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Legumes as a Cornerstone of the Transition Toward More Sustainable Agri-Food Systems and Diets in Europe

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Legume grains are important sources of nutrients in human and animal diets and have been so for millennia. Their history as part of traditional diets dates to the origins of agriculture when their benefits for soil health and agricultural productivity started to be realized, mostly empirically, by farmers. In time, legumes have lost their popularity as human food, either because of a negative connotation as "poor man's meat," occasional gastrointestinal side effects, or habitually longer preparation times when compared to other types of plant foods. Also, the steep rise in the consumption of meat derived foods in the last half of a century has taken a toll on replacing legumes as a major protein source. Alongside this negative trend in consumption, a negative drift in production was also observed, especially in Europe, where legumes currently occupy a minimal fraction of agricultural land. One of the main factors is a loss in competitive edge amongst farmers due to sustained lower public and private investments in breeding programs and legume adapted technology for planting, managing, harvesting, processing, and storing, when compared to cereals. Recently, increased awareness of the need to move to sustainable food systems is revitalizing legume production and consumption in Europe, leading to a compilation of policies and initiatives that aim to put legumes again as foundations for this transition. Legumes have been reinvented in a multitude of products (drinks, cereal bars, bread, meat replacers, snacks, flours, and several others) and included in farming systems of conservation agriculture, organic production, intercropping, and crop rotation, combining ancient traditions of legume production "with a spin," incorporating new legume technological knowledge in farming systems. However, the transition has been slow and hampered by many cultural, societal, political, and economic impediments. This paper summarizes initiatives that aim to enable the comeback of legumes and their placement in a more prominent position in human diets and agricultural fields and highlights strategies that aim at overcoming the obstacles that impede achieving the development of more sustainable agri-food systems and sustainable diets in Europe.

Keywords: climate change, food systems, legumes, sustainable development, sustainable diet

INTRODUCTION

In the context of the UN *2030 Sustainable Development Goals*, there is growing recognition of the need for profound transformations in the way we produce, process, and eat our food. This means creating agri-food systems which deliver "*food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised*" (FAO, 2018). Such changes in the realm of production should be accompanied by a transition to more sustainable food consumption patterns as well (Berners-Lee et al., 2018). A global dietary shift toward more plant-based diets has been identified as a critical necessity in the fight against malnutrition and sustainability-related issues (Willett et al., 2019). In the past few years, the search for alternatives to animal-based food has brought legumes into the spotlight as one of the best options given their multiple positive social, economic, and environmental assets (Stagnari et al., 2017), features that have long been empirically appreciated (Phillips, 1993). Legumes are plants belonging to the *Leguminosae* family, comprising about 800 genera and 20.000 species (Stagnari et al., 2017). Given their protein-rich profile, this paper will focus on grain legumes that are used for human food purposes within European countries—such as beans, peas, chickpeas, lentils, lupin, soybean, and exclude forage legumes used just for animal feed production, such as alfalfa and clover.

Literature reports legumes as one of the earliest domesticated plants (Ahmed and Hasan 2014), believed to have marked the transition from a hunting-gathering way of life to agricultural practices (Phillips, 1993). In fact, legume cultivation was widespread where agriculture was practiced, also evidenced by archaeological signs of the simultaneous existence of legumes and cereals (Phillips, 1993). It appears lentils were already present within cropping systems of ancient Egyptian civilizations and carbonized seeds dating back 7000 to 8,000 years B. C. have been found in Turkey (Ahmed and Hasan, 2014). Peas and dwarf field beans seem to have been cultivated in Switzerland between 4000 and 5000 B.C. (Ahmed and Hasan, 2014). It is believed that the cultivation of soybean in China began between 2000 and 3000 B. C. (Ahmed and Hasan, 2014). Archaeological sites revealed signs of domestication of bean crops as early as 10,000 years ago in Mexico and Peru (Gomes and Vasconcelos, 2014). Over 3,000 years ago, beans, soybean, and staple crops started being domesticated in America and Asia (Ahmed and Hasan, 2014). The use of legumes in pastures and for soil improvement purposes was already acknowledged by the Romans in 37 B.C., reflecting the intuitive use of legumes' nitrogen-fixing abilities (Gomes and Vasconcelos, 2014). Nonetheless, recognition of the value of such practices seems to have faded over the course of history, not least in Europe too.

Around the 1960s, the main grain legume production in Europe (chickpea, cowpea, groundnut, lentil, and common bean) destined for human consumption, occupied 67% of total production area, dropping to 27% by 2013 (Watson et al., 2017). Such decline appeared mostly driven by rising competition from cheaper imports, especially from Canada and the substitution of legumes intake by meat products within Mediterranean countries, the highest legume consumer populations in Europe (European Commission, 2018b). In the 1980s, pea and soybean became the two most widely grown protein crops for animal feed (Watson et al., 2017). Currently, soybean, field peas, and broad beans are the dominant grain legumes across Europe (Watson et al., 2017). Soybean alone has had a remarkable increase over the last decades, particularly driven by the great demand for high-protein materials for livestock feed in Europe (Watson et al., 2017). In 2018/2019 943,000 ha was under soy cultivation in Europe (European Commission, 2018a) and a further 44% increase (to about 1.3 million ha) is anticipated until 2030, expressing the highest growth of all European crops (European Commission, 2018a). In relation to field peas and broad beans, their combined production reached 4.4 million tons in 2018 (European Commission, 2018a). Around two-thirds of production is directed to animal feed purposes whereas just about 20% is for human consumption (European Commission, 2018a). Lupins, lentils, and chickpeas are not so abundant in the European Union (EU): most lentil and chickpea production is destined for human consumption, but lupin is mainly directed to livestock feeding (European Commission, 2018a). In 2018, grain legumes occupied only 1.4% of the total crop area in Europe (European Commission, 2018a), that is around 10% of their average role in cropping systems worldwide (Watson et al., 2017). Moreover, only 43% of the food legumes consumed in Europe are produced on European farmland (Watson et al., 2017). Europe's domestic production expresses a deficit of about 70% of high-protein materials, 87% of which rely on imported soybean and soymeal (Watson et al., 2017). Indeed, evidence suggests a continuing decline in legume production in Europe (Stagnari et al., 2017), probably explained by a relative economic un-competitiveness compared to more profitable crops, such as cereals, which account for 31% of the total utilized agriculture area in Europe (European Commission, 2018a).

The decline in grain legume production over the last decades in Europe contrasts with increases in other regions such as Australia and Canada (Stagnari et al., 2017). Concordant policy action areas are needed to offer guidance to further develop pathways for legume-based food- and feed-systems and to trigger change, at least for the European context. To this end, stakeholders, and experts from a series of regional legume-oriented value chain workshops were invited to contribute to an online Delphi exercise. Based on this, policy recommendations were identified for the alleviation of barriers, and the development of favorable policies and transition pathways, which are capable of promoting the production of legumes, and creation of legume-based products in the EU. These included: (1) investment in agri-food and -feed research and knowledge transfer; (2) preventing the use of inorganic nitrogen fertilizer; (3) nutrition, diet, and health policies and public campaigns that promote the inclusion of legumes in the human diet (Balázs, et al., 2019). This narrative review includes scientific papers and technical reports and summarizes initiatives that aim to enable the comeback of legumes and their placement in a more prominent position in human diets and agricultural fields and highlights strategies that aim at overcoming the obstacles that

impede achieving the development of more sustainable agri-food systems and sustainable diets in Europe.

LEGUMES AND SUSTAINABILITY

Food Security, Health, and Nutrition

Food Security

Food security is recognized as a universal human right with a central role in human development. However, promoting food security is a complex mission with political, economic, environmental, social, and cultural dimensions. The number of people with insufficient food worldwide is estimated at more than 820 million and many more consume an unhealthy diet that contributes to premature death and morbidity (Willett et al., 2019). In Europe in 2017, almost 12% of the population expressed an inability to afford a good-quality meal every second day (European Environment Agency, 2019b). Also, at the end of 2019 around 0.5 million people in Europe, were classified as suffering from acute food insecurity (FSIN, 2020). Hence, it is urgent to optimize food production in a sustainable way, so as to contribute to reductions in hunger, to improve life expectancy, to reduce infant and child mortality rates, and to decrease global poverty (Willett et al., 2019). Legumes, being more affordable high protein nutrient-dense foods, could contribute significantly to the eradication of hunger and malnutrition (Bessada et al., 2019).

Health and Nutrition

According to *The Lancet,* a healthy diet has appropriate caloric intake and is composed by a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars (Willett et al., 2019). However, modern diets are characterized by a high intake in calories and heavily processed and animal source foods. In fact, in the last 50 years, the intake of animal proteins among European adults, essentially meat and dairy products, has doubled and currently remains twice the global average (64 kg/year) (European Environment Agency, 2019b). Also, the consumption of sugar and sugar products per person per year (13 kg/year) seems higher than other foods, such as fish and seafood (10 kg/year) (European Environment Agency, 2019b). For sustainability and health reasons, the transformation to healthy diets by 2050 will require important dietary changes, namely a >50% reduction in global consumption of unhealthy foods, such as red meat, and sugar, and a >100% increase in consumption of healthy foods, such as nuts, fruits, vegetables, and legumes. However, the changes needed differ greatly by region (Willett et al., 2019). During the last decade, legumes have re-emerged as an interesting and balanced source of nutrients. They are nutrient-dense foods, namely of protein, fiber, and diverse minerals, like iron, zinc, and potassium (Grela and Samoli, 2017) and vitamins, such as thiamine, niacin, folate, riboflavin, pyridoxine, vitamin E, and A (Mudryj et al., 2014). Moreover, legumes provide important dietary bioactive compounds to the diet (e.g., phenolic acids, tannins, and flavonoids) known for their antioxidant potential, amongst other health-protective effects (Singh et al., 2017). Evidence suggests that legume consumption is associated with positive outcomes on cardiovascular risk factors, such as, blood lipid profile, glycaemic control, inflammatory status, oxidative stress, as well as gut microbiota composition, and activity. They also favor the control of body weight, probably because they give greater satiety (Ferreira et al., 2020).

Natural Resources and Climate Change

Land and Water Resources

Expected future higher demand for food will require not only larger areas of crop cultivation and yield increases but most worryingly, under business-as-usual projections, greater livestock production. Indeed, recent predictions suggest that global meat intake will increase by about 76% by mid-century (Godfray et al., 2018). This means that over time, if consumption patterns do not change, pressure will build upon earth's limited resources, as livestock production requires significant land areas and freshwater supplies.

Presently, both grazing land, and animal feed crops account for 80% of all agricultural land (Giovannucci et al., 2012). Also, about 29% of the water footprint of the global agricultural sector is related to the production of animal products (Mekonnen and Hoekstra, 2012). In Europe, livestock production systems represented 28% of land use in 2016 (European Environment Agency, 2019a). Also, feed and animal production require around 25% of total water extraction within the agriculture sector in the EU (European Commission, 2019a). Hence, humans and livestock will ultimately have to compete for nature's resources, as well as the same sources of food. In this context, protein-rich plant crops, such as grain legumes, could help reduce the need for animal-based protein food sources with huge environmental advantages (Stagnari et al., 2017). Lesser animal-based foods intake, and therefore lower livestock production, would allow feed crops to be converted into human food, and thereby not compromise long term food security (Giovannucci et al., 2012). This would result in better natural resources management as well, since plant-based protein agroecosystems require far less resources and energy inputs (Clark et al., 2019).

GHG's Emissions

The nutrient richness of animal-based foods, especially meat, and their significant protein content has served to justify their presence within most diets (Wood, 2017). However, there is growing evidence that meat-rich dietary patterns are closely linked to serious environmental constraints, and most significantly to global warming aggravation (Willett et al., 2019). Livestock production produces important amounts of the three main greenhouse gases, namely, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Godfray et al., 2018). Meat production alone is the single most significant source of CH_4, which is a gas with a global warming potential equivalent to 28 times CO_2. Ruminant livestock particularly, generate approximately 80 million tons of CH_4 per year. This represents around one-third of all anthropogenic emissions of CH_4 and almost 80% of agriculture emissions (Peoples et al., 2019). In Europe, the agriculture sector accounts for almost 10% of all GHGs emissions in the EU. According to the literature, a

dietary shift toward more plant-based protein food sources, like grain legumes, is a must to help mitigate global warming and therefore lighten climate changes (Willett et al., 2019). In fact, it is estimated that the production of plant-based foods can produce 25–150 times less GHGs emissions than ruminant's meat production (Clark et al., 2019). Also, substituting meat for grain legumes could actually lead to a reduction up to 74% in GHGs emissions enabling the achievement of the 2020 target for the US (Harwatt et al., 2017). Such dietary shifts among Europeans would lead as well to a 6% (22 million t CO_2 eq) reduction of the carbon footprint of the EU agricultural sector by 2030, compared to the baseline (European Commission, 2019a).

Artificial Fertilizers

Nitrogen (N) is a basic element for the formation of plants' biologic structures (Leghari et al., 2016). Hence, sufficient N supply is crucial for plant growth and development, ultimately defining the yield quality, including the nutritional composition of plant-based food products used for both animal and human feed (Peoples et al., 2019). Plants can acquire N either by root assimilation (Kiba and Krapp, 2016) or, in the case of legumes, by atmospheric fixation (Sulieman and Tran, 2015). However, the pressure to increase production has led farmers to resort to increasing use of synthetic N, in the form of fossil fuels-derived chemical fertilizers, to support crop productivity and guarantee profitable harvests. However, the vast use of N-rich artificial fertilizers over time has raised important environmental concerns particularly due to the multiple loss processes that labile reactive forms of N may suffer. Volatile losses as ammonia (NH_3) or nitrous oxide (N_2O), as well as leaching of both nitrate (NO_3^-) and organic N threatens the quality of air, soil, and water resources, affecting global ecosystems (Sutton et al., 2011). It was estimated that synthetic N fertilizers directly account for approximately 12% of the annual average 5180 million tons of CO_2 equivalent GHG emissions associated with agriculture activities between the year of 2010 and 2014 (Peoples et al., 2019) and it has been estimated that nitrogen pollution can cost the EU up to €485 billion per year (Sutton et al., 2017). The ability of legumes to biologically fix atmospheric N_2 in a symbiotic association with soil bacteria rhizobia creates a continuous N supply within agroecosystems without the use of additional artificial fertilizers (Clúa et al., 2018) and the presence of legumes within mixed croplands could ultimately stimulate soil fertility and enhance yields, all with less environmental impact. Grain legumes also release high-quality organic matter into the soil and facilitate nutrients' circulation by promoting water retention (Stagnari et al., 2017). The potential yield gains can even occur without compromising the nutritional composition of the harvest, namely its protein content (Plaza-Bonilla et al., 2017). The adoption of crop rotation systems including legumes is expected to increase not only overall crop's profitability but also reduce total production costs (Preissel et al., 2015; Mahmood et al., 2018). On the one hand, it has been demonstrated in Kenya that legume-cereal rotations have gross margins equal to or higher than cereal rotations alone (Rao and Mathuva, 2000). Indeed, the inclusion of peas in five-year rotations with 80% cereals within French territories was able to lift the gross margin by 11.0%, that is 29€/ha (Von Richthofen G. L. Pro Partners, 2006). The total production costs could be minimized as well, by 50€/ha, if legume crops were to be incorporated within continuous cereals rotations (Von Richthofen G. L. Pro Partners, 2006). Notwithstanding, the maximum economic benefits from legumes will only be achieved after long-periods of crop rotations, when tangible monetary profits start to become apparent (Mahmood et al., 2018).

Biodiversity

Legumes have also an important role in protecting natures' biodiversity. Over the years, the intensification of agriculture production has led to the wide dissemination of the most profitable crops at the expense of landscapes' diversity, as well as, natural habitats of different species (Everwand et al., 2017). Excessive N inputs from massive use of artificial fertilizers may be one major contributor, causing soil acidification and direct toxicity, among other negative consequences (European Commission, 2018a). Globally, ecosystems are losing the ability to provide basic needs and natural resources such as crop pollination, clean air, and water, and control of floods or soil erosion (European Commission, 2011). In this way the world's biodiversity is becoming greatly jeopardized, including across the EU (European Commission, 2011). Literature suggests that the presence of legumes within current intensive cropping and cereal-dominated agri-food systems promotes the conservation of habitat heterogeneity and ensures the continuity of multiannual habitats for species considered critical for nature conservation, such as arthropods, bird populations, and small mammals (Peoples et al., 2019). Also, legume crops offer vital floral resources that guarantee the survival of populations of pollinators which in turn benefit food production and plant breeding (Marzinzig et al., 2018). Ultimately, the beneficial effects of legumes in increasing biodiversity should be more widely promoted and used as an incentive to promote their production.

MAIN OBSTACLES TO INCREASE LEGUME PRODUCTION AND CONSUMPTION

Breeding Programs

The world has witnessed an astonishing period of food crop output growth over the past 60 years, especially for cereals, even in the face of increasing land shortage and increasing land prices. In this time period populations more than doubled, and the production of cereal crops tripled, with only a 30% increase in land area cultivated (Pingali, 2012). Cereals have been the focus of plant breeding programs prior to and since the Green Revolution, including the development of N-responsive varieties that deepened dependence on chemical fertilizers, all of which has overshadowed the contribution of legumes and their traditional synergy with cereals. The yearly productivity gains from 1960 to 2000 for cereal germplasm improvement alone averaged 1.0% for wheat, 0.8% for rice, 0.7% for maize, and 0.5, and 0.6% for sorghum and millets, respectively (Evenson and Gollin, 2003). On the contrary, legumes breeding has lacked investment and research has been identifying possible ways to turn them

into more economically attractive crops (Watson et al., 2017). Indeed, important advances in yield and yield stability could be performed considering unique traits of each crop, in order to favor species with higher resistance to biotic and abiotic stresses (Watson et al., 2017). Pea crops suffer from poor standing ability, poor ground coverage, low competitive ability against weeds and general low productivity on many soil types (Watson et al., 2017). Faba bean is adapted to heavy or clay-rich soils but expresses high sensitivity to water deficit on sandy soils (Watson et al., 2017). Only the white lupin expresses good ground coverage whereas the yellow lupin is the most drought tolerant and suitable for the sandiest soils (Watson et al., 2017). Frost tolerance is limited in soybean and appears unknown in common bean (Watson et al., 2017). Specific tolerance to insect pests and diseases are also important priorities to consider in future breeding programs (Watson et al., 2017).

Farming Policies and Technologic Barriers

Alongside these breeding effort inequalities, policy and structural barriers restricted their supply responsiveness. Policies that promoted staple crop production, such as fertilizer and credit subsidies, price supports, and irrigation infrastructure (particularly for rice), tended to exclude the production of traditional non-staple crops, such as legumes (Welch and Graham, 2000). In fact, the evolution of agricultural practices has been based on the adoption of most widely used and highest profitable techniques (Magrini et al., 2018) and adopting crops. This has led to a technologic lock-in, favoring crop specialization and marginalizing less cost-responsive species (Watson et al., 2017). As a consequence, competition within the agri-food sector caused producers to resort to more lucrative crops, namely cereals, at the expense of crops with lower and more variable yields, such as grain legumes (Magrini et al., 2016). In this context, the promotion and use of agrochemicals became the dominant model with evident disregard for potential environmental hazards (Therond et al., 2017). The lack of technical advice about the use of nitrogen-fixing plants like grain legumes, which reduce the need for synthetic inputs, has been a significant part of these practices (Watson et al., 2017). Thus, research has shown that legumes' low profitability for farmers may be attributed to three important reasons, that is, (i) lack of appreciation for legumes' benefits because margins and yields calculations do not consider the scale of crop rotations; (ii) lack of interest from the agro-industrial supply chain that jeopardizes legumes' added value, and (iii) low profits cause insufficient compensation for the associated reduction in artificial fertilizers use (Magrini et al., 2016). Thus, at the present time cereals dominate agricultural food and feed production around the world and Europe alone is the top producer of wheat (Magrini et al., 2018). Growing consumption of cereal-based food products has also contributed to create such scenario within food sectors (Magrini et al., 2018). According to the EU *Agricultural Outlook 2019-2030*, the EU market for cereals is expected to continue growing, reaching about 320 million tons by 2030 (European Commission, 2019a).

Challenges exist when a farmer or business is to define the optimal route to market for a legume crop. This will have to start by identifying the value network structure, collaborative partners and grasp a deep understanding of the market drivers and barriers which are defined by the specific contexts for operation (Hamann et al., 2019). Once a link with the market has been established, the business will be looking for options to both maintain and expand the business and this requires links to the upstream and downstream "value network." A successful legume commercialization strategy should ideally allow for "scaling up" (or "scaling out"), which means that the strategy must also consider the value network capacities (Hamann et al., 2019), and in the case of legumes, a lack of economy of scale is often pointed out as one of the major barriers for a wider legume adoption. The low levels of legume production do not allow for cost advantages that are often available when growing other more productive crops. Hence, increasing production, would address the economy of scale obstacle and promoting demand and consumption of (locally grown) legumes could work as direct drivers to stimulate farmers to produce more legumes.

Consumers

It has been acknowledged that the adoption of healthier food habits may be impaired by consumers' low health/nutrition literacy (Magrini et al., 2018). This situation is aggravated by the fact that there seems to exist great variability among food intake recommendations in general, and particularly regarding grain legumes (Marinangeli et al., 2017) which can be extended to cooking skills. In fact, lack of know-how as well as, time-related constraints (e.g., long soaking or cooking time) have been pointed out as significant barriers to regular consumption of legumes (Havemeier et al., 2017). Also, misconceptions surrounding potential gastrointestinal discomfort following legumes' intake, may have led to the over exclusion of these foods by many consumers (Hall et al., 2017). Last, but not least, the choice for animal products' alternatives such as legumes may be compromised by a reduced environmental awareness which remains very common across society (Hartmann and Siegrist, 2017). Indeed, it appears consumers underestimate the environmental impact of meat consumption/production and demonstrate rather low willingness to change meat intake habits (Hartmann and Siegrist, 2017).

Food Industry

Nevertheless, globally the food industry has been increasingly orienting its activity in order to reflect contemporary dietary trends (e.g., flexitarian, vegetarian, "gluten-free") and to increase the incorporation of legumes and legume-based ingredients, thereby creating healthier and more sustainable food products (Lascialfari et al., 2019). Even during the 2000s many soybean and wheat protein-based food products were developed to meet such trends (Lascialfari et al., 2019). In 2013, these kind of products still represented 90% of all plant-based foodstuffs innovations (European Commission, 2018b). However, since 2010 the development of new products containing pulses, such as chickpea, pea, bean or lentil has boosted (European Commission, 2018b). Indeed, the demand for lentils and chickpea for human consumption in Europe has increased 24 and 20%, respectively, since 2014 (European Commission, 2018a).

A review performed by The Canadian Ministry of Agriculture and Agri-Food revealed that between 2010 and 2014, more than 3.500 new pulse-based food products were launched in the EU food market (European Commission, 2018b). The vast majority of the products represent highly processed foods based on legume ingredients, containing, chickpea (35%), pea (34%), bean (25%) and lentil (14%) (European Commission, 2018b). Such products have been mostly promoted based on nutrition-related claims, namely the nutrient-dense high-protein quality of legumes (European Commission, 2018b). In fact, animal protein substitutes appear one of the key market drivers which express an annual growth rate of 14% (European Commission, 2018c). Convenience and environmentally friendly aspects seem important assets as well (European Commission, 2018b). Today a wide range of legume-based products can be found on the European markets, including flours, pastas, and all kinds of plant-based snacks (European Commission, 2018b). Still, there is room for critical technological improvements in order to produce fully satisfying products and broaden their public reach, especially where factors like taste, texture, anti-nutrient management and convenience are concerned (Sozer et al., 2016). The downside is that Europe's grain legume production is not sufficient to meet such increasing demand (European Commission, 2018a) with just 69% self-sufficiency in tradable plant protein (Watson et al., 2017) and, consequently, supplies rely heavily on imports from other countries such as the USA, Latin America and Canada (European Commission, 2018a).

DISCUSSION

It is widely recognized that legume crop production has lacked public investment over the years (Magrini et al., 2018). Food markets express a preference for crops like cereals, hence the worth of legumes has been neglected for quite some time (Magrini et al., 2016). However, the mitigation of the environmental consequences caused by the agri-food sector has been a hot topic on the agenda of diverse political entities in the past few years, especially within the EC (European Commission, 2018a). The need to invest in alternative plant protein food sources has been widely acknowledged and strongly advocated. Indeed, the EC in a recent report recommends that more investment should be applied to the development of plant proteins among European countries, reaching as far as consumer behavior (European Commission, 2018c). Taking the example of Portugal, in 2017 Portugal's government approved a new law demanding the inclusion of a vegetarian plate in every public canteen (Assembleia da República, 2017). This has created momentum for the inclusion of legumes across the wider community and has the potential to have a positive impact for the increase in legume consumption. Also, few countries have opted to have legume grains in a separate category of their national food guides (as is the case of Portugal), which may showcase legumes in a more positive and higher profile role. On a more general level, however, it is still apparent that legume-focused policies are confusing and scattered when looking at different local, regional, national, and international scales.

The reintroduction of legumes within present-day agriculture and food practices has been extensively discussed especially during the last 8 years. The designation of 2016 as the *International Year of Pulses* by FAO (in 2013) and the creation of a World Pulses Day every 10th February (since 2019) has paved the way for several other international campaigns for the promotion of more sustainable food production systems where grain legumes appear as key contributors, especially as potential dietary protein sources (Calles et al., 2019). Since then, several joint initiatives from both political parties and food companies have been put into practice (Global Pulse Confederation Pulses, n.d.). From Canada (Pulse Canada, n.d.) to Australia (Pulse Australia, n.d.), a global movement has spread to raise awareness about the need to increase production, as well as, consumption of legumes instead of relying on animal products for dietary protein sources. In Portugal, for instance, the Portuguese Nutrition Association has created a unique campaign to promote the intake of one portion (80 g cooked; 25 g raw) of grain legumes per day (Portuguese Nutrition Association, n.d.). Global intake recommendations are not consensual though and grain legumes are still underrepresented in most official food guides. While there is a growing number of legumes promotion initiatives, information regarding the actual impact of such campaigns, including within the Portuguese population, is missing making it difficult to plan future interventions (Calles et al., 2019).

Yet given the complexity of the food sector, major transformations of current procedures in order to increase the role of legumes throughout food supply chains will not occur overnight. Moreover, such changes will require both upstream and downstream approaches, involving all kinds of stakeholders (Magrini et al., 2018). Some examples are summarized in **Table 1**. Ultimately, collaborations between public research and small companies should be stimulated to help disseminate new understanding regarding both legume production and processing (Lascialfari et al., 2019). Also, companies should nurture close relationships with their agricultural growers or cooperatives, assuring locally produced legume supplies so that the desired higher legume consumption can rely on European legume cultivation rather than on higher levels of imports (Lascialfari et al., 2019). Research institutions could also be strong allies in this grand transition, particularly stimulating research and providing technologic support (Magrini et al., 2016). In this context, new tools and cropping systems designs could be used, such as, field on-farm experiments where farmers test new practices on their farms and cropping system planning tools (Watson et al., 2017).

In terms of food policies, the EC has set up a wider and stronger plan to be put into action from 2020: The *European Green Deal* aims to transform the EU *"into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use"* (European Commission, 2019b). The climate-neutrality target was transposed into law in March 2020, through the *European Climate Law*. It has proposed a reduction of about 50%-55% of EU's GHG's emissions by 2030, compared with 1990 levels. Such

TABLE 1 | Summary of main actions to promote legumes within sustainable agri-food systems.

Governments/Institutions	Agriculture production	Food industry	Consumers
- Foster information dissemination - Promote educational programs for farmers - Increase incentives for legume crops and legume specific extension services - Improve legume promotion campaigns	- Increase locally grown legumes as feeds and reduce soybean importation dependency - Increased adoption of intercropping, crop mixtures and crop rotations with legumes - Increase farmers know-how on legume production - Increase the share of organic farming including legumes - Adopt biological-regulated production models - Breeding and selection of locally adapted legume varieties - Adapt logistics—harvesting/storage firms and market organizations	- Advance research on legume health claims - Improve legume technologic traits (e.g., reduce cooking time) - Design new foods with legumes, especially targeting young audiences (e.g., children) - Improve legumes promotion campaigns	- Dietary shift toward more plant-based diets - Increase legume intake - Improve nutritional education - Improve cooking skills - Improve environmental information

a plan will embrace all kinds of stakeholders, including regions, local communities, civil society, industry and schools. In relation to the food sector itself, a *Farm to Fork* strategy has been created within the *European Green Deal* objectives, "*designing a fair, healthy and environmentally-friendly food system,*" able to support sustainable food production and consumption chains. Again, the selection of alternative protein food sources is reinforced, in light of EC's previous reports (European Commission, 2018c).

CONCLUSIONS

The increase in legume production, and therefore intake, turn out as a major contribution to help mitigate current health and environmental-related global crises. Dried legumes are excellent sources of protein/amino acids, fatty acids, fibers, carbohydrates, and phytochemicals, also possessing a low glycaemic index. Legumes are also ecosystem service providers and environmental "guardians", as they reduce the need for synthetic N fertilization, promote soil conservation, and create more diversified and biodiverse agricultural systems. The acknowledgment of these facts by public authorities and decision-makers may be one important step at overcoming the obstacles that impede the return of legumes to their rightful place within agri-food systems in Europe.

Still, changes in the European food sector will demand high efforts from all stakeholders from both up and downstream the food supply chain. Close collaborations between governments, academic institutions, industries, and farmers are needed in order to facilitate the transition process. Currently, legume production demands more public financial and academic/technologic support, as well as changes in consumers dietary habits. Thus, more research considering legumes cultivation methods and techniques (e.g., genetic trait selection) is highly advisable, together with improvements in farmer's knowledge, especially as far as crop rotation and fertilizers use are concerned. Also, more legumes promotion campaigns are needed and their impact on consumer's behavior needs to be carefully assessed. Recent legal documents published by the EC may have open the way to a more favorable scenario regarding the reintroduction of legumes within European agri-food systems, yet there is still much to be done. In this context, one major future challenge arises regarding the best strategies to successfully accomplish the desirable transformations, particularly considering knowledge dissemination from farmers down to consumer level.

AUTHOR CONTRIBUTIONS

HF is the first author of the manuscript and was responsible for the main scientific search as well as the final elaboration of the present review. EP and MV were equally senior contributors to this manuscript providing expert advice on areas directly related to their research fields, namely, nutrition and sustainable food production, respectively. Also, both helped put together the final manuscript suggesting meaningful and thorough corrections and improvements. All authors contributed to the article and approved the submitted version.

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REFERENCES

Ahmed, S., and Hasan, M. M. (2014). Legumes : an Overview. *J. Pharm. Pharm. Sci.* 2, 34–38.

Assembleia da República (2017). Lei n°11/2017 de 17 de abril—Estabelece a obrigatoriedade de existência de opção vegetariana nas ementas das cantinas e refeitórios públicos. *Diário da República −1.ª série/N.° 75*.

Balázs, B., Kelemen, E., Centofanti, T., Vasconcelos, M., Maa,ß, H., Kolmans, A., et al., (2019). Application of Delphi for governance contexts which favour legume-supported value chains: D7.3 (D42) for the EU-H2020 project, "TRansition paths to sUstainable legume-based systems in Europe" (TRUE), funded under Grant Agreement Number 727973.

Berners-Lee, M., Kennelly, C., Watson, R., and Hewitt, C. N. (2018). Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. *Elementa* 6, 2–14. doi: 10.1525/elementa.310

Bessada, S. M. F., Barreira, J. C. M., and Oliveira, M. B. P. P. (2019). Pulses and food security: dietary protein, digestibility, bioactive and functional properties. *Trends Food Sci. Technol.* 93, 53–68. doi: 10.1016/j.tifs.2019.08.022

Calles, T., Xipsiti, M., and del Castello, R. (2019). Legacy of the international year of pulses. *Environ. Earth Sci.* 78, 1–8. doi: 10.1007/s12665-019-8106-6

Clark, M., Science, N. R., Paul, S., and States, U. (2019). *Changing Dietary Patterns as Drivers of Changing Environmental Impacts*. Philadelphia, PA: Elsevier.

Clúa, J., Roda, C., Zanetti, M. E., and Blanco, F. A. (2018). Compatibility between legumes and rhizobia for the establishment of a successful nitrogen-fixing symbiosis. *Genes (Basel).* 9:125. doi: 10.3390/genes9030125

European Commission (2011). *Communication From the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions—Our Life Insurance, our Natural Capital: an EU Biodiversity Strategy to 2020*. Brussels: European Comision.

European Commission (2018a). *EU Agricultural Outlook for Markets and Income, 2018–2030*. Brussels: European Commision.

European Commission (2018b). *Market Developments and Policy Evaluation Aspects of the Plant Protein Sector in the EU—Final Report*. Brussels: European Commision.

European Commission (2018c). *Report from the Commision to the Council and the European Parliament on the development of plant proteins in the European Union*. Brussels: European Commission.

European Commission (2019a). *EU Agricultural Outlook for Markets and Income, 2019–2030*. Brussels: European Comision.

European Commission (2019b). *The European Green Deal*. Brussels: European Commission.

European Environment Agency (2019a). *Climate Change Adaptation in the Agriculture Sector in* Europe.

European Environment Agency (2019b). *Land and Soil in Europe. Why we Need to Use These Vital and Finite Resources Sustainably*. Copenhagen: European Environment Agency.

Evenson, R., and Gollin, D. (2003). Assessing the impact of the green revolution, 1960 to 2000. *Science* 80, 758–762. doi: 10.1126/science.1078710

Everwand, G., Dauber, J., Cass, S., and Williams, M. (2017). "Legume Crops and Biodiversity," in *Legumes in Cropping Systems*, eds D. Murphy-Bokern, F. L. Stoddard, and C. A. Watson (Wallingford: CAB International) 55–69.

FAO (2018). *Sustainable food systems—Concept and framework*. Rome: Agriculture Organization of the United Nations (FAO) Available online at: http://www.fao.org/3/ca2079en/CA2079EN.pdf.

Ferreira, H., Vasconcelos, M. W., Gil, A. M., and Pinto, E. (2020). Benefits of pulse consumption on metabolism and health: a systematic review of randomized controlled trials. *Crit. Rev. Food Sci. Nutr.* 85. doi: 10.1080/10408398.2020.1716680

FSIN (2020). *2020 Global Report on Food Crises*. Available online at: https://www.fsinplatform.org/sites/default/files/resources/files/GRFC_2020_ONLINE_200420.pdf.

Giovannucci, D., Scherr, S. J., Nierenberg, D., Hebebrand, C., Shapiro, J., Milder, J. C., et al., (2012). Food and Agriculture: the future of sustainability. A strategic input to the Sustainable Development in the 21st Century (SD21) project. New York Available online at: http://www.un.org/esa/dsd/dsd_sd21st/21_pdf/agriculture_and_food_the_future_of_sustainability_web.pdf.

Global Pulse Confederation Pulses. (n.d.). Available online at: https://pulses.org/global (accessed March 16, 2020).

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., et al., (2018). Meat consumption, health, and the environment. *Science* 80:361. doi: 10.1126/science.aam5324

Gomes, A. M., and Vasconcelos, M. W. (2014). "The legume grains: when tradition goes hand in hand with nutrition," in *ISEKI Food Series volume 10 Traditional Foods; General and Consumer Aspects*, eds K. Kristbergsson and J. Oliveira (Boston, MA: Springer).

Grela, E. R., and Samoli, W. (2017). Content of minerals and fatty acids and their correlation with phytochemical compounds and antioxidant activity of leguminous seeds. *Biol. Trace Elem. Res.* 180, 338–348. doi: 10.1007/s12011-017-1005-3

Hall, C., Hillen, C., and Robinson, J. G. (2017). Composition, nutritional value, and health benefits of pulses. *Cereal Chem.* 94, 11–31. doi: 10.1094/CCHEM-03-16-0069-FI

Hamann, K., Vasconcelos, M., Löhrich, N., Odee, D., Vickers, R., Blazon, N., et al., (2019). A map of value chains for legumes used as food: D4.1 (D23) for the EU-H2020 project, 'TRansition paths to sUstainable legume-based systems in Europe' (TRUE), funded under Grant Agreement Number 727973.

Hartmann, C., and Siegrist, M. (2017). Consumer perception and behaviour regarding sustainable protein consumption: a systematic review. *Trends Food Sci. Technol.* 61, 11–25. doi: 10.1016/j.tifs.2016.12.006

Harwatt, H., Joan, S., Gidon, E., Sam, S., and William, R. (2017). Substituting beans for beef as a contribution toward US climate change targets. *Climatic Change* 143, 261–270. doi: 10.1007/s10584-017-1969-1

Havemeier, S., Erickson, J., and Slavin, J. (2017). Dietary guidance for pulses: the challenge and opportunity to be part of both the vegetable and protein food groups. *Ann. N. Y. Acad. Sci.* 1392, 58–66. doi: 10.1111/nyas.13308

Kiba, T., and Krapp, A. (2016). Plant nitrogen acquisition under low availability: regulation of uptake and root architecture. *Plant Cell Physiol.* 57, 707–714. doi: 10.1093/pcp/pcw052

Lascialfari, M., Magrini, M.-B., and Triboulet, P. (2019). The drivers of product innovations in pulse-based foods: insights from case studies in France, Italy and USA. *J. Innov. Econ. Manag.* 28, 111–143. doi: 10.3917/jie.028.0111

Leghari, S. J., Wahocho, N. A., Laghari, G. M., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K., et al., (2016). Role of nitrogen for plant growth and development : a review. *Adv. Environ. Biol.* 10, 209–218.

Magrini, M. B., Anton, M., Chardigny, J. M., Duc, G., Duru, M., Jeuffroy, M. H., et al., (2018). Pulses for sustainability: breaking agriculture and food sectors out of lock-in. *Front. Sustain. Food Syst.* 2, 1–17. doi: 10.3389/fsufs.2018.00064

Magrini, M. B., Anton, M., Cholez, C., Corre-Hellou, G., Duc, G., Jeuffroy, M. H., et al., (2016). Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? analyzing lock-in in the French agrifood system. *Ecol. Econ.* 126, 152–162. doi: 10.1016/j.ecolecon.2016.03.024

Mahmood, F., Shahzad, T., Hussain, S., Shahid, M., Azeem, M., and Wery, J. (2018). "Grain legumes for the sustainability of european farming systems," in *Sustainable Agriculture Reviews 32*, ed. L. E. (New York, Ny: Springer) 105–133.

Marinangeli, C. P. F., Curran, J., Barr, S. I., Slavin, J., Puri, S., Swaminathan, S., et al., (2017). Enhancing nutrition with pulses: defining a recommended serving size for adults. *Nutr. Rev.* 75, 990–1006. doi: 10.1093/nutrit/nux058

Marzinzig, B., Brünjes, L., Biagioni, S., Behling, H., Link, W., and Westphal, C. (2018). Bee pollinators of faba bean (*Vicia faba L.*) differ in their foraging behaviour and pollination efficiency. *Agric. Ecosyst. Environ.* 264, 24–33. doi: 10.1016/j.agee.2018.05.003

Mekonnen, M. M., and Hoekstra, A. Y. (2012). A Global assessment of the water footprint of farm animal products. *Ecosystems* 15, 401–415. doi: 10.1007/s10021-011-9517-8

Mudryj, A. N., Yu, N., and Aukema, H. M. (2014). Nutritional and health benefits of pulses. *Appl. Physiol. Nutr. Metab.* 39, 1197–1204. doi: 10.1139/apnm-2013-0557

Peoples, M. B., Hauggaard-Nielsen, H., Huguenin-Elie, O., Jensen, E. S., Justes, E., and Williams, M. (2019). "The Contributions of Legumes to Reducing the Environmental Risk of Agricultural Production," in *Agroecosystem Diversity* (Philadelphia, PA: Elsevier Inc.) 123–143.

Phillips, R. D. (1993). Starchy legumes in human nutrition, health and culture. *Plant Foods Hum. Nutr.* 44, 195–211. doi: 10.1007/BF01088314

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *PNAS* 12302–12308. doi: 10.1073/pnas.0912953109

Plaza-Bonilla, D., Nolot, J. M., Raffaillac, D., and Justes, E. (2017). Innovative cropping systems to reduce N inputs and maintain wheat yields by inserting grain legumes and cover crops in southwestern France. *Eur. J. Agron.* 82, 331–341. doi: 10.1016/j.eja.2016.05.010

Portuguese Nutrition Association 1 porção de leguminosas por dia. (n.d.). Available online at: https://www.apn.org.pt/ver.php?cod=0D0I (accessed March 16, 2020).

Preissel, S., Reckling, M., Schläfke, N., and Zander, P. (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: a review. *F. Crop. Res.* 175, 64–79. doi: 10.1016/j.fcr.2015.01.012

Pulse Australia. (n.d.). Available online at: http://www.pulseaus.com.au/ (accessed March 16, 2020).

Pulse Canada. (n.d.). Available online at: http://www.pulsecanada.com/ (accessed March 16, 2020).

Rao, M. R., and Mathuva, M. N. (2000). Legumes for improving maize yields and income in semi-arid Kenya. *Agric. Ecosyst. Environ.* 78, 123–137. doi: 10.1016/S0167-8809(99)00125-5

Singh, B., Singh, J. P., Shevkani, K., Singh, N., and Kaur, A. (2017). Bioactive constituents in pulses and their health benefits. *J. Food Sci. Technol.* 54, 858–870. doi: 10.1007/s13197-016-2391-9

Sozer, N., Holopainen-Mantila, U., and Poutanen, K. (2016). Traditional and new food uses of pulses. *Cereal Chem.* 94, 66–73. doi: 10.1094/CCHEM-04-16-0082-FI

Stagnari, F., Maggio, A., Galieni, A., and Pisante, M. (2017). Multiple benefits of legumes for agriculture sustainability: an overview. *Chem. Biol. Technol. Agric.* 4, 1–13. doi: 10.1186/s40538-016-0085-1

Sulieman, S., and Tran, L. S. P. (2015). "Introduction," in *Legume Nitrogen Fixation in a Changing Environment: Achievements and Challenges*, eds S. Sulieman and L. S. P. Tran (Switzerland: Springer International Publishing), 1–3.

Sutton, M. A., Howard, C. M., Brownlie, W. J., Skiba, U., Kevin Hicks, W., Winiwarter, W., et al., (2017). "The European Nitrogen Assessment 6 years after: What was the outcome and what are the future research challenges?," in *Innovative Solutions for Sustainable Management of Nitrogen. Procs. From the International Conference*, eds J. Gristensen, T. Dalgaard, J. E. Olesen, J. K. Schjorring, J. S. Jensen, H. Vejre, P. S. Andersen, P. Gundersen, B. H. Jacobsen, J. Jensen, B. Häsler, M. Termansen, O. Hertel, S. Brock, B. Kronvang, J. C. Svenning, T. Sigsgaard, B. Hansen, L. Thorling, A. L. Højberg, I. A. Wiborg (Denmark: Aarhus University and the dNmark Research Alliance), 40–49. Available online at: http://sustainablenconference.dnmark.org/wp-content/uploads/2017/06/JYC_Final_Book-of-abstracts160617.pdf

Sutton, M. A., Oenema, O., Erisman, J. W., Leip, A., Van Grinsven, H., and Winiwarter, W. (2011). Too much of a good thing. *Nature* 472, 159–161. doi: 10.1038/472159a

Therond, O., Duru, M., Roger-Estrade, J., and Richard, G. (2017). A new analytical framework of farming system and agriculture model diversities. a review. *Agron. Sustain. Dev.* 37:429. doi: 10.1007/s13593-017-0429-7

Von Richthofen and G. L. Pro Partners (2006). *Economic and Environmental Value of European crop- ping Systems that Include Grain Legumes*. Grain legumes No. 45–1st quarter 2006 Special report UNIP. France Available online at: http://www.ias.csic.es/grainlegumesmagazine/Grain_Legumes_issue_45.pdf.

Watson, C. A., Reckling, M., Preissel, S., Bachinger, J., Bergkvist, G., Kuhlman, T., et al., (2017). Grain legume production and use in european agricultural systems. *Adv. Agron.* 144, 235–303. doi: 10.1016/bs.agron.2017.03.003

Welch, R., and Graham, R. (2000). A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. *Food Nutr Bull* 361–366. doi: 10.1177/156482650002100404

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al., (2019). Food in the Anthropocene : the EAT-Lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447. doi: 10.1016/S0140-6736(18)31788-4

Wood, J. D. (2017). "Meat Composition and Nutritional Value," in *Lawrie's Meat Science (Eighth Edition)* (Philadelphia, PA: Elsevier Ltd), 635–659.

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