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Legumes in a sustainable healthy diet: (How) to be or not to be, that is the question

ABSTRACT

One of the staple foods in a healthy and sustainable diet is legumes. As such, new dietary guidelines around the globe now include higher intakes of legumes. For example, the most recent Danish dietary guidelines recommend a daily intake of 100 g of cooked legumes. This is, however, far from current intakes. The question is then, how should legumes be (or not be) designed to enable this grand dietary transition necessary to contribute to current global sustainability goals? One option has been to produce legume-based meat alternatives. But is this the only way to go? In this opinion, we debate this solution. We outline the processing, health and climate aspect of legume product consumption and argue that we do not have the right information to be able to appropriately design future legume-based foods. We conclude that processing must be part of the solution as we also need to replace red meat with legumes and re-design traditional meals to include legumes or legume

KEYWORDS

disease
climate
food processing
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plant-based meat substitutes

products. Finally, to create the necessary lasting impact for planetary and population health, further dimensions such as food culture, equitability and affordability should also be in focus.

INTRODUCTION

Feeding populations a healthy and sustainable diet is a cross-cutting theme of the United Nation Sustainable Development Goals (Grosso et al. 2020). At a global scale, a sustainable and healthy diet has been proposed by the EAT–Lancet Commission to answer this need (Willett et al. 2019). Local implementations of this suggested diet are underway and are being implemented in dietary guidelines across the world. For example, in 2021, the Danish dietary guidelines were updated to include considerations with regards to the climate impact of diets, in addition to the health impacts (Ministeriet for Fødevarer Landbrug og Fiskeri 2020). Legumes are recognized as a good source of protein in a sustainable diet and the new Danish dietary guidelines recommend a daily intake of 100 g of cooked legumes. While the updated Danish dietary guidelines are based on the EAT–Lancet diet and adapted to Danish food culture, the 100 g/day recommendation is, however, far from the current daily intake in the adult Danish population, which was estimated to be about 3 g/day (Lassen et al. 2020). Indeed, despite more Danes wanting to lower the climate impact of their diets, they do not act accordingly (Klimarådet 2021). The situation is similar in many other western countries with low intakes of legumes. The question is then, how can we change current food culture and consumption patterns to increase the intake of legumes and legume products in the population?

The new Danish dietary guidelines emphasize legume dishes cooked from scratch, starting with dried, canned or frozen pulses, allowing legumes to appear – *to be* – in their own guise. A commercial solution has been to design legume-based products that resemble meat products, also called plant-based meat alternatives, in which their presence is hidden – *not to be*. But is this the only way to provide consumers in Denmark and beyond with alternatives to current food product choices? In this opinion, we debate these limited solutions and argue that we just do not have sufficient knowledge to be able to design our future foods, in particular regarding how different forms of legumes impact our health and our climate.

LEGUMES IN ALL SIZES AND SHAPES

Legumes are plants from the *Leguminosae* family which is the third largest family of flowering plants. The plants used for human food are grain legumes, of which pulses are the edible part of the plant. Pulses include beans, lentils and peas. The nutritional composition varies between types of legumes (Table 1). In general, legumes are a good source of amino acids, fibre, folate, iron, magnesium and potassium. They may also 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 (Samtiya et al. 2020).

Processing legumes alters their nutritional composition. Domestic processing includes soaking (pre-processing), cooking and baking, whereas industrial processing can vary from dry and wet fractionations to isolate particular components, to autoclaving, baking and extrusion. A study comparing the

Table 1: Nutritional composition and environmental impact of different types of legumes.

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/100 g)	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/100 g)	11.6	6.5	8.2	6.4	8.5	6.0	5.9
Water-soluble vitamins (µg/100 g)							
Folate	19.5	21.2	67.6	34.3	26.0	25.0	54.0
Minerals (mg/100 g)							
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/100 g)							
Phytic acids	627.0	386.0	694.0	526.0	714.0	–	–
Saponins	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

[1]Nutritional composition data from Margier et al. (2018).
[2]Nutritional composition data from USDA FoodData Central: https://fdc.nal.usda.gov/index.html.
[3]Nutritional composition data from Frida database: https://frida.fooddata.dk/?.
[4]Environmental impact data from Potter et al. (2020).

nutritional composition of legumes by traditional forms of processing, household cooking (domestic form) or canning (industrial form), found that canning resulted in lower levels of protein, fibre and, for kidney beans and chickpeas, lower iron and magnesium content (Margier et al. 2018). However, canning also resulted in lower levels of phytates and tannins than household cooking (Table 1). More recently, 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 fibre, vitamins and minerals than home cooked legumes. These products would be defined as ultra-processed foods according to the initial NOVA classification (Table 2) (Monteiro et al. 2010). For this reason, the Danish dietary guidelines note that plant-based meat alternatives are less nutrient dense than other forms of legumes and thus these products

Table 2: NOVA classification[1] of foods according to degree of processing.

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

[1]Source: Monteiro et al. (2010).

cannot be the only type of legumes consumed. However, 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. This creates a Shakespearian paradox of food processing: familiarity vs. nutrition. To be or not to be.

HEALTH IMPACT OF LEGUMES

Evidence from published studies on legume intake and development of non-communicable diseases suggests that consumption of legumes is related to a lower risk of cardiovascular diseases (CVD) and colorectal cancer, whereas the evidence for type 2 diabetes is inconclusive (Table 3). In a meta-analysis of cohort studies, a higher intake of legumes, compared with a lower intake of other non-specified foods, was associated with a lower risk of coronary heart disease but not stroke (Martini et al. 2021). For colorectal cancer, a lower risk was suggested, although this was mainly driven by the lower risk observed in Asian cohorts (Martini et al. 2021). For type 2 diabetes, there was much more uncertainty in risk estimates and no strong conclusion could be made (Tang et al. 2020). A central limitation of such meta-analyses is varying definitions of legumes and analysis plans across studies. Still, a federated meta-analysis of 27 cohorts using standardized definitions and analysis plans found no consistent association between intake of legumes and risk of type 2 diabetes (Pearce et al. 2021). A slightly higher risk of type 2 diabetes was observed in European cohorts, mainly driven by a German and a UK cohort. These studies exemplify the importance of considering the context around dietary habits: participants in the two cohorts who had a high intake of legumes may have consumed these as part of stews prepared with pork, beef and beans or as processed legume dishes with added sodium and sugar (e.g. baked beans), as these are traditional staple foods. An important limitation is that food replacements were not specified, meaning that a higher intake of legumes was

Table 3: Characteristics of meta-analyses of cohorts and randomized controlled trials investigating the health associations of legumes and subtypes of legumes.

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		0.83 (0.68, 1.01)
		Soy milk			5		0.89 (0.71, 1.11)
		Tofu			4		0.92 (0.84, 0.99)
Pearce et al. (2021)	Type 2 diabetes	All types	20 g/d higher	20 g/d lower and higher of other foods	27	IRR	1.02 (1.01, 1.04)
		Pulses[1]			13		1.02 (1.00, 1.03)
		Total soy			10		1.02 (0.99, 1.04)
Randomized controlled trials							
Bazzano et al. (2011)	Total cholesterol[2]	Pulses[3]	80–440 g/d	Spaghetti, wheat, carrots or matched	10	MD	−11.8 (−16.1, −7.5)
	LDL cholesterol[2]						−8.0 (−11.4, −4.5)

(Continued)

Table 3: Continued.

Reference	Outcome	Legume	Dose	Comparison	*n* studies	Measure of association	
	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/d	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-oilseed pulses[5]	16–377 g/d	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)

HDL: high-density lipoprotein; HOMA-IR: homeostatic model assessment for insulin resistance; HR: hazard ratio; IRR: incidence rate ratio; LDL: low-density lipoprotein; MD: mean difference; s/d: serving per day; SMD: standardized mean difference.
[1]Studies from Martini et al. (2021).
[2]mg/dL
[3]Pea, bean, chickpea and lentil.
[4]mmHg,
[5]Excluding soybeans and peanuts.

accompanied by a concomitant lower intake of other foods, depending on the habits of the particular study population. A recent study investigated the use of legumes as a replacement of red meat in a large European cohort and the results showed no clear association of the replacement with type 2 diabetes development (Ibsen et al. 2020). In general, from the available data, it is possible to conclude that the current low intake of legumes in western populations adds much uncertainty to investigations of potential health benefits or harms of their consumption.

Randomized controlled trials (RCTs) enable some mechanistic understanding of the effect of certain dietary changes on physiological biomarkers. For example, RCTs have investigated the effect of legume intake on cardiometabolic risk markers such as blood lipids, blood pressure and blood glucose (Table 3). Meta-analyses of RCTs found that, compared to different other foods, intake of 80–440 g/day of legumes for a minimum of three weeks reduces total cholesterol and low-density lipoprotein in the blood (Bazzano et al. 2011) and blood pressure (Jayalath et al. 2014); both CVD risk markers. Various foods were used as comparisons (Table 3). In another meta-analysis, legumes were analysed as part of a larger group of plant-based protein sources and, compared to red meat, shown to lower blood lipids (Guasch-Ferré et al. 2019). Intake of legumes was also found to lower fasting blood glucose and fasting insulin, risk markers of type 2 diabetes (Sievenpiper et al. 2009). The most beneficial effects on blood glucose regulation were observed at intakes <100 g/day with no consistent differences in effects of different physical forms (e.g. cooked whole beans or bean flour) (Sievenpiper et al. 2009). Potential mechanistic explanations could be the dietary fibre intake and the low saturated fat content of the high-legume intervention diets, as both of these factors have been proven to lower blood lipids. Other characteristics of these diets, such as plant proteins, minerals, especially high potassium and low sodium levels, are also important factors in reducing blood pressure.

There is a significant gap in understanding the effects of processing legumes, given the recent influx of many highly processed legume-based products such as plant-based meat alternatives. In a metabolic ward human feeding study, comparing two diets consumed ad libitum with similar macronutrient compositions, energy densities, fibre and sodium content, but varying in degree of processing, the diet high in ultra-processed foods (as defined by the NOVA classification) increased total energy intake and body weight over two weeks, compared with the minimally processed diet (Hall et al. 2019). This raises concerns about downstream effects of ultra-processed foods, such as some plant-based meat alternatives, on both individual and population health. In particular, overweight and obesity, but also diseases such as type 2 diabetes, CVD and cancer. In a recent RCT, the short-term health effects of consuming plant-based meat alternatives compared with animal meat were investigated over eight weeks in 36 participants (Crimarco et al. 2020). During the plant-based meat alternative consumption period, a lower intake of saturated fat, higher intake of fibre and no difference in sodium was observed. The plant-based diet lowered body weight, LDL-cholesterol and an emerging biomarker for CVD, trimethylamine-N-oxide. There was no difference in energy intake, blood pressure or blood glucose measures (Crimarco et al. 2020). This study suggests that plant-based meat alternatives, compared with animal meats, are not detrimental to health, and may even be beneficial in the short-term, but further studies are needed to understand the effects of the broad range of processing techniques on nutritional quality of this class of food products.

Overall, despite the presence of evidence for some health benefits of consuming a diet including legumes, there is still uncertainty regarding the effects of different ways to process legumes, the role of other ingredients (e.g. starches, fibre), relevant replacement foods or dishes and the role of the habitual dietary context. Most interventions have focused on whole beans or bean flour and less on how fractionated ingredients (i.e. various types of flours) behave nutritionally when processed or cooked. A combination of longer-term highly controlled intervention studies and more recent cohort studies that have collected more detailed information on intake of plant-based meat alternatives, using food intake biomarkers to track metabolic effects, could help bring more mechanistic evidence on the health effects of plant-based foods, and legumes in particular in the diet. This knowledge is critical to designing new foods with high nutritional value.

CLIMATE IMPACT OF LEGUMES

Legumes are generally considered to have low climate impact per kg 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 and different results may be obtained when comparing environmental footprint per kg of protein. 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 (Smetana et al. 2015). 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 (Potter et al. 2020). In comparison, different types of beef have a carbon footprint between 10 and 45 kg CO_2/kg meat (Mogensen et al. 2015). 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. Taking the nutrient density of such products, which can vary substantially, into account is important when evaluating carbon footprints of different foods. Further, when designing sources of protein, processing should minimize waste or losses, as this together with impact from processing will also affect the final footprint of the food product.

Replacing animal-based protein and especially meat, with legumes as a protein source could be an efficient way to reduce the climate impact of a meal. One study estimated that nine meals based on lentils could be consumed at the same climate impact of one meal based on beef in a Danish dietary context (Lassen et al. 2020). Thus, there are major climate gains to be made by replacing some meat with legumes. The climate impact of the average Swedish diet would be reduced by 20 per cent and land use by 23 per cent if meat consumption in Sweden was reduced by 50 per cent and the meat was replaced with regionally grown legumes (Röös et al. 2020). Regional Nordic legumes can include, for example, dried yellow peas and broad beans. It is important to note, however, that legumes need to be consumed in combination with other protein sources in the diet, to obtain the right balance of amino acids and other nutrients, and only with a careful design of food product formulations or diets will it be possible to provide the right balance between sustainability and nutrition.

Finding more sustainable protein sources is necessary to meet the increasing demand of protein of the growing population in the future. Legumes

have a high protein content and cultivation requires very little nitrogen due to symbiotic nitrogen fixation. There are very few studies which quantify the sustainability index for legumes, especially after processing to ingredients and concentrates, and even less for final food products such as a plant-based meat alternatives. Higher refinement naturally results in extensive use of resources and creation of by-products, which will impact the carbon footprint. Furthermore, often only one or few impact categories are evaluated, typically climate impact. In the future, more environmental impact categories should be assessed, with particular attention to the processing history of the final foods, the creation of waste or by-products or the use of energy and water during processing, to ensure robust results. Analyses of environmental impacts in relation not only to product mass but also, for example, protein mass or nutrient density, should be detailed further.

LEGUME PRODUCTS OF THE FUTURE

Returning to the initial question of how to change current dietary patterns to include greater consumption of legumes, we have summarized current knowledge about legumes in terms of processing, health and climate in Figure 1. While intake of legumes seems to lower risk of CVD and colorectal cancer and generally has a low climate impact, there is much uncertainty regarding how highly processed plant-based meat alternatives affect long-term health and what the climate and health co-benefits are, when replacing foods with different types of legume products. Our key questions (Figure 1) call for a multidisciplinary approach at the intersection between health, climate and processing. The current lack of data collected with such an approach makes designing the food of the future extremely challenging. Food design is the key, as formulations will also need to consider taste and convenience, to ensure population acceptance.

One of the few good examples of success in shifting population dietary habits in western countries is the Danish whole grain partnership. This inter-sectoral work contributed to an increased intake of whole grains in the Danish population from an average of 33–58 g/day from 2000–04 to 2011–13 (Lourenço et al. 2019). An important part of the strategy was product development, but it also included increased availability as well as considering the cultural context within which the products fit. Given the low intake of legumes in current western diets, we need to better understand the drivers of food culture in order for us to enable such radical dietary shifts. 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 (Lourenço et al. 2019). 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. In contrast, more traditional eating patterns include legumes to a higher degree (Huebbe and Rimbach 2020).

To enable the transition towards healthy and sustainable diets, we not only need to reformulate foods, but also entire dietary patterns. These transformative changes will require co-creation with consumers, with respect to food cultures and food norms. Solutions could be to co-create and re-invent popular dishes to contain legume-based ingredients or to re-introduce more

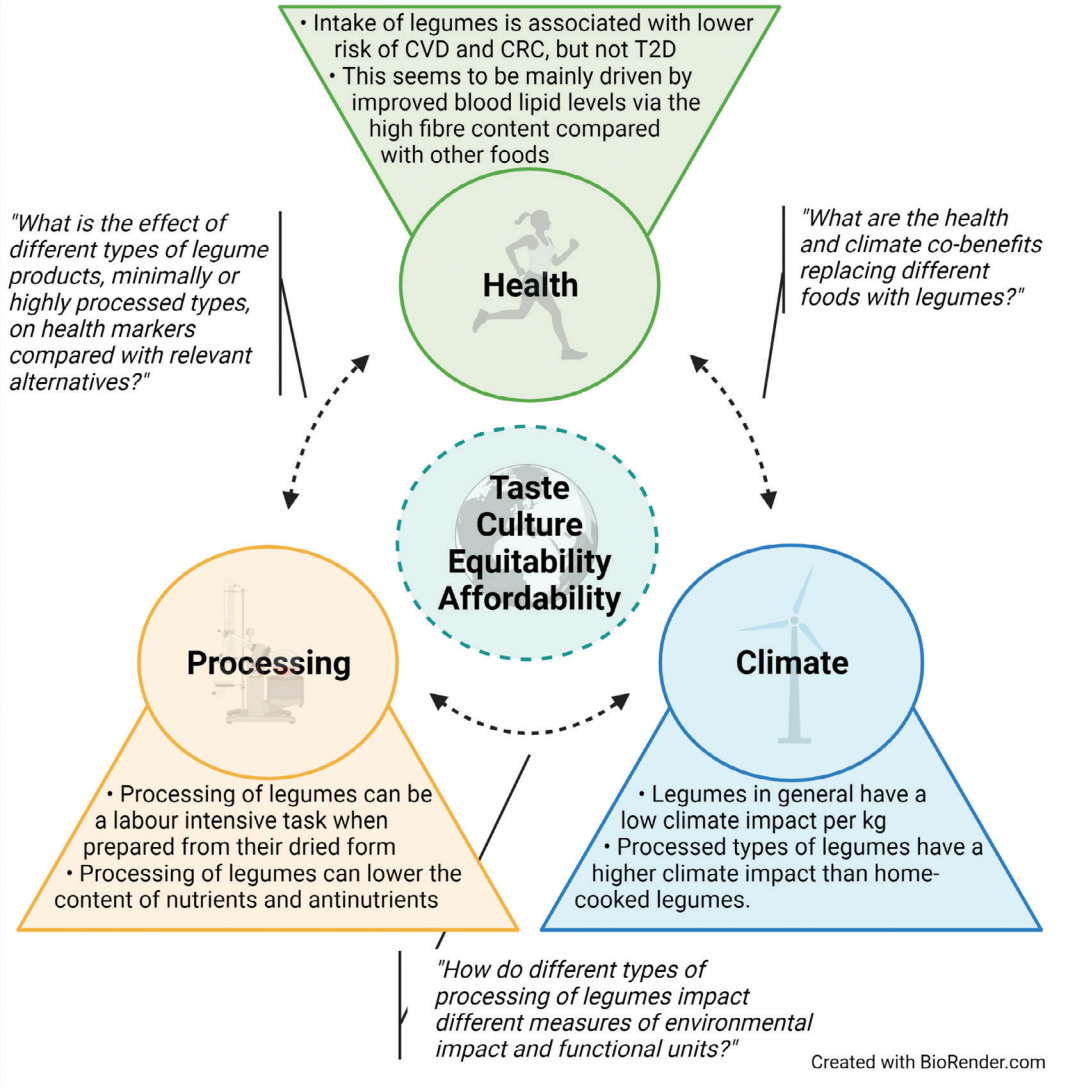

Figure 1: Three key considerations for design of legume products. Filled boxes summarize current evidence in each of the three domains. Key questions at the intersection between each of the three domains are posed to address current gaps in the literature. Cardiovascular disease (CVD), colorectal cancer (CRC), type 2 diabetes (T2D).

traditional dishes with legumes; all replacing more unhealthy and unsustainable foods, like red meat, with legumes. Still, we will need to design new dishes and products based on convenience and taste preferences. A large consumer survey conducted in ten European countries found that, among those eating according to a flexitarian diet (i.e., a diet high in plant-based foods and low in, though not excluding, meat intake), taste and health were key drivers of which plant-based foods were purchased (Smart Protein 2021).

It will be critical to build a holistic model of the broader consequences of the implementation of these new healthy food products in our society, ensuring that they can also be affordable and equitable. Furthermore, the foods of the future will need new ways of processing new ingredients, as the current infrastructure is based on old paradigms such as recipes and processing conditions optimized on animal-based ingredients' performance. This has the potential to solve our Shakespearian paradox. A full systems approach is ultimately needed to implement impactful dietary changes.

CONCLUSION

In order to increase the consumption of legumes in our diets, we need to design new legume-based products. However, as we have mapped out, 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. We acknowledge that it may be near impossible to design foods that fulfil all the features we have discussed here, but an ambitious evidence-based attempt is a step in the right direction. These important considerations need to be balanced as well as possible, and it is likely that population-level changes will take place concurrently with research, design and implementation of new improved food products. 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. It is imperative that this balance favours population and planetary health.

To take further steps, there is an urgent need to collect research data that enable making the right decisions, as the dietary shift to more sustainable diets will take a significant effort. Therefore, new interdisciplinary collaborations linking disciplines interested in health, climate and food product development and design based on food culture, taste, history and policy are needed to help shape a new food future.

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