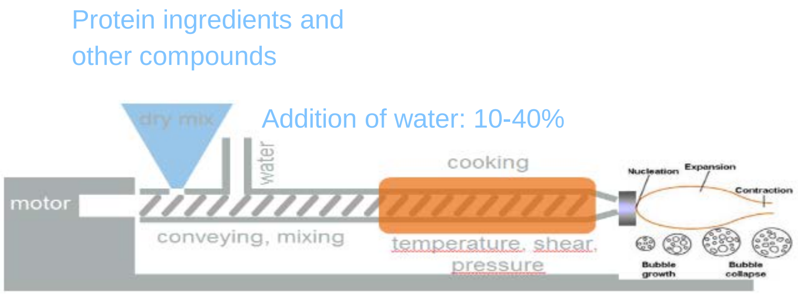
Proteins have a lot of functionalities in food products



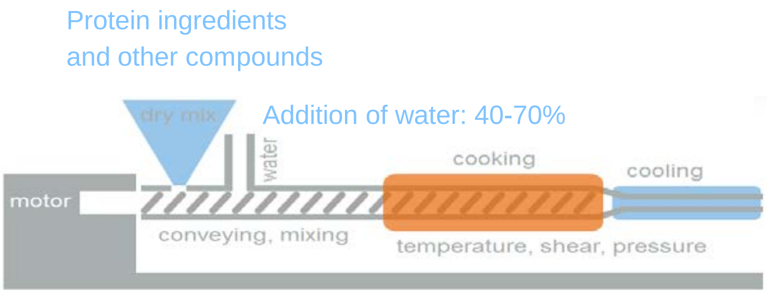
Schweiggert-Weisz, U., Etzbach, L., Gola, S., Kulling, S.E., Diekmann, Ch., Egert, S., Daniel, H. (2024) Mol. Nutr. Food Res., 68, 2400376

How are meat alternatives produced?

Low-Moisture Extrusion Cooking

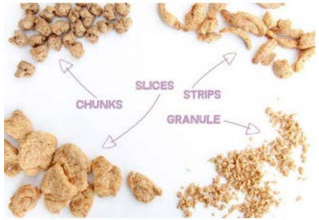


High-Moisture Extrusion Cooking



Temperatures in between 120°C and 180°C (depending on the process and recipe)

Texturization to porous foam-like network



Texturization in long cooling to fibrous network

Pictures: Fraunhofer IVV (with permission) and Pixabay

Osen, R., Schweiggert-Weisz, U. (2016) High-moisture extrusion: meat analogues. Reference module in Food Science, https://doi.org/10.1016/B978-0-08-100596-5.03099-7; Osen, R., Toelstede, S., Wild, F., Eisner, P., Schweiggert-Weisz, U. (2014) J. Food Engin., 127, 67-74; Osen, R., Toelstede, S., Eisner, P., Schweiggert-Weisz, U. (2015) Food Sci. Technol., 50, 1390-1396.

How does extrusion influence the chemical composition and nutritional quality of meat alternatives?

- **Cholesterol, zinc, selenium, pantothenic acid, and vitamin B12** levels are often lower in meat alternatives (PBMA) than meat products within the same category.
- **Iron, calcium and other micronutrient contents** were often higher for meat alternatives than comparable meat products.

Extract out of: Lindberg, L., Reid McCann, R., Smyth, B., Woodside, J.V. (2024) Trends in Food Sci. & Technol., 104483.

What else has to be considered?

Extrusion can lead to

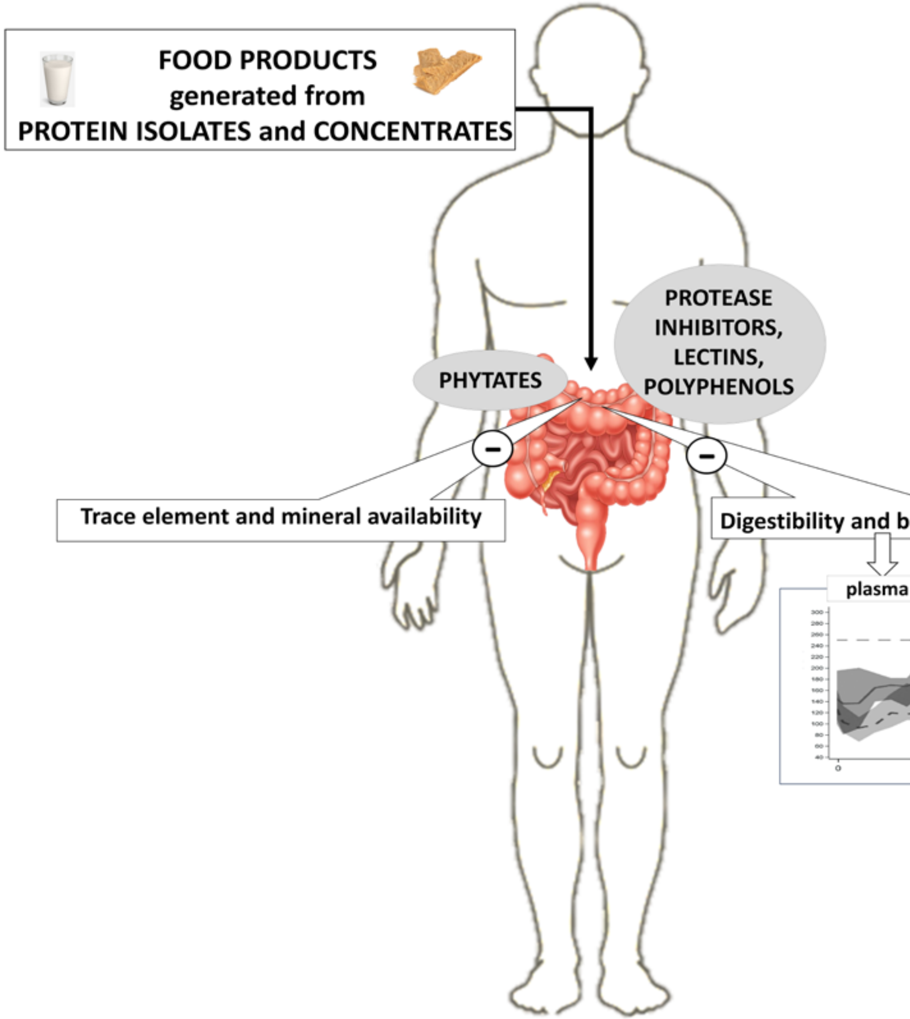
- Improvement of protein digestibility[1,2]
- Inactivation of (thermally instable) antinutritive factors like protease inhibitors[1,2]
- Decline of insoluble dietary fibre while soluble fibre levels may increase[3]

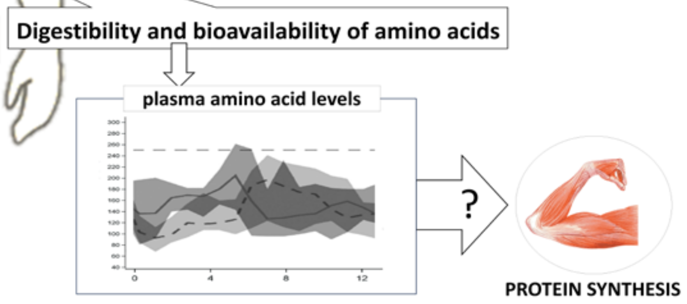
However, most studies have been conducted ´in-vitro´

Extrusion may lead to

- Decrease in thermo-labile compounds like Vitamins[4]
- Promotion of the formation of Lysinoalanine and therefore a reduction of lysine[2]

[1]Orozco-Angelino, X., Espinosa-Ramirez, J., Serna-Saldivar, S.O. (2023) Food Res Int, 169, 112889; [2]Nikmaram, N. et al., (2017) Food Control, 79, 62-73, [3]Naumann, S., Schweiggert-Weisz, U., Martin, A., Schuster, M., Eisner, P. (2021), Food Hydrocolloids, 111, 106222. [4]Brennan, C., Brennan, M., Derbyshire, E., Tiwari, B.K. (2011) T*rends in Food Sci.Technol.,* 22, 570-575.






Molecular Nutrition
Food Research

Review | Open Access

Opinion Piece: New Plant-Based Food Products Between Technology and Physiology

Ute Schweiggert-Weisz, Lara Etzbach, Susanne Gola, Sabine E. Kulling, Christina Diekmann, Sarah Egert, Hannelore Daniel

First published: 30 September 2024 | https://doi.org/10.1002/mnfr.202400376

The Skeletal Muscle Anabolic Response to Plant- versus Animal-Based Protein Consumption

Stephan van Vliet,[2,3] Nicholas A Burd,[2,3] and Luc JC van Loon[3]*

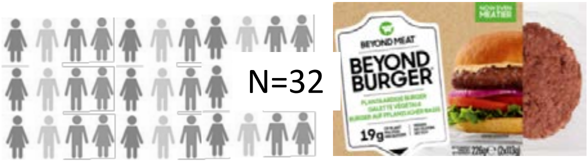
[2]Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, Urbana, IL; and [3]Department of Human Movement Sciences, Faculty of Health, Medicine, and Life Sciences, School for Nutrition and Translational Research in Metabolism (NUTRIM), Maastricht University, Maastricht, Netherlands

The Journal of Nutrition
Critical Review

Source	Leucine, % total protein	Representative amount of protein to be ingested per meal for ~3 g leucine, g	Representative amount of the food source to be ingested per meal, g
Plant sources			
Maize	12.3	25	264
Spirulina	8.5	36	63
Black bean	8.4	36	167
Rice	8.2	37	500
Soy	8.0	38	104
Lentil	7.9	39	150
Pea	7.8	39	180
Oat	7.7	35	236
Quinoa	7.2	43	302
Hemp	6.9	45	121
Wheat	6.8	45	299
Mycoprotein	6.2	49	447
Potato	5.2	58	2891
Animal sources			
Whey	13.6	23	27
Milk	10.9	28	876
Casein	10.2	30	35
Beef	8.8	35	164
Egg	8.5	36	5[2]
Cod	8.1	38	211

J Nutr 2015;:

Plasma Amino Acid Appearance and Status of Appetite Following a Single Meal of Red Meat or a Plant-Based Meat Analog: A Randomized Crossover Clinical Trial



age 28.0 ± 3.8 y

Estimated nutrient composition of participants' dietary intake the day before the clinic visit when a particular meal was consumed, based on 24-h dietary recall[1]

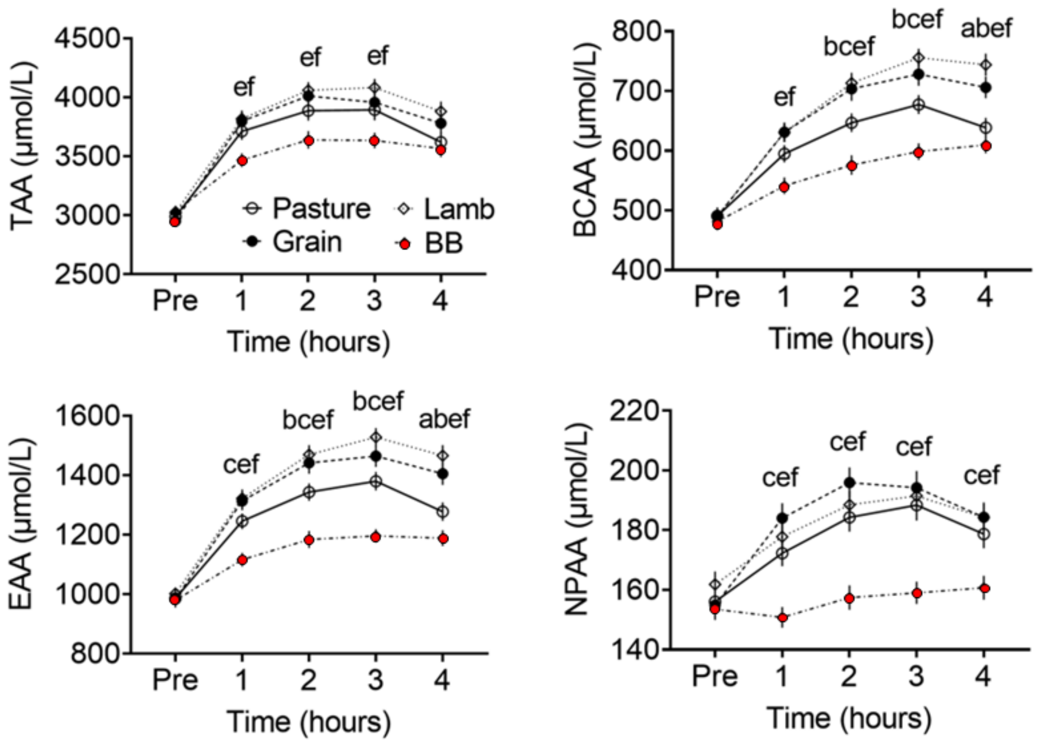
Nutrient	Pasture	Grain	Lamb	BB
Energy, kJ	9920 ± 4690	9956 ± 3910	9932 ± 3780	9644 ± 4740
Protein, g	118 ± 49	117 ± 44	118 ± 46	117 ± 59
Total fat, g	103 ± 70	102 ± 73	92 ± 43	96 ± 49
Carbohydrates, g	232 ± 116	238 ± 95	248 ± 124	230 ± 133
Fiber, g	23 ± 12	24 ± 12	24 ± 12	21 ± 11

[1]Values are means ± SDs. The test meal groups contained either pasture-raised beef (Pasture), grain-finished beef (Grain), pasture-raised lamb (Lamb), or BB. BB, Beyond Burger (Beyond Meat).

Nutrient composition of the raw meats in their minced forms, the PBMA as commercially packaged, and the cooked meals (units per 100 g, 470 g per meal)[1]

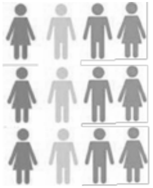
Nutrient	Pasture	Grain	Lamb	BB
Raw meats and PBMA, g				
Crude protein	18.7	18.4	21.4	18.7
Fat	17.7	9.1	2.4	17.8
Cooked meal				
Crude protein, g	10.3	11.2	12.4	10.7
Fat, g	11.1	6.7	4.3	10.1
Carbohydrates, g	18.1	18.4	19.1	18.3
Total dietary fiber, g	1.6	1.1	1.7	1.9
Sugars, g	3.5	4.0	4.0	3.8
Sodium, g	0.3	0.3	0.3	0.4
Iron, mg	<2.0	<2.0	<2.0	1.9
Zinc, mg	1.2	1.4	1.2	1.1
Cholesterol, mg	27.9	26.0	27.4	<0.5

[1]The test meal groups contained either pasture-raised beef (Pasture), grain-finished beef (Grain), pasture-raised lamb (Lamb), or BB. BB, Beyond Burger (Beyond Meat); PBMA, plant-based meat analog.



Curr Dev Nutr 2022;6:nzac082.

Peripheral Amino Acid Appearance Is Lower Following Plant Protein Fibre Products, Compared to Whey Protein and Fibre Ingestion, in Healthy Older Adults despite Optimised Amino Acid Profile



N=12

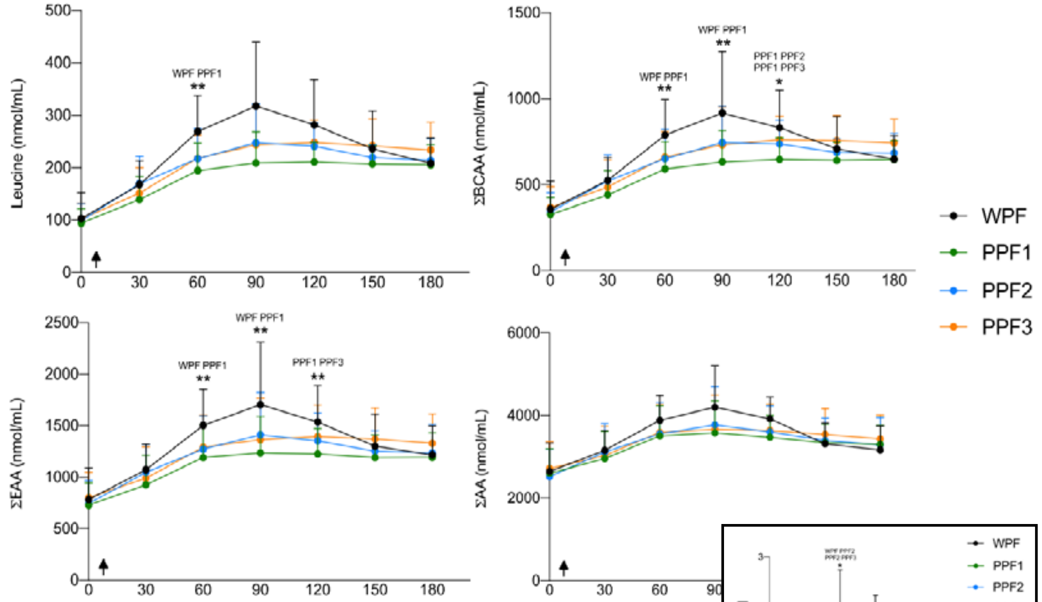
aged > 65 ± 4 y

30-40g of protein based on leucine levels

Meal Composition	WPF	PPF1	PPF2	PPF3
Lipids, g	30.0	30.0	30.0	30.0
CHO, g	15.2	15.2	15.2	15.2
Protein, g	30.9	41.3	41.8	41.1
Salt + ash, g	0.8	1.4	1.5	1.1
Energy, kcal	454.2	495.7	497.8	495.2

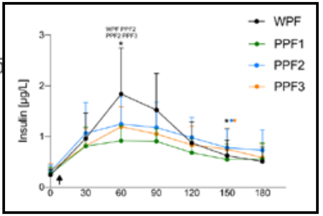
[1] Macronutrients and energy theoretical values (calculated from the manufacturer's food nutrition label). CHO, carbohydrate; PPF, plant protein fibre; WPF, whey protein fibre.

A. Protein sources	protein content (g/ 100 g dry matter basis)	PPF1	PPF2	PPF3
Rice protein isolate	91	0%	0%	18%
Pea protein isolate	88	54%	54%	36%
Pumpkin protein concentrate	62	26%	0%	0%
Soy protein isolate	92	0%	0%	26%
Oat protein concentrate	55	0%	17%	0%
Almond protein concentrate	59	0%	9%	0%
Pea fibre	11	20%	20%	20%



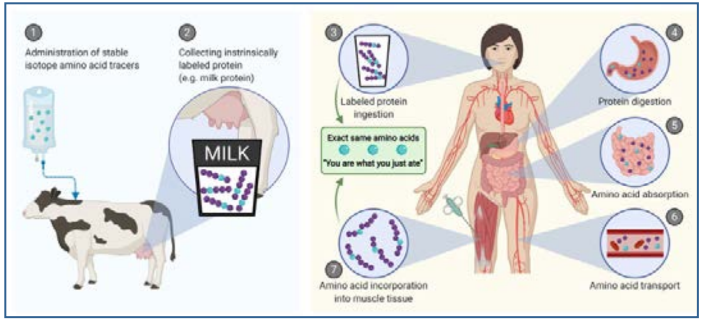
In vitro protein digestibility of plant protein (PP) and plant protein fibre (PPF) products [1].

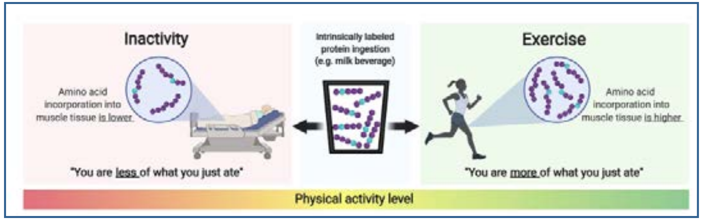
	In Vitro Digestibility (%)	
	PP	PPF *
PP 1: Pea (67%), Pumpkin (33%)	114 ± 5	110 ± 0
PP 2: Pea (68%), Oat (21%), Almond (11%)	108 ± 3	103 ± 3
PP 3: Pea (45%), Soy (33%), Rice (22%)	109 ± 1	105 ± 0

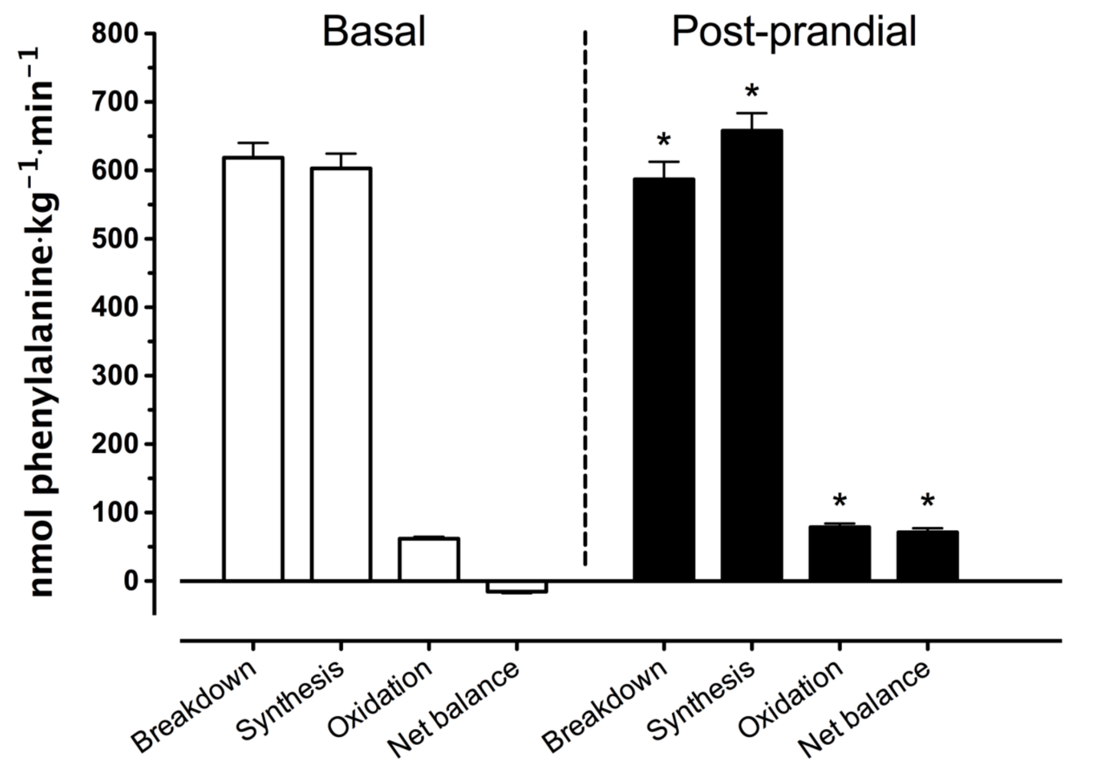


de Marco Castro E, Valli G, Buffière C, Guillet C, Mullen B, Pratt J, Horner K, Naumann-Gola S, Bader-Mittermaier S, Paganini M, De Vito G, Roche HM, Dardevet D; APPETITE Consortium. Peripheral Amino Acid Appearance Is Lower Following Plant Protein Fibre Products, Compared to Whey Protein and Fibre Ingestion, in Healthy Older Adults despite Optimised Amino Acid Profile. Nutrients. 2022 Dec 21;15(1):35. doi: 10.3390/nu15010035. PMID: 36615694; PMCID: PMC9824653.

Effect size of postprandial protein synthesis in humans assessed via oral administration of stable-isotope labeled dairy protein







Whole body phenylalanine protein kinetics. Rates of whole body protein breakdown, synthesis, and oxidation and whole-body net protein balance (expressed as nmol phenylalanine·kg^{-1}·min^{-1}) assessed during the basal (t = -180 –t = 0 min) and post-prandial (t = 0 –t = 300 min) period. Values represent means ± SEM. * Indicates a significant difference compared to basal values, *P*<0.05.

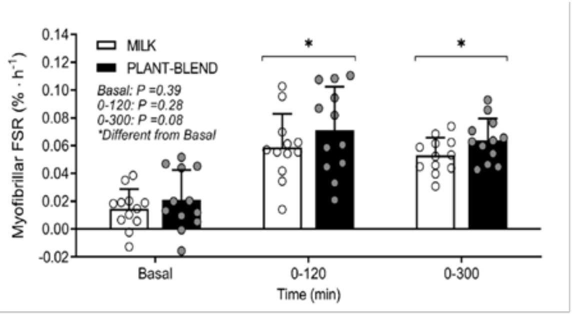
Groen BB et al. Post-Prandial Protein Handling: You Are What You Just Ate. PLoS One. 2015 Nov 10;10(11):e0141582. doi: 10.1371/journal.pone.0141582.

The Muscle Protein Synthetic Response to the Ingestion of a Plant-Derived Protein Blend Does Not Differ from an Equivalent Amount of Milk Protein in Healthy Young Males

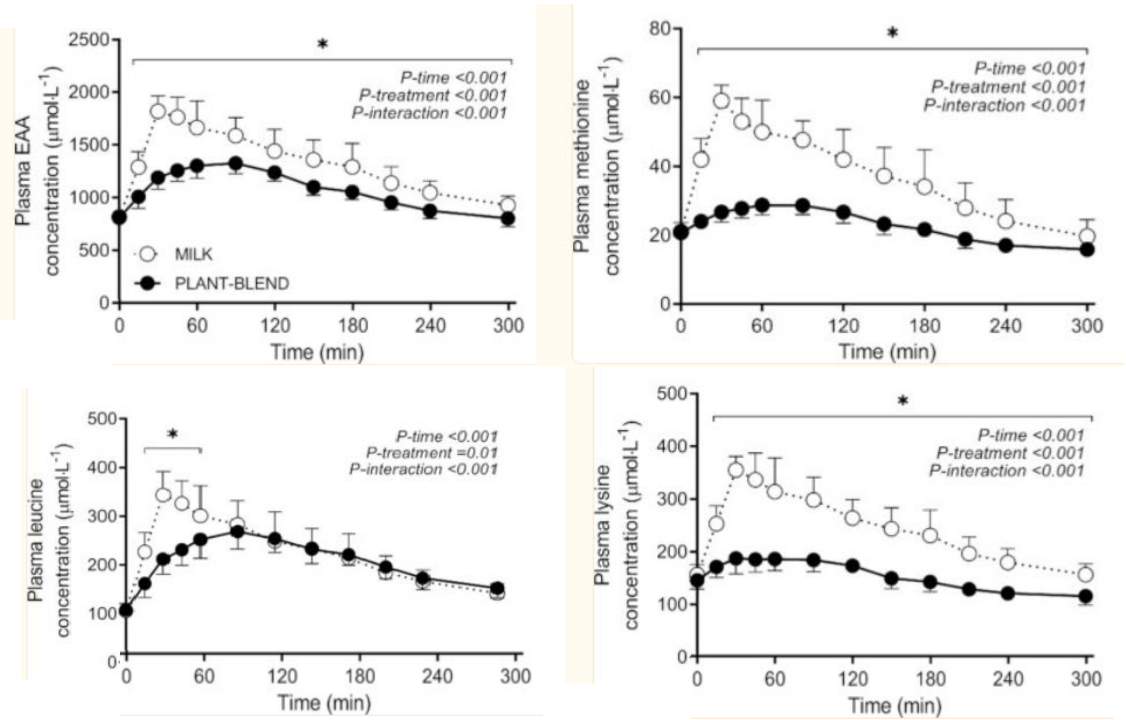
N=24

aged 24 ± 4 years

They ingested 30 g milk protein (MILK) or a 30 g plant-derived protein blend combining 15 g wheat, 7.5 g corn, and 7.5 g pea protein (PLANT-BLEND).

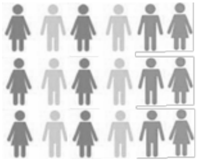


Myofibrillar protein fractional synthetic rates (FSR) at different time periods prior to and following ingestion of MILK vs. PLANT-BLEND in healthy young males (n = 12 per group). Values represent means ± SD.



Pinckaers, P.J.M. et. Al. (2023). The Muscle Protein Synthetic Response to the Ingestion of a Plant-Derived Protein Blend Does Not Differ from an Equivalent Amount of Milk Protein in Healthy Young Males. *J Nutr.* 152(12):2734-2743. doi: 10.1093/jn/nxac222.

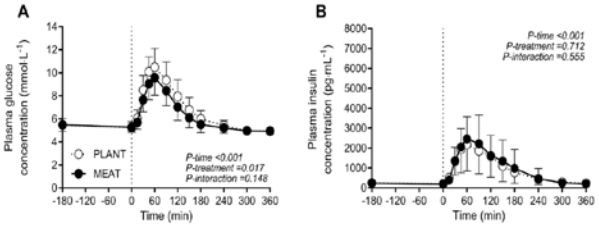
Higher Muscle Protein Synthesis Rates Following Ingestion of an Omnivorous Meal Compared with an Isocaloric and Isonitrogenous Vegan Meal in Healthy, Older Adults

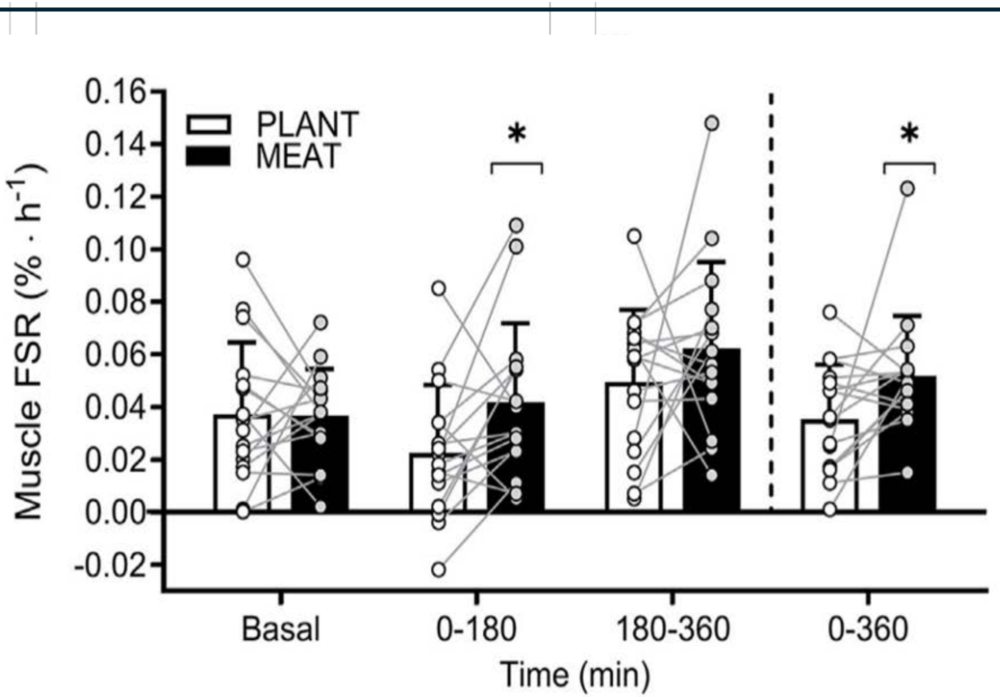


N=16

age: 65–85 years

(8 males, 8 females)

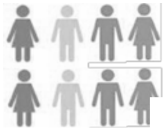




Mixed-muscle protein fractional synthetic rates (FSR) at different time periods prior to and following the ingestion of MEAT compared with PLANT meal in healthy, older individuals

The Journal of Nutrition, Volume 154, Issue 7, July 2024, Pages 2120-2132

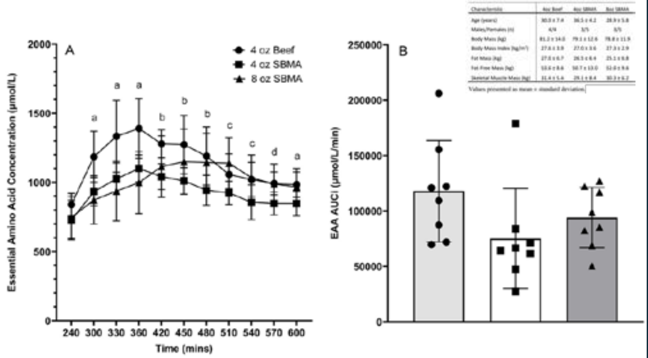
The anabolic response to a ground beef patty and soy-based meat alternative: A randomized controlled trial

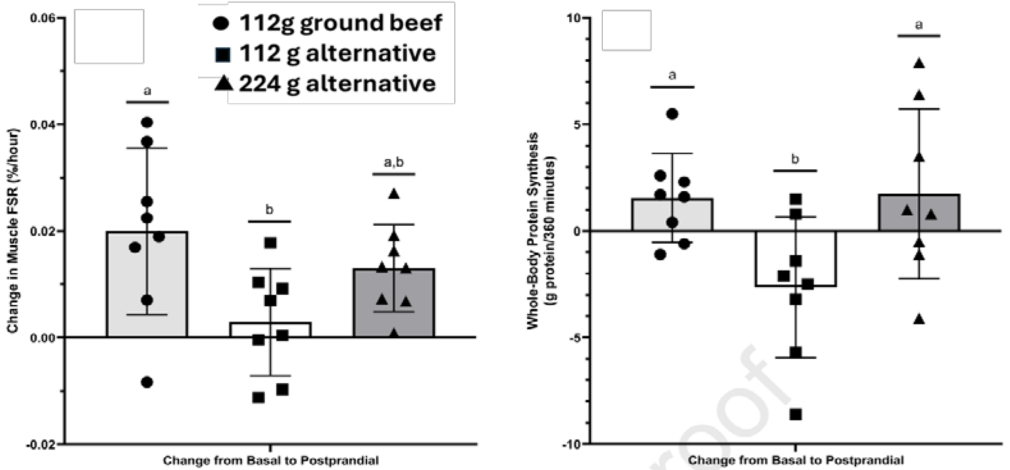


age: 18-40 years
(4males, 4 females)

Macronutrient content of three meal options

Nutrient	4oz Beef	4oz SBMA	8oz SBMA
Calories (kcal)	279	231	462
Protein (g)	27.3	20.5	40.9
ΣEAA (g)	10.2	7.5	15
Leucine (g)	1.96	1.53	3.06
Carbohydrates (g)	0	9	18
Sugars (g)	0	<1	<1
Fats (g)	18	13	26
Saturated fats (g)	8	6	12



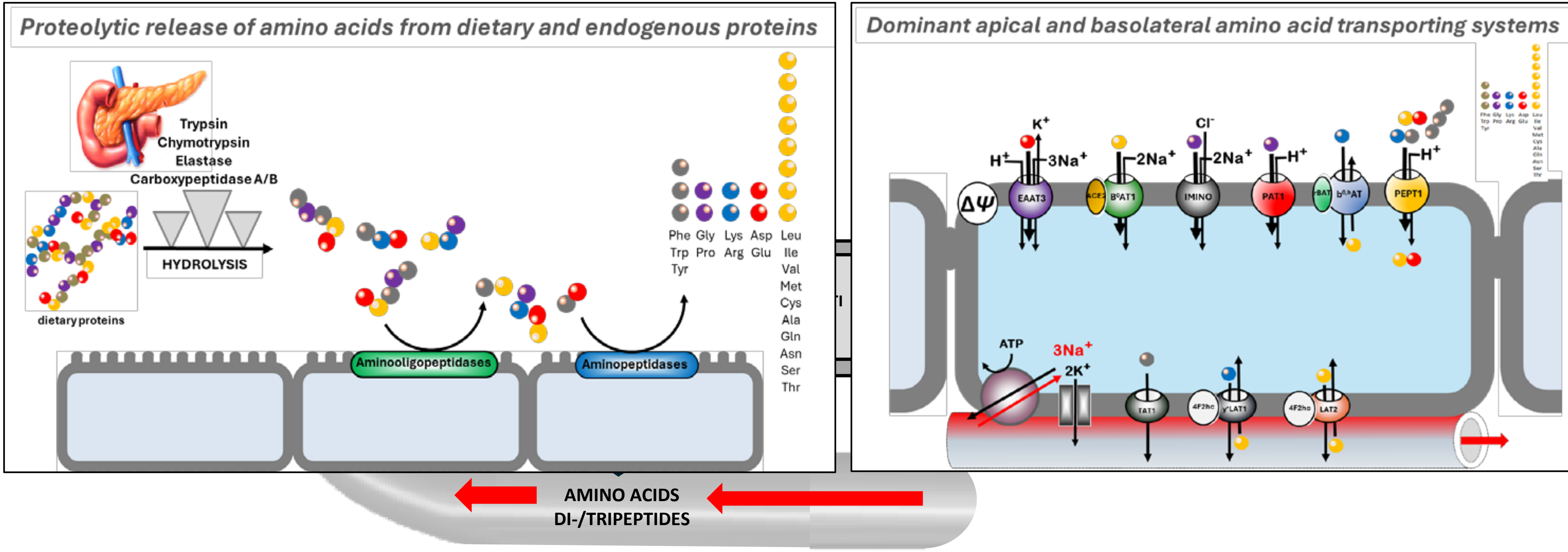


Church et al. The anabolic response to a ground beef patty and soy-based meat alternative: a randomized controlled trial. Am J Clin Nutr. 2024 Aug 31:S0002-9165(24)00727-5.

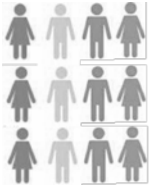
Protein digestion & nitrogen handling in the human intestine

- things to be considered -

Protein digestion and nitrogen handling in the human intestine
- things to be considered -



Appearance of Di- and Tripeptides in Human Plasma after a Protein Meal



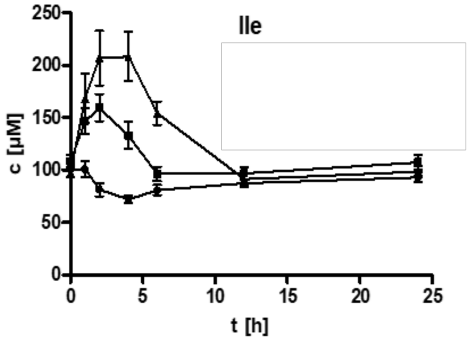
N=12

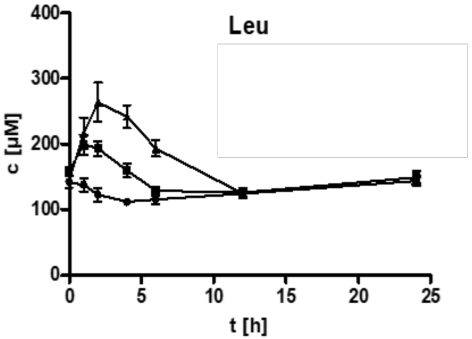
Age: 18-40 years

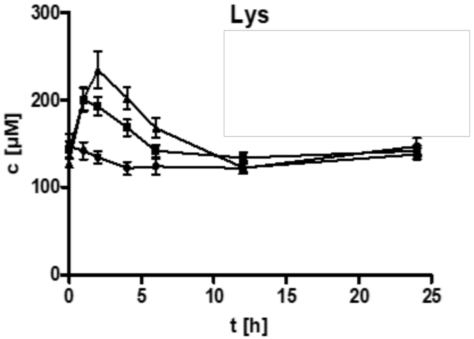
125g rice

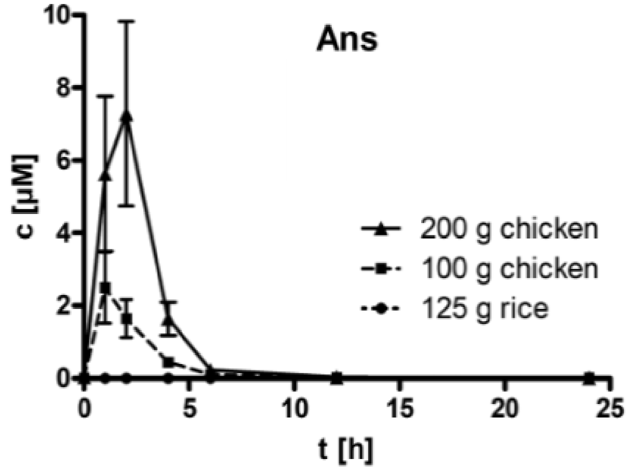
100g chicken

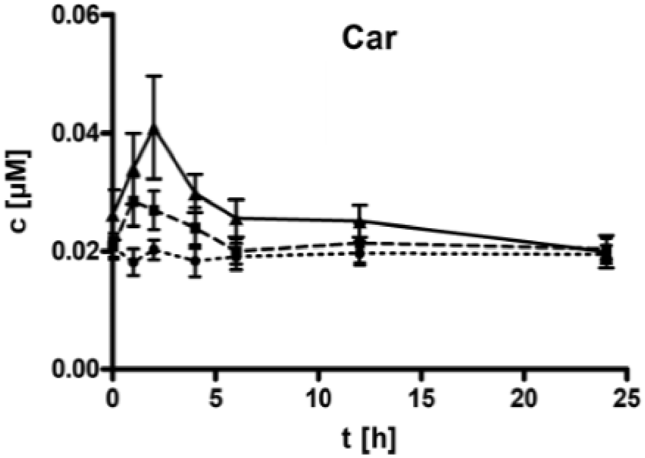
200g chicken





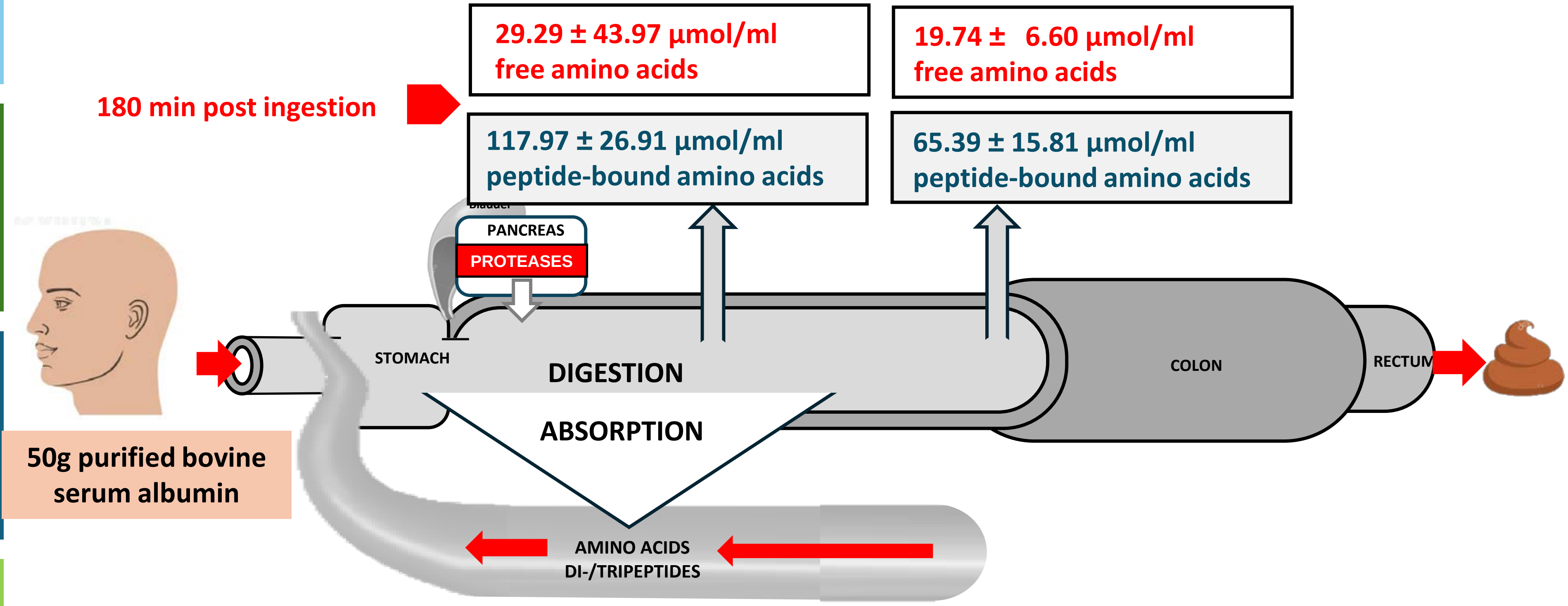






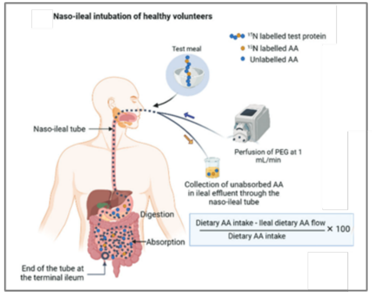
Rohm F, Skurk T, Daniel H, Spanier B. Mol Nutr Food Res. 2019 Mar;63(5):e1801094.

Protein digestion and nitrogen handling in the human intestine - things to be considered -

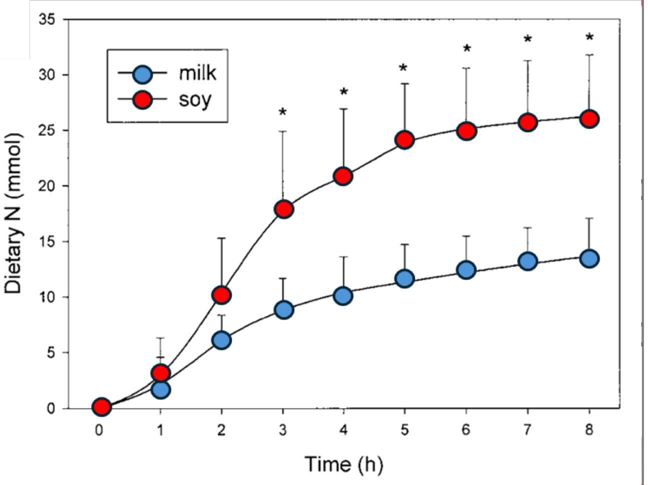


Adibi SA and Mercer DW, The Journal of Clinical Investigation Volume 52 July 1973.1586-1594

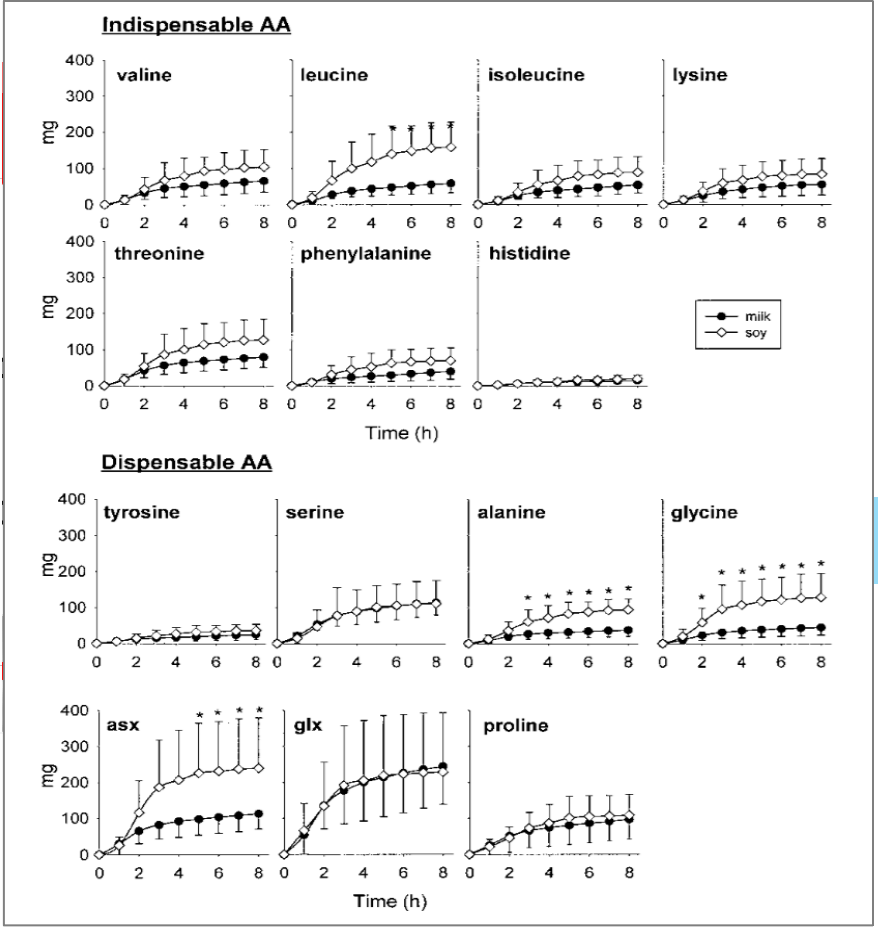
Ileal Losses of Nitrogen and Amino Acids in Humans and Their Importance to the Assessment of Amino Acid Requirements



30g each in 500ml



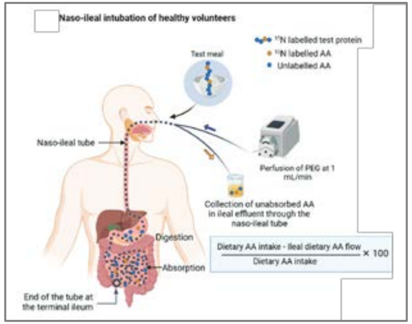
Cumulative dietary nitrogen appearance in human ileal effluents after the ingestion of milk or soy protein

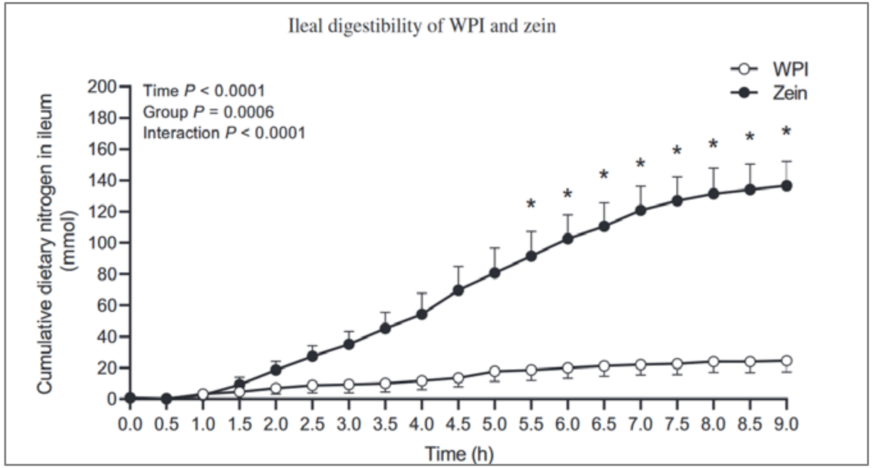


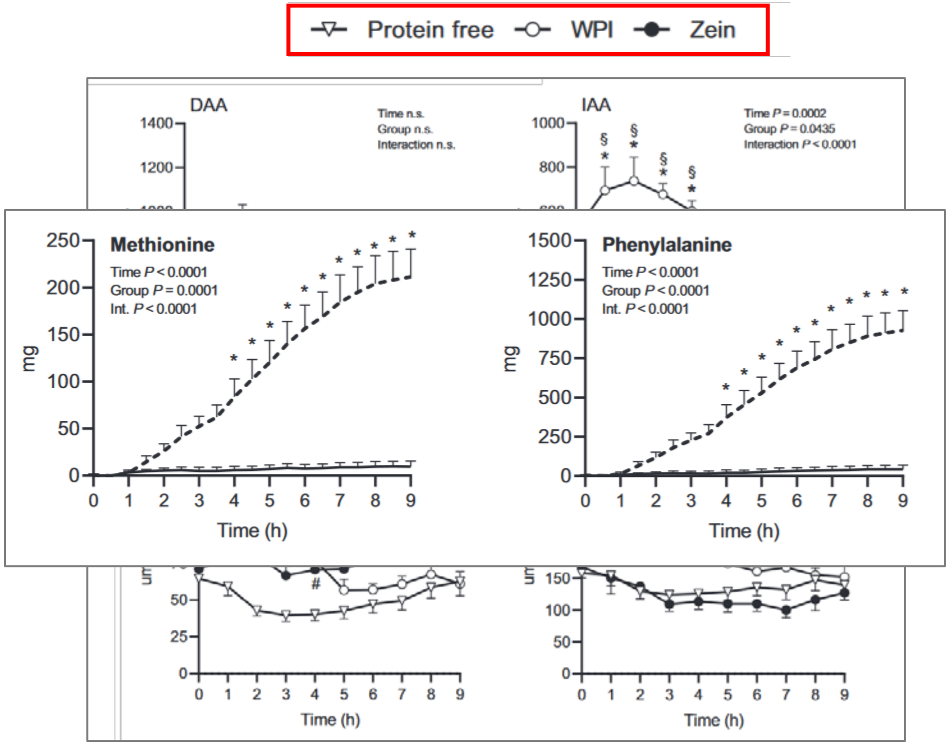
CLAIRE GAUDICHON, CECILE BOS, CELINE MORENS, KLAUS J. PETZKE, FRANCOIS MARIOTTI, JULIA EVERWAND, ROBERT BENAMOUZIG, SOPHIE DARE´,DANIEL TOME´, and CORNELIA C. METGES. ***GASTROENTEROLOGY 2002;123:50 –59***

Very low ileal nitrogen and amino acid digestibility of zein compared to whey protein isolate in healthy volunteers.

Calvez J, Benoit S, Piedcoq J, Khodorova N, Azzout-Marniche D, Tomé D, Benamouzig R, Airinei G, Gaudichon C



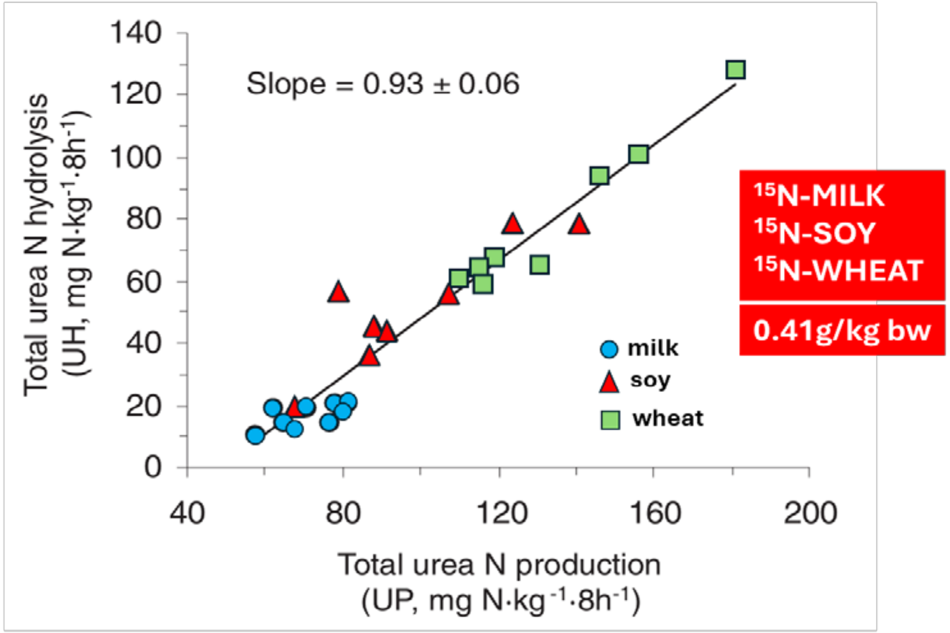




Am J Clin Nutr. 2021 Jan 4;113(1):70-82. doi: 10.1093/ajcn/nqaa274. PMID: 33021640.

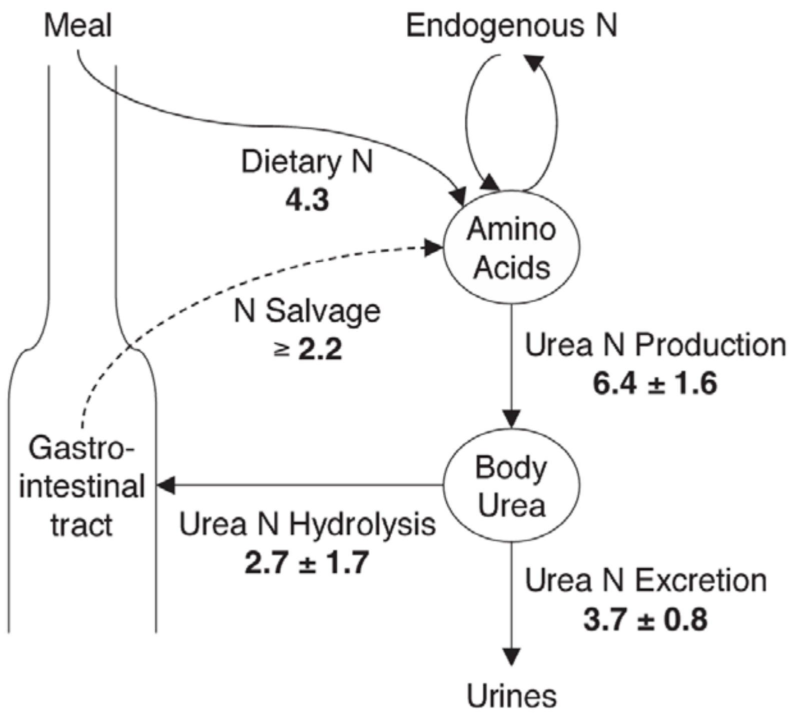
True ileal nitrogen digestibility of zein was markedly lower than WPI with 60.2 ± 4.5% and 91.2 ± 2.6%, respectively.

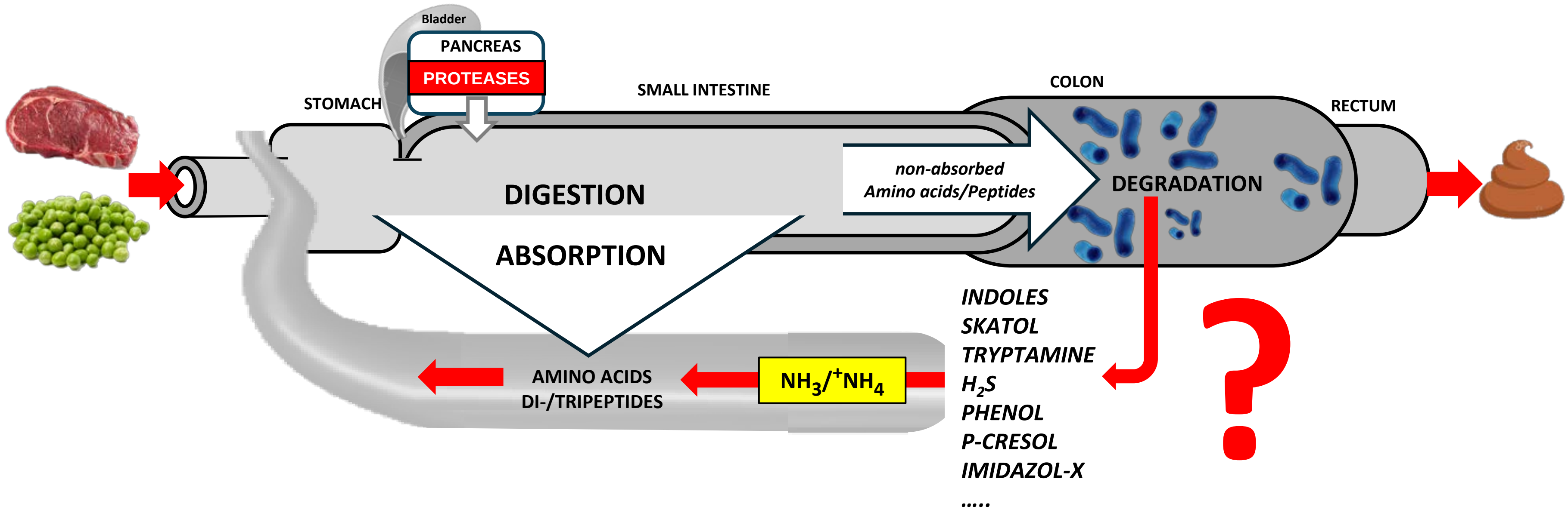
Postprandial (8h) urea/nitrogen turnover in response to ingestion of milk, soy or wheat protein in human volunteers



Relation between total urea nitrogen hydrolysis (UH) and production (UP) in subjects adapted to a normal-protein diet after the ingestion of a single mixed meal containing either milk(n 8), soy (n 8), or wheat(n 8) protein. Correlation(Pearson'sr 0.96, P 0.0001) is expressed by UH 0.93 UP–44.69.

Am JClin Nutr 2008;87:1702–14.




Bladder
PANCREAS
PROTEASES
STOMACH
SMALL INTESTINE
COLON
RECTUM
DIGESTION
ABSORPTION
non-absorbed
Amino acids/Peptides
DEGRADATION
AMINO ACIDS
DI-/TRIPEPTIDES
NH_3/$^+NH_4$
INDOLES
SKATOL
TRYPTAMINE
H_2S
PHENOL
P-CRESOL
IMIDAZOL-X
.....
?

TAKE HOME

We need to understand better WHAT CAUSES the lower bioavailability of amino acids and lower protein synthesis rates from the plant-based preparations and the corresponding effects on the gut micobiome.

We need a better characterisation of protein isolates/concentrates for use in replacer products regarding compounds that limit the dietary quality (mineral/micronutrient availability, amino acid utilisation).

Since replacer products in most cases fall under UPF-classification, we need a science-based discourse on „conflicts of objectives“ (between clean label and environmental burden).

It would be relevant to provide advice to producers of food products based on new protein sources on which nutrients are critically affected by the source and to which extent micronutrients need to be added (min-max).