Legumes in a sustainable healthy diet

(How) to be or not to be,
that is the question

Daniel Ibsen, postdoc
For more about plant-based diets and health
follow along on Twitter **@daniel_Ibsen**
Or get in contact via email: **daniel.Ibsen@mrc-epid.cam.ac.uk**

MRC Epidemiology Unit
University of Cambridge
DANMARKS FRIE FORSKNINGSFOND
INDEPENDENT RESEARCH FUND DENMARK

Agenda

- Nutritional composition
- Protein myths
- Legumes and health
  - Ultra-processed foods and plant-based meat alternatives
- Legumes and environmental impact
- Future foods

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Legumes in all sizes and shapes

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Nutritional composition

- Legumes are a good source of **amino acids, fiber, folate, iron, magnesium and potassium**
- Legumes contain antinutrients such as **phytates, alkaloids, saponins, tannins, and short chain oligosaccharides**, which may **decrease the bioavailability and absorption of micronutrients, lower protein digestibility and cause intestinal discomfort in humans**
- **Processing** legumes alters their nutritional composition

Processing alters nutritional composition

Pulses	Kidney beans[1]		Chickpeas[1]		Green lentils[1]	Soybeans[2]	Peas[3]
Processing	Household cooking	Canning	Household cooking	Canning	Household cooking	Boiled	Raw
Proteins (g/100g)	9.7	6.7	7.8	6.5	8.3	17.6	4.9
Essential AA	4.5	3.2	3.5	2.9	3.4	6.6	1.9
Non-essential AA	5.2	3.6	4.4	3.6	4.9	11.0	3.0
Dietary fibre (g/100g)	11.6	6.5	8.2	6.4	8.5	6.0	5.9
Water-soluble vitamins (µg/100g)							
Folate	19.5	21.2	67.6	34.3	26.0	25.0	54.0
Minerals (mg/100g)							
Iron	2.3	1.8	1.3	1.3	2.0	5.1	1.8
Magnesium	39.0	26.0	44.0	28.0	32.0	86.0	28.0
Potassium	300.0	250.0	190.0	140.0	230.0	515.0	300.0
Antinutrients(mg/100g)							
Phytic acids	627.0	386.0	694.0	526.0	714.0	-	-
Saponnins	106.0	119.0	122.0	117.0	174.0	-	-
Tannins	6.8	5.4	16.6	16.7	12.5	-	-
Environmental impact per kg dry food in supermarket[4)]							
Climate impact (kg CO_2/kg)	0.6		0.6		0.6	0.6	0.7

Ibsen et al. 2022. Int J Food Design (In press)

Plant-based meat alternatives

- Legume flour has been processed into new texturized products to mimic traditional meat-based products such as burgers, sausages and nuggets
- In these foods, legumes are processed to change the properties of the proteins, creating structures more familiar to our current diets, such as fibrous chicken, minced meat or sausages
- These formulations often include added sodium, saturated fat, or carbohydrates, while simultaneously having a lower content of dietary fiber, vitamins and minerals than home cooked legumes
- These products would be defined as ultra-processed foods according to the NOVA classification

NOVA classification

Food group	Extent and purpose of processing	Examples
Group 1: Unprocessed or minimally processed foods	No processing, or mostly physical processes used to make single whole foods more durable, accessible, convenient, palatable, or safe	Frozen and dried beans and other pulses
Group 2: Processed culinary or food industry ingredients	Extraction and purification of components of single whole foods, resulting in producing ingredients used in the preparation and cooking of dishes and meals made from Group 1 foods in homes or traditional restaurants, or else in the formulation by manufacturers of Group 3 foods	Bean flours, and “raw” bean pastas and noodles (made from flour with the addition only of water)
Group 3: ultra-processed food products	Processing of a mix of Group 2 ingredients and Group 1 foodstuffs in order to create durable, accessible, convenient, and palatable ready-to-eat or to-heat food products liable to be consumed as snacks or desserts or to replace home-prepared dishes	Plant-based meat alternatives like plant-based burgers

Monteiro et al. 2010. Cadernos de Saude Publica

Plant-based vs meat-based products

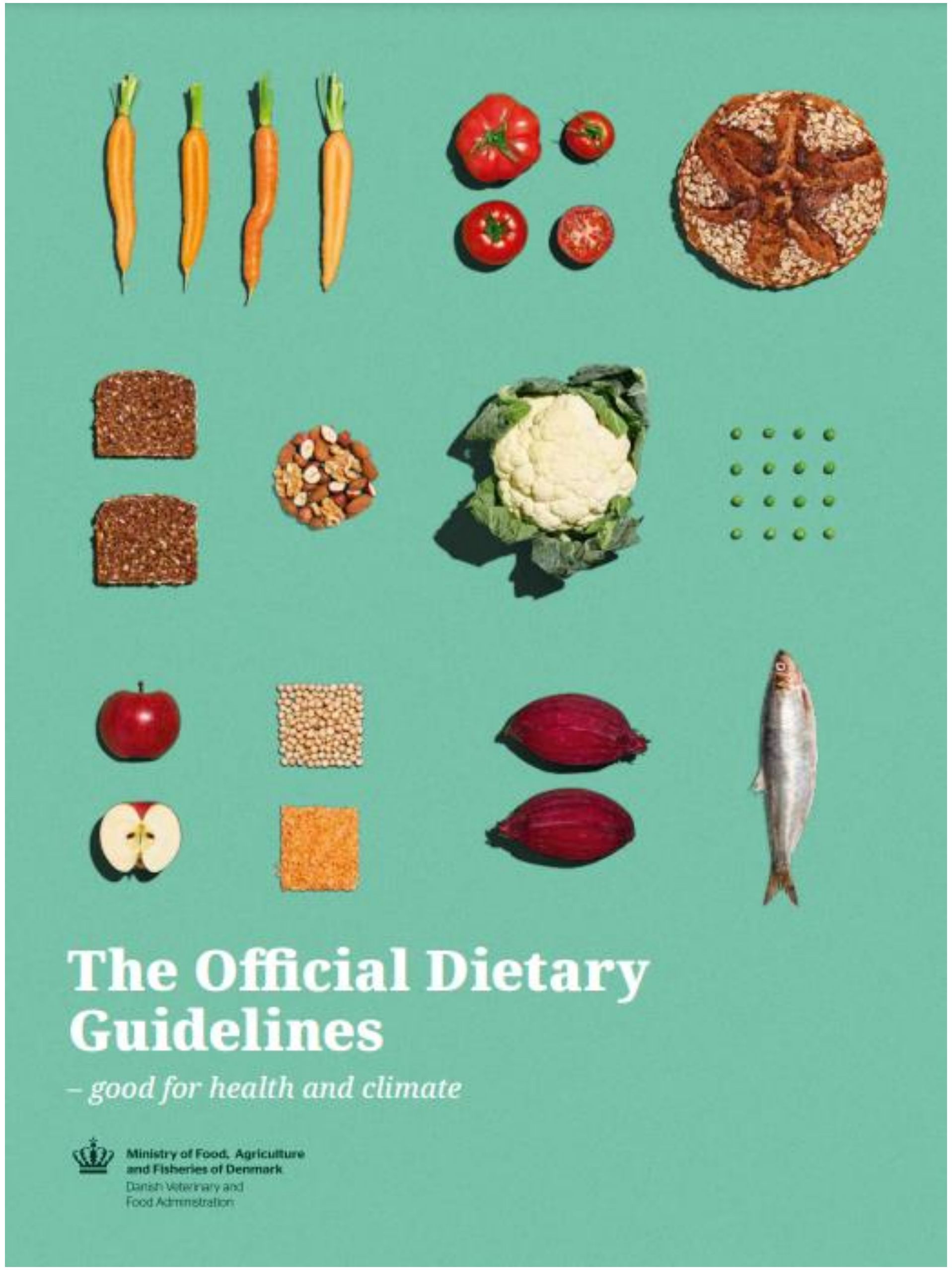
A cross-sectional study of the commercial plant-based landscape across the US, UK and Canada.

Nicola Guess PhD RD 1,2, Kevin Klatt PhD RD 3, Dorothy Wei BSc 4, Eric Williamson MSc CSSD 5, Ilayda Ulgenalp BSc 6, Ornella Trinidade MSc ANutr 7, Eslem Kusaslan 8, Azize Yilidrim MSc RD 9, Charlotte Gowers 10, Robert Guard BSc 11 Chris Mills MPH RD 12

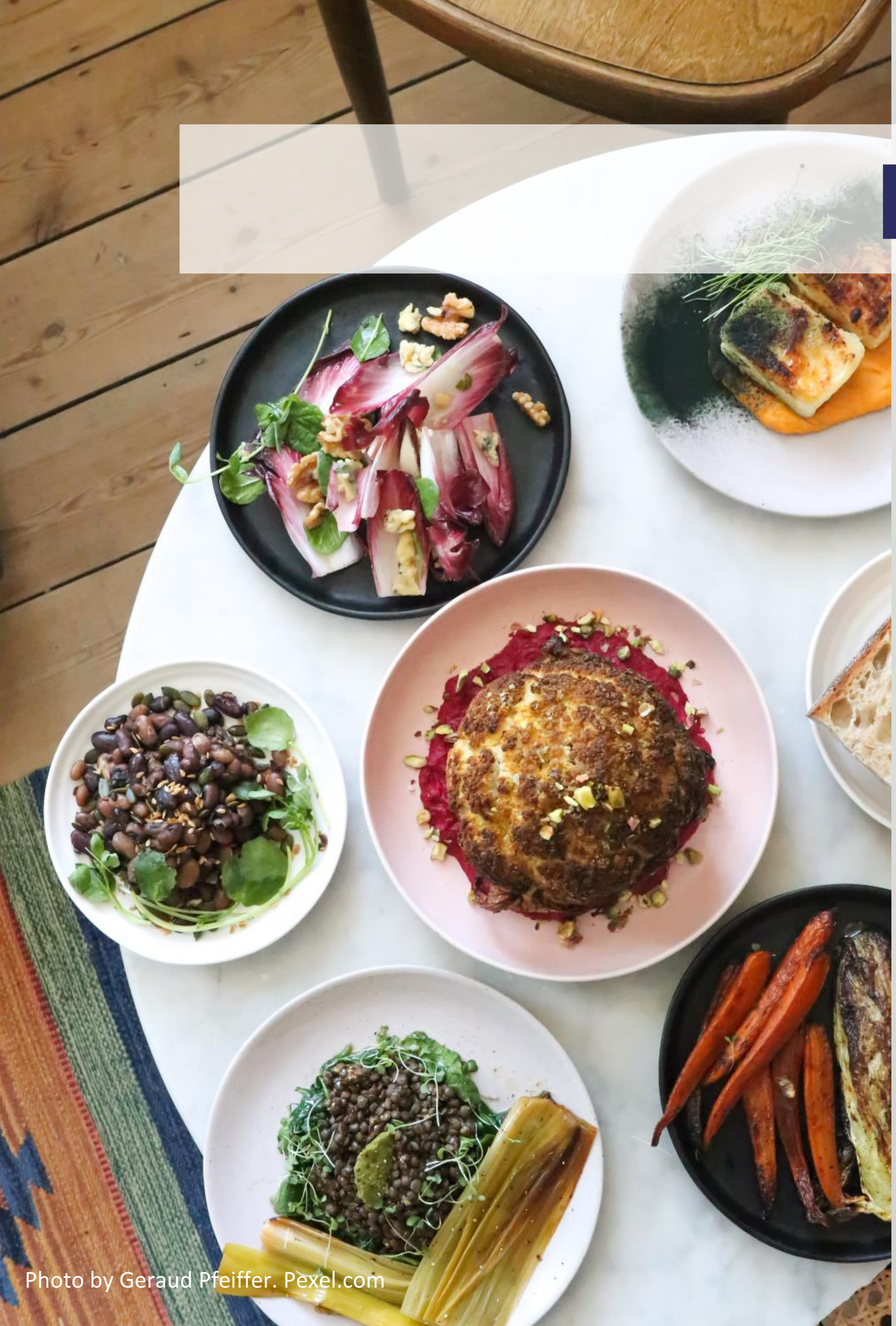
- Meat-based products higher in energy, protein and sodium compared with vegetarian and vegan products
- Meat-based products higher in saturated fat and lower in fibre than vegan but not vegetarian options

Plant-based meat alternatives

- The Danish dietary guidelines note that plant-based meat alternatives are less nutrient dense than other forms of legumes, and thus these products cannot be the only type of legume consumed
- Given the time it takes to prepare legumes from their dried form, it seems evident that new product development and processing will be necessary to improve convenience and increase consumption of legumes.



Protein myths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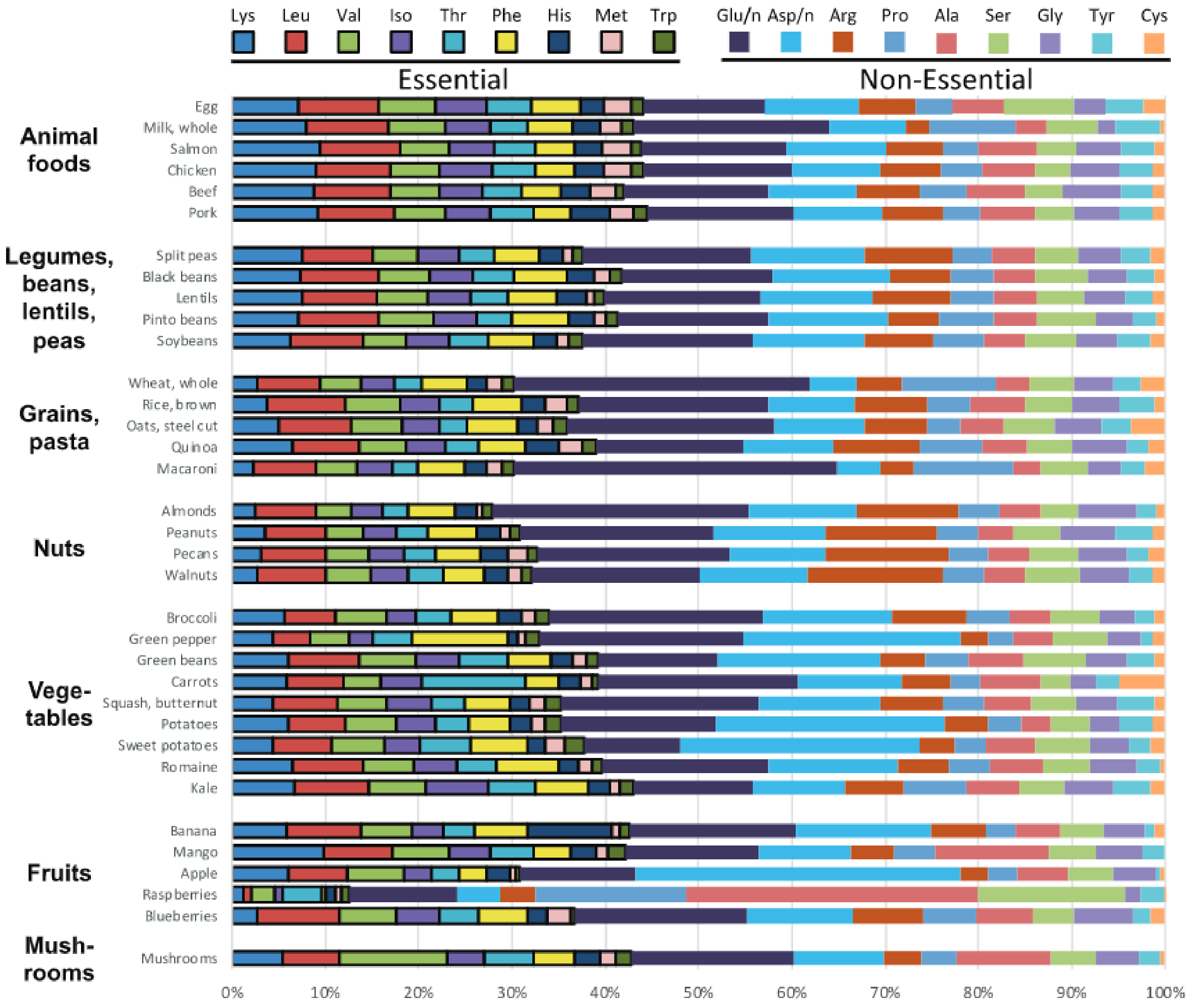
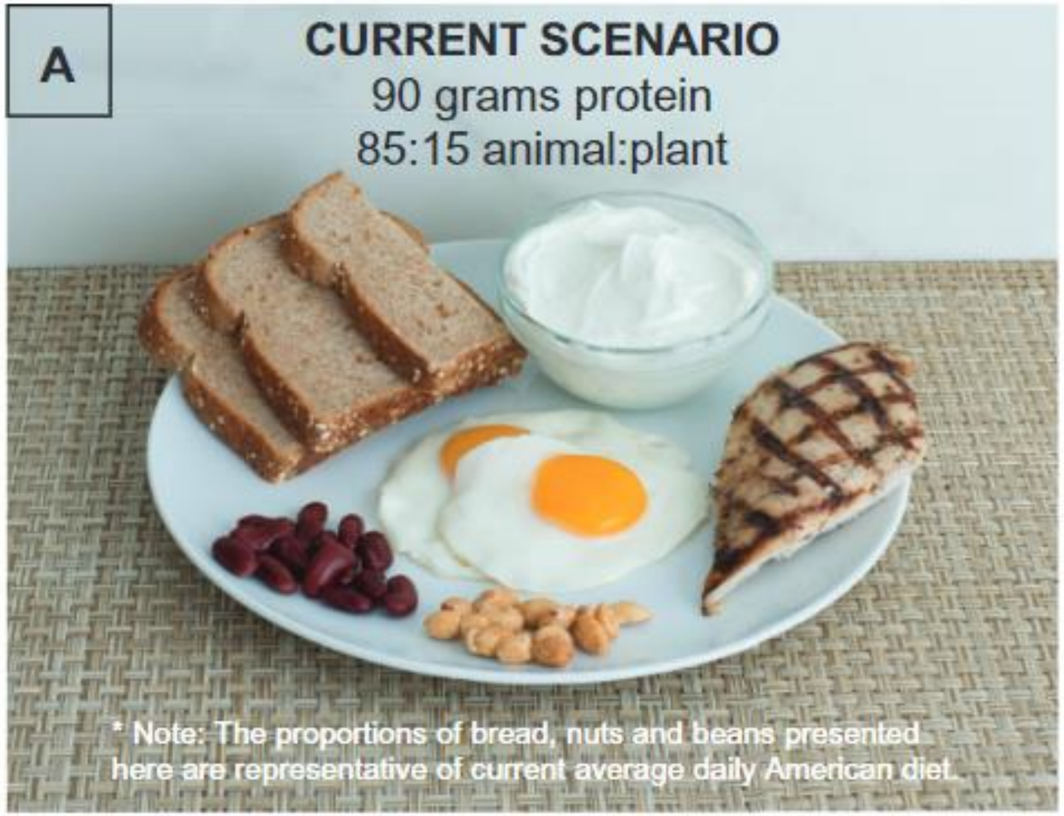
For most, getting the "right" protein: not be a concern



- All plant foods have all 20 amino acids
- Should only be concerned about complementary protein sources when:
  - Eat little total protein
  - Little dietary variety
  - No milk or meat intake
- Average intake of protein in the UK: 72 g/day, 16.1% of total energy intake in adults (per NDNS 2020)

Gardner et al. 2019. Nutr Rev

Likely dietary shifts: not a concern for protein intake



Gardner et al. 2019. Nutr Rev

Legumes and health

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Overall, legumes seems to be related to lower risk of disease

Reference	Outcome	Legume	Dose	Comparison	n studies	Measure of association	
				Cohort studies			
Marventano et al. 2017[1]	Cardiovascular disease	All types	<1 s/d to 3-4 s/d	Lowest category of exposure	18	HR	0.94 (0.89, 1.00)
Marventano et al. 2017[1]	Coronary heart disease				12		0.90 (0.84, 0.97)
Marventano et al. 2017[1]	Stroke				8		1.01 (0.89, 1.14)
Zhu et al 2015[1]	Colorectal cancer	All types	Highest category of intake	Lowest category of exposure	14	HR	0.91 (0.84, 0.98)
	Colorectal cancer	Beans			5		1.00 (0.89, 1.13)
	Colorectal cancer	Soybeans			3		0.85 (0.73, 0.99)
Tang et al. 2020	Type 2 diabetes	All types	Highest category of intake	Lowest category of exposure	7	HR	0.95 (0.79, 1.14)
		Total soy			9		0.8[illegible] (0.68, 1.01)
		So[illegible]k			[illegible]		0.8[illegible] (0.71, 1.[illegible]1)
		Tofu			4		0.92 (0.[illegible]4, 0.99)
Pearce et al. 2021	Type 2 diabetes	All ty[illegible]	20 g/day higher	20 g/day lower and higher of other foods	27	IRR	1.02 (1.01, 1.04)
		Pulses[1]			13		1.02 (1.00, 1.03)
		Tot[illegible]oy			[illegible]		1.0[illegible] ([illegible], 1.04)
				Randomized controlled trials			
Bazzano et al. 2011	Total cholesterol[2]	Pulses[3]	80-440 g/day	Spaghetti, wheat, carrots or matched	10	MD	-11.8 (-16.1, -7.5)
	LDL cholesterol[2]						-8.0 (-11.4, -4.5)
	HDL cholesterol[2]						0.9 (1.6, 3.3)
	Triglycerides[2]						-18.9 (-38.9, 0.1)
Jayalath et al. 2014	Systolic blood pressure[4]	Pulses[3]	81-275 g/day	Fatty fish, wheat, potato flakes or matched	8	MD	-2.3 (-4.2, -0.3)
	Diastolic blood pressure[4]						-0.7 (-1.7, 0.3)
	Mean arterial pressure[4]						-0.8 (-1.4, -0.1)
Sievenpiper et al. 2009	Fasting blood glucose	Non-oil-seed pulses[5]	16-377 g/day	Spaghetti, wheat, potato flakes, oat bran, rice or carrots	11	SMD	-0.8 (-0.9, -0.1)
	Fasting blood insulin				9		-0.5 (-0.9, 0.0)
	HOMA-IR						-0.4 (-1.0, 0.1)

Ibsen et al. 2022. Int J Food Design [in pres]

Ultra-processed foods and plant-based meat alternatives


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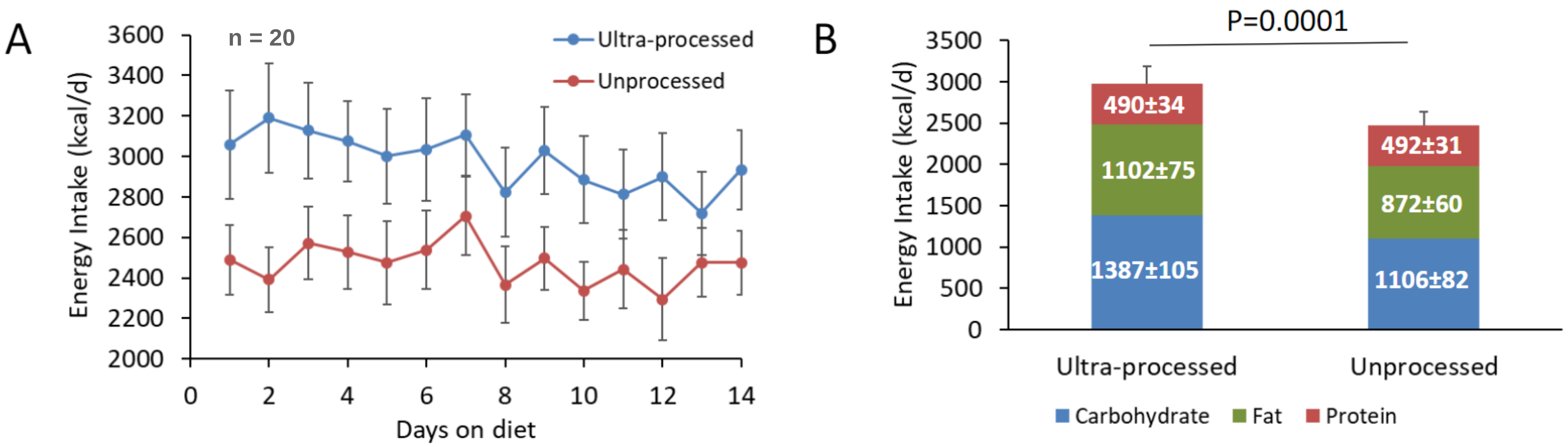
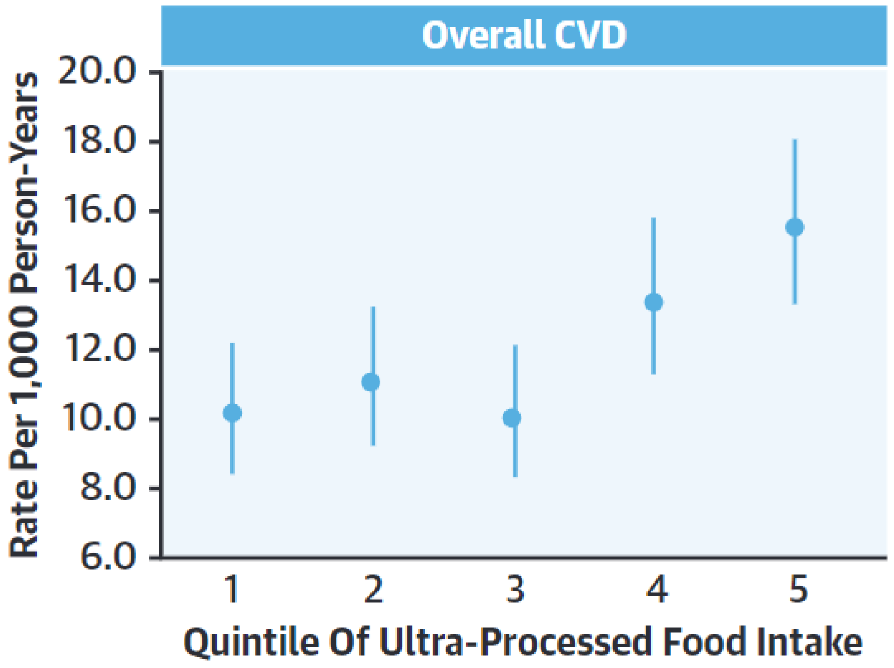
Food processing can have a big impact on health



Hall et al. 2019. Cell Metab

Ultra-processed foods are associated with greater risk of disease



Juul et al. 2021. JACC

Table 3. Associations Between the Proportion (in Weight) of UPF in the Diet and Risk of Type 2 Diabetes From Cause-Specific Multiadjusted Cox Proportional Hazard Models in 104 707 Patients in the NutriNet-Santé Cohort (2009-2019)[a]

Variable	Absolute Increment of 10% of UPF in the Diet, HR (95% CI)	*P* Value
No. of cases/total	821/104 707	
Model 1	1.15 (1.06-1.25)	.001
Model 2	1.19 (1.09-1.30)	<.001
Model 3	1.14 (1.04-1.25)	.005
Model 4	1.13 (1.03-1.23)	.006
Model 5[b]	1.13 (1.01-1.27)	.04

Srour et al. 2020. JAMA Int Med

In the short-term, plant-based meat alternatives compared with meat products show favorable health benefits

TABLE 4 Outcome levels at the end of the 8-wk phases[1]

Outcome	Plant, mean ± SEM	Animal, mean ± SEM	Plant–Animal difference, mean (95% CI)	*P* value[2]
Primary				
TMAO,[3] µM	2.7 ± 0.3	4.7 ± 0.9	−2.0 (−3.6, −0.3)	0.012
Secondary				
IGF-1, ng/mL	147.6 ± 7.5	152.3 ± 8.3	−4.7 (−13.9, 4.5)	0.30
Weight, kg	78.7 ± 3.0	79.6 ± 3.0	−1.0 (−1.5, −0.5)	<0.001
Insulin, µIU/mL	9.2 ± 1.1	8.8 ± 0.9	0.4 (−0.7, 1.5)	0.38
Glucose, mg/dL	94.9 ± 1.6	94.5 ± 1.4	0.5 (−1.8, 2.8)	0.65
Lipids, mg/dL				
LDL-C	109.9 ± 4.5	120.7 ± 4.5	−10.8 (−17.3, −4.3)	0.002
HDL-C	62.5 ± 2.2	61.8 ± 2.5	0.7 (−2.4, 3.8)	0.66
Triglycerides	99.7 ± 7.3	100.2 ± 7.0	−0.6 (−10.5, 9.2)	0.89
Blood pressure, mm Hg				
Systolic	114.5 ± 2.1	113.1 ± 1.9	1.2 (−1.4, 4.1)	0.31
Diastolic	70.0 ± 1.4	68.8 ± 1.2	1.1 (−0.8, 3.2)	0.20

[1] $n = 36$. Animal, animal meat; HDL-C, HDL cholesterol; IGF-1, insulin-like growth factor 1; LDL-C, LDL cholesterol; Plant, plant-based alternative meat; TMAO, trimethylamine-N-oxide.

[2] Likelihood ratio test from mixed-effects model evaluating change from baseline for each product type (Plant compared with Animal), adjusting for order and phase.

[3] Significant order effect in model ($P = 0.023$).

Crimarco et al. 2020. Am J Clin Nutr

In the short-term, plant-based meat alternatives compared with meat products show favorable health benefits

TABLE 2 Results[1]

	4 weeks		8 weeks		Adjusted mean difference from baseline (95% CI)[2]			
	Intervention ($n = 57$)[3]	Control ($n = 57$)[4]	Intervention ($n = 56$)[5]	Control ($n = 56$)[6]	4 weeks ($n = 114$)[7]	P value	8 weeks ($n = 112$)[8]	P value
Total meat consumption,[9] g/day	51 (49)	116 (63)	81 (78)	122 (70)	− 63 (−82 to −44)	<0.0001	− 39 (−62 to −16)	0.0009
Weight,[10] kg	73.1 (19.8)	73.3 (16.2)	72.7 (20)	73.5 (16.2)	− 0.5 (−0.9 to −0.2)	0.0037	− 0.6 (−1.2 to −0.1)	0.0266
BMI, kg/m^2	25.2 (5.4)	25.2 (5.1)	25.1 (5.5)	25.2 (5)	− 0.2 (−0.3 to −0.1)	0.004	− 0.2 (−0.4 to 0)	0.0307
Body fat percentage, %	26.9 (10.8)	27.2 (9.8)	26.4 (11)	27.4 (9.7)	− 0.2 (−0.7 to 0.3)	0.4245	− 0.8 (−1.7 to 0.1)	0.0887
Total cholesterol, mmol/L	4.5 (1)	4.5 (0.8)	4.6 (1)	4.6 (0.8)	− 0.1 (−0.3 to 0.1)	0.2125	0 (−0.2 to 0.1)	0.6151
HDL cholesterol, mmol/L	1.4 (0.4)	1.4 (0.4)	1.4 (0.4)	1.4 (0.4)	0 (−0.1 to 0)	0.218	0 (−0.1 to 0)	0.3103
Non-HDL cholesterol, mmol/L	3.1 (1)	3.2 (0.9)	3.2 (1)	3.2 (0.9)	0 (−0.2 to 0.1)	0.5648	0 (−0.2 to 0.2)	0.9148
LDL cholesterol, mmol/L	2.6 (0.9)	2.6 (0.7)	2.7 (0.9)	2.6 (0.7)	0 (−0.2 to 0.1)	0.7215	0 (−0.1 to 0.2)	0.7278
Triglycerides, mmol/L	1.3 (0.6)	1.3 (0.6)	1.3 (0.6)	1.3 (0.8)	0 (−0.2 to 0.2)	0.9012	− 0.1 (−0.3 to 0.1)	0.5403
Systolic blood pressure, mmHg	117.1 (11)	117.1 (12.7)	115.7 (12)	115.3 (12.3)	0 (−2.4 to 2.4)	0.9833	0.9 (−1.9 to 3.6)	0.5352
Diastolic blood pressure, mmHg	79.4 (6.9)	78.9 (8.4)	78.8 (8.4)	78.3 (8.6)	0.3 (−1.4 to 2)	0.7017	0.5 (−1.4 to 2.4)	0.6013

Bianchi et al. 2021. Am J Clin Nutr

Legumes and environmental impact

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Major climate gains when replacing meat with legumes

- Legumes are generally considered to have low climate impact per kg food, compared to animal-based products, such as meat, milk and dairy products. However, carbon footprints depend on the type of product and the resources used during processing and supply chain steps.
- Plant-based products, such as tofu, will often be an environmentally good alternative to meat, although replacing meat with less processed legumes will usually be even better in terms of climate footprint
- Plant-based protein sources like green peas, yellow peas, dry bean, broad beans, chickpeas and dry lentils have carbon footprint of **0.5-0.8 kg CO_2/kg food**
- In comparison, different types of beef have a carbon footprint between **10-45 kg CO_2/kg food**
- Plant-based meat alternatives like tofu and tempeh, soy-based, Quorn and pea-protein products lie between these two extremes, with carbon footprints of **2.2-2.7 kg CO_2/kg food**, depending on the level of refinement and processing history
- One study estimated that **9 meals based on lentils** could be consumed at the same climate impact of **1 meal based on beef** in a Danish dietary context
- The climate impact of the average Swedish diet would be **reduced by 20% and land use by 23% if meat consumption in Sweden was reduced by 50% and the meat was replaced with regionally grown legumes**

Future foods

How to re-design current dietary patterns to include greater consumption of legumes

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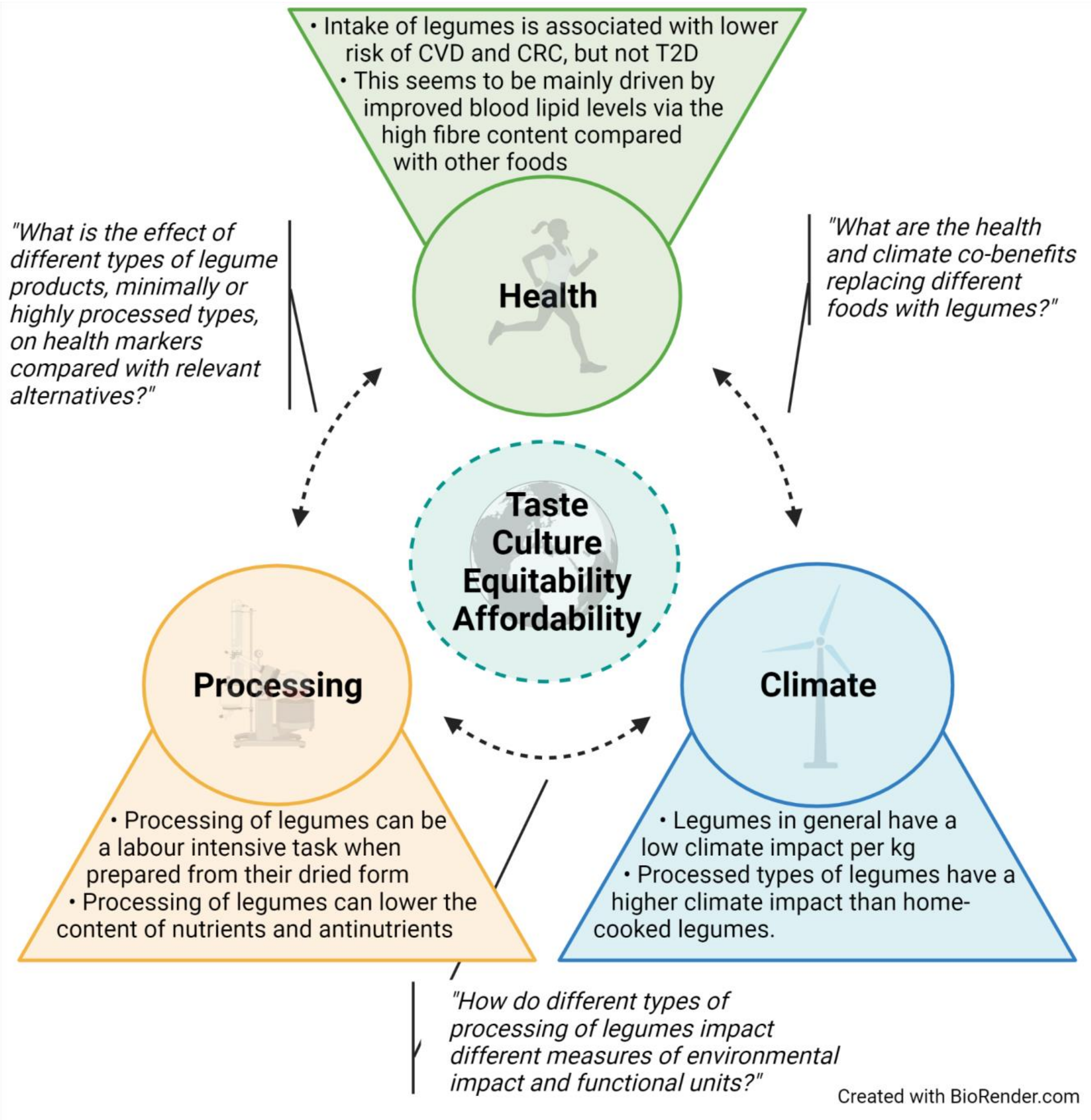

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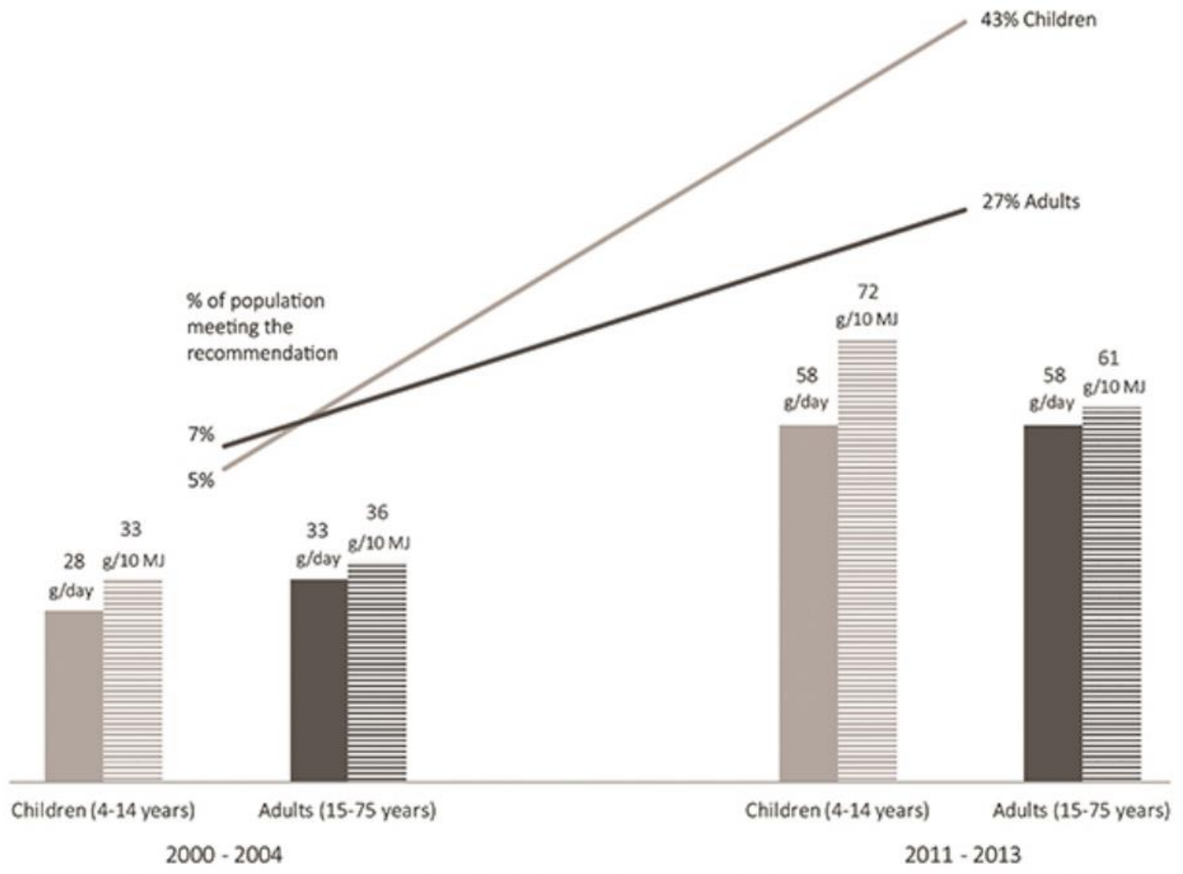
Ibsen et al. 2022. Int J Food Design (In press)

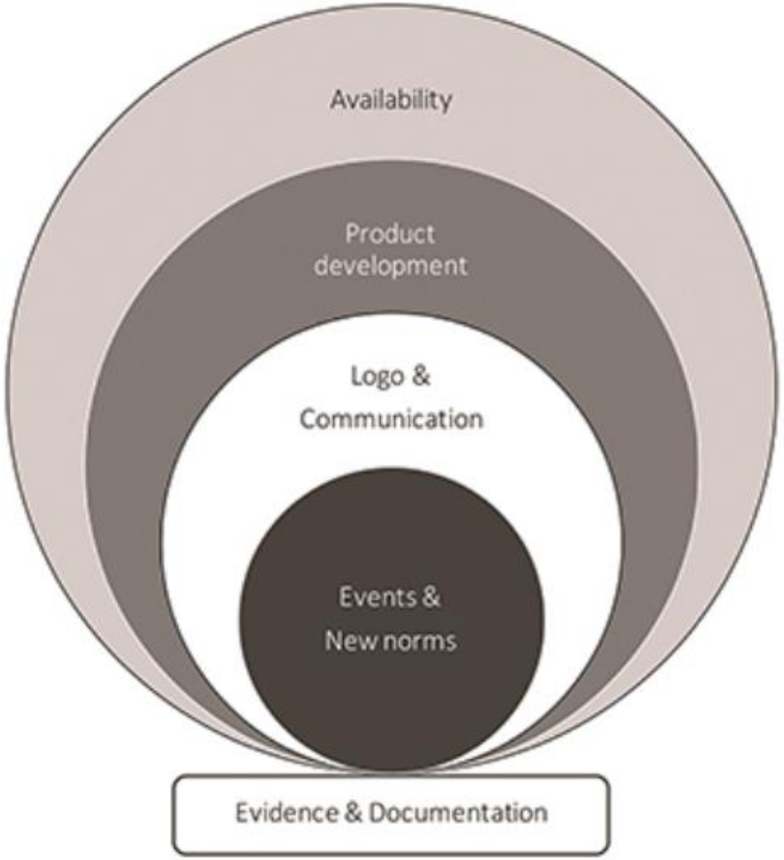
A major challenge will be to change our food culture



Lourenco et al. 2019. Cereal Foods World

A major challenge will be to change our food culture

Lourenco et al. 2019. Cereal Foods World



But it won’t be that “easy” this time

- The increase in whole grain consumption in Denmark was based **on the advantage that grain-based products already were a significant part of the Danish diet and food culture**, and habits including replacing refined grain for whole grain products were relatively easy for consumers to adopt
- **Legumes do not have this advantage**. New food products, such as plant-based meat alternatives, are important innovations, however, foods like **plant-based burgers still enforce a food context which may include highly processed side dishes such as fries and sugar-sweetened drinks**
- To enable the transition towards healthy and sustainable diets, **we not only need to reformulate foods, but also entire dietary patterns**
- Solutions could be **to co-create and re-invent** popular dishes to contain legume-based ingredients, or to re-introduce more traditional dishes with legumes; all replacing more unhealthy and unsustainable foods, like red meat, with legumes
- We will need to design new dishes and products based on convenience and taste preferences
- It will be critical to **consider the broader consequences** of the implementation of these new healthy food products in our society, ensuring that they can be **affordable and equitable**

To be or not to be?

- **To increase the consumption of legumes in our diets, we need to design new legume-based product**
- **There are substantial research gaps at the intersection between health, climate and processing technology**
- **Without the right information on all aspects of the food system it will be challenging to design the best food for the future**
- **Our prediction is that there will be a balance in the use of minimally processed – *to be* – and more processed – *not to be* – legume products in our diets.**

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ARTICLES
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nature food

Check for updates

Incorporation of novel foods in European diets can reduce global warming potential, water use and land use by over 80%

Rachel Mazac[1,2] ✉, Jelena Meinilä[3], Liisa Korkalo[2,3], Natasha Järviö[1,2,4], Mika Jalava[5] and Hanna L. Tuomisto[1,2,6]

Table 2 | Diet environmental impacts and optimization constraints

	CD	OMN diet	VEG diet	NFF diet
Environmental impacts				
GWP (kg CO_2 equivalent)	6.61	1.14 ± 0.03	1.00 ± 0.02	1.09 ± 0.03
Scarcity-weighted WU (m^3)	7.46	1.22 ± 0.03	1.26 ± 0.03	1.15 ± 0.03
LU (m^2 arable land equivalent)	5.95	1.13 ± 0.02	1.13 ± 0.02	0.75 ± 0.02
Optimization constraints				
Feasible consumption	-	All food products within the 5th–95th percentile CD consumption, vegetables ≥200 g per day, fruits ≥100 g per day, liquid plant-based alternatives ≤297 g per day, alcoholic beverages ≤20 g per day, water = mean of CD		
Nutrition	-	Daily intake of kcal, fat, carbohydrates, protein, fibre, calcium, iron, potassium, manganese, magnesium, sodium, phosphorus, selenium, zinc, folate, niacin, riboflavin, thiamine, essential amino acids and vitamins A, C, D*, B_{12}*, B_6, E and K		
Food groups excluded	-	NFFs	Meats, dairy, eggs, fish/seafood, animal fats and NFFs	Meats, dairy, eggs, fish/seafood and animal fats

Total environmental impact (mean ± s.d.) calculated for the optimized OMN, VEG and NFF diets per day by minimum objective function and non-optimized CD for comparison. Uncertainty is shown in ± s.d. calculated from 100 optimizations with 100 Monte Carlo iterations for each product in the diets. More details on the constraint values are provided in Supplementary Table 3. *Vitamins D and B_{12} are not included in the VEG nutrition constraints.

- Novel foods are those from new production technologies or that are under novel regulatory frameworks such as **cell-culturing** technologies or where production capacity could scale up like **insects and spirulina**
- **Optimized diets**
  - OMN = omnivore
  - VEG = vegan
  - NFF = new novel foods