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RESEARCH ARTICLE — OPEN ACCESS

Pea and rapeseed acreage and land use for plant-based meat alternatives in the EU[☆]

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Abstract – Plant-based meat alternatives from grain legumes and oil crops are expected to play an increasing role in human nutrition. Several commercially available products use pea protein isolate as protein basis and rapeseed oil as lipid basis. The aim of the present study is to estimate the prospective area of peas and rapeseed for plant-based meat alternatives in the EU. A simple calculation model is employed to assess the impacts on land use and imported deforestation, in case plant-based meat alternatives substitute meat consumption in different shares. Various data sources and scenarios were used to estimate the cultivation potential. While pea acreage would increase considerably compared to current production, additional rapeseed acreage would be more limited. Even in an extreme scenario of 100% substitution only 12% of EU's arable land would be used for pea and rapeseed as main ingredients for plant-based meat alternative. If pea protein isolate and rapeseed oil as main ingredients of plan-based meat alternatives increase, the land currently used for animal feed production would become partly available and imported deforestation could be decreased: a substitution of 25% of meat consumption would allow to provide the equivalent of food proteins without extending the cultivated areas in Europe, while avoiding soybean and maize imports for feed.

Keywords: cultivation area / legumes / rapeseed / plant-based meat alternatives / pea protein isolate / land use / imported deforestation

Résumé – Superficie des cultures de pois et de colza et utilisation des terres pour les substituts de viande d'origine végétale dans l'UE. Les substituts de viande d'origine végétale issus de légumineuses à graines et de cultures oléagineuses devraient jouer un rôle croissant dans l'alimentation humaine. Plusieurs produits disponibles dans le commerce utilisent l'isolat de protéine de pois comme base protéique et l'huile de colza comme base lipidique. L'objectif de la présente étude est d'estimer la superficie potentielle de pois et de colza pour les substituts de viande d'origine végétale dans l'UE. Un modèle de calcul simple est utilisé pour évaluer les impacts sur l'utilisation des terres et la déforestation importée, dans le cas où les substituts de viande d'origine végétale remplacent la consommation de viande dans des proportions différentes. Différentes sources de données et différents scénarios ont été utilisés pour estimer le potentiel de culture. Alors que la superficie consacrée aux pois augmenterait considérablement par rapport à la production actuelle, la superficie supplémentaire consacrée au colza serait mineure. Même dans un scénario extrême de substitution à 100 %, seuls 12 % des terres arables de l'UE seraient utilisés pour les pois et le colza comme principaux ingrédients des substituts de viande d'origine végétale. Si l'isolat de protéines de pois et l'huile de colza comme principaux ingrédients des substituts de viande d'origine végétale augmentaient, les terres actuellement utilisées pour la production d'aliments pour animaux deviendraient en partie disponibles et la déforestation importée pourrait être réduite : une substitution de 25 % de la consommation de viande permettrait de fournir l'équivalent des protéines alimentaires sans étendre les surfaces cultivées en Europe, et en évitant les importations de soja et de maïs pour l'alimentation animale.

Mots clés : zone de culture / légumineuses / colza / substituts de viande d'origine végétale / isolat de protéine de pois / utilisation des terres / déforestation importée

☆ Contribution to the Topical Issue "Creating new oil & protein crop value chains / Construire de nouvelles filières oléoprotéagineuses"
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1 Introduction

Plant-based meat alternatives from grain legumes and oil crops are expected to play an increasing role in human nutrition (Röös et al., 2018; van der Weele et al., 2019; Aiking and de Boer, 2020). Several commercially available products use pea protein isolate as protein basis and rapeseed oil as the lipid basis. While rapeseed oil cultivation and processing is well established in the EU, pea production and processing are yet emerging. Increasing the availability of proteins from legumes is pursued through increased legume production at the primary production level and advances in food processing within the EU. Especially in organic agriculture legumes play a major role as a N-fixing crop (Schmidt et al., 2012). Yet, the orientation of European agriculture towards the massive production of commodities led to an impoverishment of European cropping systems, with important adverse effects on the sustainability of the agro-ecosystems (Schott et al., 2010). In order to diversify crop rotations, legumes are recommended in conventional agriculture (Magrini et al., 2018). To this end, EU and national policies have provided the framework for several programs and strategies offering incentives for the establishment of more legume cultivation and value-adding (Kuhlman et al., 2014). The aim of the present study is to estimate the prospective area of peas and rapeseed as main ingredients for plant-based meat alternatives in the EU within a simple calculation model. Thereby we aim to assess the impacts on land use and imported deforestation, in case plant-based meat alternatives substitute meat consumption to different degrees. It shows that a total substitution of meat consumption in EU by plant-based substitutes would mobilize around 12% of the EU arable land for "pea meat" production, and that a substitution of 25% of meat consumption would allow to provide the equivalent of food proteins without extending the cultivated areas in Europe while avoiding soybean and maize imports for feed at the same time.

2 Background

2.1 Legumes as innovative food ingredient

Different private and public initiatives have started to develop innovative foods from European legumes like for example faba bean, pea, lupins, lentils and chickpeas or soybean. At the consumption level diverse diets that include legumes make important contributions to healthiness (Foyer et al., 2016). The health benefits of legumes include positive effects on cholesterol levels, decrease diabetes, heart diseases, hypertension and have preventive effects on cancer (Dahl et al., 2012; Madar and Stark, 2002; Trinidad et al., 2010). Although there are possible challenges related to less absorption of some vitamins and low content of some essential minerals and amino acids, diet specialists recommend legume consumption (Baldwin et al., 2017). Food innovations that highlight positive health aspect and more explicit dietary guidelines are relevant steps for increasing consumption of legumes (Figueira et al., 2019; Magrini et al., 2019). More than 3,500 new legume-based products were introduced in the European food market, particularly in the UK, France, Germany, Spain and Italy in the period 2010–2014, products mainly based on chickpea (31%), pea (30%), beans (25%), lentils (14 %), of which only 13% are organic (Hamann, 2019). In 2016, the consumption of pulses per person per year in Europe was on average 3 kg, but with large variations between countries (Hamann, 2019).

At the opposite, the diets in Europe are relatively rich in meat (Tab. 1): 68.6 kg/capita in 2017, with internal differences of quantities and composition between regions of EU, when the consumption is 34.5 kg/capita at world level, from 26.6 in developing countries to 69.3 in OECD countries (OECD/FAO Outlook 2020–2029, as retail weight).

Protein flours, concentrates and isolates from legumes are used in an increasing number of innovative food products having the potential to partly replace meat and dairy products (Singhal et al., 2016). Protein meals and isolates from legumes have the potential to improve the protein content of traditional flours in the baking industry to sustain the functional properties of traditional flours with low protein contents (Turfani et al., 2017). Innovative food products also include a whole range of products based on legume protein such as vegan ice cream or vegan yoghurts (e.g. Lim et al., 2019) and drinks (Qamar et al., 2019; Lopes et al., 2020; Nawaz et al., 2020; Verni et al., 2020). Also a high diversity of spreads has been and is being developed. In addition, low-carb diets depend on protein rich ingredients for which legume-based protein meals and isolates can be used. Additionally, ingredients in food supplements for sportspeople have been introduced. Direct meat and sausage imitates depend on plant-based protein alternatives for which legumes function as important alternatives (Joshi and Kumar, 2015; Dreher et al., 2020; Sha and Xiong, 2020). Some of the innovations are already in the market but constitute only small market shares. Other legume-based food products are still in the R&D pipeline with possible market potential (Murphy-Bokern et al., 2019).

2.2 Plant-based meat alternatives

Peas play an important role in human and animal nutrition in the EU, whereby the use for feed dominates. Within the EU countries, the share for food and feed can be totally different. While 36% of the national consumption of peas are used for food in Germany, it is more than 80% in the UK (Kezeya Sepngang, 2019). According to Eurostat, pea is the second most produced grain legume in the EU with a production of 2 Mio.t, after soybeans, 2.9 Mio.t in 2018. The trend of pea production in the EU is increasing. This increased production during the last five years is partly due to the Common Agricultural Policy (CAP) implemented in 2015 that consider legumes' growing areas as ecological focus areas (Wobser, 2018). The leading producers of pea in the EU are France, Germany, Lithuania, Spain, Romania and UK. These countries represent more than 75% of the EU production.

The US-based company Beyond Meat is a major innovator in plant-based meat alternatives. Beyond Meat entered the EU retail market in the UK, the Netherlands and Germany with a pea-based vegan burger patty in 2019 which is seen as accelerating the trend towards plant-based meat alternatives in the EU (Bloomberg, 2019; Reuters, 2019). Comprehensive

Table 1. Average consumption of meats in EU 28, and differences between EU15 (Member States before 2004) and EU13 (States joining EU after 2004).

Type meat (kg r.w.e.)*	Beef and veal meat	Sheep and goat meat	Pigmeat	Poultry meat	Total
Per capita consumption	10.8	1.8	31.9	24.1	68.6
Of which EU-15	12.6	2.1	31	24.1	69.8
Of which EU-N13	3.9	0.7	35.5	23.9	64.0

Source: EU Agricultural Outlook for the Agricultural markets and income 2017–2030. EU Commission, 2017, table 9.27–9.30.
*r.w.e.: retail weight equivalent; coefficients to transform carcass weight into retail weight are 0.7 for beef and veal, 0.78 for pigmeat and 0.88 for both poultry meat and for sheep and goat meat.

advantages of the Beyond Meat patties over patties from US beef production were found in a life-cycle assessment by Heller and Keoleian (2018). Pea protein isolate is the protein basis of the Beyond Meat burger patty (Beyond Meat, 2019a, 2019b). The raw material basis for the protein isolate is assumed to be peas from the northern states of the US and from Canada (Bloomberg, 2019; Heller and Keoleian, 2018). Additional cultivation areas and additional general cultivation potential for peas are forecasted for the short to medium term (Bloomberg, 2019; Reuters, 2019). European peas may become increasingly relevant as raw materials in the future if the expected market growth evolves with a regional origin of the raw materials. This would result in additional sales potential for EU legume producers with growing cultivation areas. The French company Roquette's partnership with Beyond Meat gives an indication of the strategic supply development (Beyond Meat, 2020). Increase production of plant-based meat alternatives has consequences for pea production and transforms the food sector as pea-based meat alternatives have further synergies with the vegetable oils sector.

The Beyond Meat patties are made of the following ingredients: water, pea proteins and rice proteins for the protein fraction, coconut oil and rapeseed oil for the lipid fraction, potato starch and methylcellulose for carbohydrates, plus minerals and natural flavors (source: Beyondmeat.fr website, December 2020). The European Union is also a producer of vegetable oils from diverse crops species, mainly rapeseed (the winter type equivalent of canola), sunflower and soybean, and evident synergies with the oil sector would appear in case of "pea meat" development. Natural meat contains significant quantities of lipids, sometimes called "hidden lipids", mostly as saturated and mono-unsaturated fats (see ANSES, 2020 – French food composition table at https://ciqual.anses.fr/#). Lipids are necessary both for nutritional value and for taste, and a vegetable meat formula must include a reasonable amount of lipids.

2.3 Data and methods

A simple calculation model is employed to assess the impacts on land use and imported deforestation, in case plant-based meat alternatives substitute meat consumption in different shares. Various data sources were used to estimate the cultivation potential of peas and rapeseed for the production of "pea meat". In our analysis here, "pea meat" is defined as a plant-based alternative to animal meat based on field pea protein and vegetable oils fatty acids. The calculation model assumes the same proportion of peas and rapeseed utilized for the Beyond Meat patty also for "pea meat" in general. In this way the amount of peas and rapeseed for a certain amount of "pea meat" can be calculated. Based on average yields of peas and rapeseed the required cultivation area can be derived. We assume constant pea and rapeseed yields as well as constant protein and oil content in our model although this might change with increased breeding efforts. In the calculation, plausible assumptions were made in case of unavailable data.

Table 2. Nutritional comparison of beyond burger and 80/20 beef.

	Beyond burger 4 oz BB patty 4 oz	80/20 beef (USDA, 2015)
Weight (g)	113	113
Protein (g)	20	19
Cholesterol (mg)	0	80
Total fat (g)	22	23
Saturated fat (g)	5	9
Unsaturated fat (g)	17	14
Calories	290	287
Iron (DV)	25%	12%

As the share of rapeseed oil is not given in the list of ingredients, we have to calculate this share. The nutritional composition of Beyond Meat burger as reported in Heller and Keoleian (2018) is given in Table 2.

The presence of coconut oil is probably linked to technological constraints and functional qualities of saturated oils to make a more solid or palatable product. To evaluate the rapeseed oil content, we have to focus on the lipid composition, and consider that coconut oil and rapeseed oil contain 84.5% and 7.4% saturated fatty acids, and 14% and 91.4% unsaturated fatty acids respectively. These average compositions may be sufficient for a basic evaluation of the respective shares of coconut oil and rapeseed oil since no other ingredient contains lipids or fats. We have a system of two equations with two values to determine: if C is coconut oil weight and R Rapeseed oil weight, $C \times 0.845 + R \times 0.074 = 5$ g and $C \times 0.14 + R \times 0.914 = 17$ g, leading to $C = 4.347$ g and $R = 17, 933$ g/patty. Let us consider on the basis of the previous assumptions that 17.9 g of rapeseed oil per patty are needed. On the basis of this figure, we can complete the calculations made for peas acreage by calculating the corresponding rapeseed acreage, using average rapeseed yields in Europe.

The calculation model is described in Table 3, with assumed parameter values and respective sources; it has been developed as a spreadsheet and does not consider feed-back interactions.

The pea protein isolate quantity and the pea equivalent quantity per patty can be calculated based on the weight of the "pea meat" burger patty, the proportion of pea protein isolate in the recipe and the pea protein content in peas as well as in the pea protein isolate. If the pea equivalent quantity per patty is set in relation to the pea yield, the necessary pea cultivation area for one "pea meat" burger patty is obtained. In the same way the quantity of rapeseed oil per patty together with the exploitation rate of oil can be used to derive the equivalence quantity of raw rapeseed per patty. If this quantity is set in relation to rapeseed yields, the rapeseed area per patty can be calculated (Tab. 4).

To estimate future consumption shares, an expert panel was interviewed as part of the European joint project LegValue. Thirty-one of the 42 participants in the annual project meeting in 2019 answered the following question in a smartphone-based online survey: "What is your estimate of the percentage share of EU "vegan meat" consumption from European legumes in 2030?" Minimum, median, maximum values from the survey were respectively 2%, 12.5% and 40%. More extreme value of 50%, 75% and 100% were used as the basis for calculations for the EU.

3 Results

3.1 Quantity and area effects of plant-based meat alternative development

Based on per capita consumption of animal meat, consumption volumes of "pea meat" can be estimated. Four scenarios are assumed for the annual consumption of "pea meat" with consumption shares of 2%, 12.5%, 50% and 75% of the animal meat consumption of 64 kg per capita per year in the EU. This makes it possible to estimate corresponding consumption quantities for the total population in EU (Fig. 1). The pea protein isolate content in the recipe and the pea protein yield can be used to calculate the required pea quantity. If this is set in relation to the pea yield, the required pea cultivation area is obtained. This can be set in relation to the previous pea cultivation area or to the total arable land of approximately 103 million ha in the EU. In the same way the above calculated rapeseed oil content and the oil yield can be used to calculate the required rapeseed quantity. This quantity can be set in relation to rapeseed yields to derive the required rapeseed cultivation area (Fig. 2).

The expeller pression of oilseeds (and not extraction) is mentioned in the ingredients list: we estimated the oil extraction rate to 39% oil, for an average oil content in seeds of 43%, considering a remaining 6% oil in expeller cakes corresponds to a current level for oil industries, but this depends on the conditions of the process (cold/hot, more or less pressure). It may reach up to 12% oil remaining in meals. A difference of one point on extraction rate (for example 38% instead of 39%, corresponding to 8.7% oil remaining in meals), leads to a difference of 2.6% on acreages (+13,700 ha for 12.5% scenario). At last, it must be added that the classical solvent extraction leaves no more than 3% oil in meals, which could lead to lower acreages. Nevertheless, expeller pression brings a better image of the product for consumers.

The final result of the calculation, adding pea and rapeseed acreages shows that, in theory, about 11.5% of the EU 28 arable land would be needed, with the present yields, for a complete substitution of animal meat by pea-based products for direct food consumption. This conclusion is relatively robust in case of yields evolutions: within a range of −20% to +20% compared to the present pea and rapeseed average yields to share of EU arable land would represent from 9.6% to 14.4% (Fig. 3).

The next step of our theoretical calculation is to assess the potential effect on land use in Europe, under the assumption that all the feed quantities would be produced in Europe, including cereals, fodders and soybean. A similar calculation could be done to assess the effect on imported deforestation, on the basis of soybean yields in Brazil.

3.1.1 Effects on general EU feed consumption and land use

To assess the potential effect of "pea meat" substitution on land use, we have to consider on one side the acreage needed for "pea meat" production, and on the other side, the acreage needed to produce the feed for animal husbandry. For a simple and general approach, we work on sectoral statistics, starting from the total feed consumption statistics obtained from the EU Agricultural Outlook 2017–2030 (2015/2016 data), which is affected to each animal category (Tab. 5)

The EU protein balance sheet published by the EU Commissions gives a higher total of 266 MT for ingredients of vegetable origin, probably due to other animal productions like aquaculture or petfoods. If we compare these statistics with FEFAC (2018) (European Feed Industries) statistics, we can see that the compound feed industries produced 156 MT of feed, *i.e.*, 59% of the total feed consumption in EU28, of which 7.9 MT for other animal categories than poultry, cattle and pigs. If we assume a similar share of on-farm-made feed for these other categories, the total amount for EU would be 13.4 MT. Added to 253.2, the result is 266.6 MT, consistent with the statistics of the European Commission (2019) for the total vegetable ingredients for feed uses (Tab. 6): 265.6 MT in 2015/2016 and 266.4 MT in 2017/2018.

We shall keep the amount of 253 million tons for the productions related to meat production and have to make two adjustments:

- this feed consumption includes dairy and eggs productions: we shall make the assumption that 15% of the consumption is affected to meat production in the case of dairy cows, and 25% in the case of laying hens, on the total life duration of these animals (Flysjö *et al.*, 2011; Mackenzie *et al.*, 2017). The compound feed consumption table for meat production is then adjusted as follows, giving a total feed amount of 205 million tons/year (Tab. 7):
- we must readjust these data proportionally to the net meat consumption in EU, and cancel the quantities corresponding

Table 3. Calculation model, assumed parameter values and respective sources.

Parameter	Code	Calculation	Scenario 1%	Unit	Source
Population EU (2017) EU 28	O		511.4	million persons	Eurostat for 2017
Per capita meat consumption EU	M		64.4	kg/person × year	Eurostat for 2017
Arable land EU	V		103,080.8	1000 ha	Eurostat for EU 2016
EU28 pea area 2017	y		1,025.8	1000 ha	Eurostat for 2017
EU28 pea production 2017	Y		2,782.4	1000 t	Eurostat for 2017
EU28 rapeseed cropping area 2017	z		6,749.0	1000 ha	Eurostat for 2017
EU28 rapeseed production 2017	Z		21,914.0	1000 t	Eurostat for 2017
Pea component					
Weight of Beyond Meat Patty unit	A		113.5	g	Beyond Meat, 2019a
Share of pea protein isolate	B		18.0	%	Beyond Meat, 2019a
Weight of pea protein isolate per patty unit	C	A × B	20.4	g/patty	Own calculation
Share of protein in pea protein isolate	D		85.0	%	AGT, 2020
Protein content in peas seeds	E		24.0	%	Emsland, 2015
Extraction rate of pea protein isolate	F	D × E	28.2	% (g isolate/100 g peas)	Own calculation
Equivalent pea seeds weight per patty unit	G	C/F × 100	72.4	g/patty	Own calculation
Share of pea equivalents in patty	H	G/A × 100	63.8	%	Own calculation
Pea yield EU (conv. & org.)	K		2.7	t/ha	Eurostat, 2017
Required pea growing area per patty EU per year	L	G/(L × 1,000,000) × 10,000	0.27	m^2/patty	Own calculation
Substitution share of pea meat from animal meat	r		1.0	%	Assumption
Assumed per capita per year pea meat consumption	N	M × (r/100)	0.64	kg/person × year	Own calculation
Total pea meat in EU	P	O × 1,000,000 × N/1,000,000	329.3	1000 t/year	Own calculation
Quantity of peas for pea meat	Q	P × H/100	209.9	1000 t/year	Own calculation
Pea cropping area for pea meat	S	Q/K	77.4	1000 ha	Own calculation
required land for pea component per ton of pea meat (ha)	T	S/Q	0.37	ha	Own calculation
Rapeseed component					
quantity of rapeseed oil per patty (g/patty)	c		17.9	g/patty	Own calculation
% rapeseed oil in pea meat	h	c/A	0.16		Own calculation
% oil in rapeseed seeds (%)	e		43.0	%	Terres Univia, 2020
Extraction rate for expeller pressed rapeseed oil (goil/100 g seeds)	f		39.0	% (g oil/100 g of seeds)	Own calculation; assuming 6% oil in expeller meal
needed rapeseed weight per patty (g/patty)	g	c/f × 100	45.9	g/Patty	Own calculation
rapeseed yield EU (conv. & org.) (t/ha)	k		3.2	t/ha	Eurostat, 2017: 21.914 MT on 6.749 Mha
Required land per patty for rapeseed oil component (m^2/patty)	l	g/(k × 1,000,000) × 10,000	0.14	m^2/patty	Own calculation
Rapeseed quantity for pea meat (1000 tons)	q	P × h/f × 100	133.2	1000 t/year	Own calculation
Rapeseed cropping area for pea meat (1000 ha/year)	s	q/k	41.0	1000 ha/year	Own calculation
required cropping area for rapeseed oil component per ton of pea meat (ha)	t	(l × 100/A) × 10,000/10,000	0.1	ha	Own calculation
Share of pea for pea meat in total pea production	U	Q/Y × 100	7.5	%	Own calculation
Share of pea for pea meat in EU28 total cropping area	W	S/V × 100	0.1	%	Own calculation
Current share (2017) of peas in total EU arable area	X	y/V × 100	1.0	%	Own calculation
share of rapeseed acreage for pea meat in total EU28 cropping area (%)	w	s/V × 100	0.04	%	Own calculation
current share (2017) of rapeseed in total EU arable area	x	z/V × 100	6.5	%	Own calculation
total cropping area for pea + rapeseed production for pea meat		S + s	118.4	1000 ha	Own calculation
share of required cropping area of pea + rapeseed for pea meat in EU28 arable utilized acreage (%)		(S + s)/V × 100	0.11	%	Own calculation

Table 4. Calculated parameter values set in relation to one pea patty.

Parameters	Value
Peas	
Quantity of pea protein isolate	20.43 g/patty
Exploitation rate of pea protein isolate from raw peas	28.2%
Equivalence quantity of raw peas per patty	72.36 g/patty
Pea area per patty	0.27 m^2/patty
Rapeseed	
Quantity of rapeseed oil	17.90 g/patty
Exploitation rate of rapeseed oil from raw rapeseed	39.0%
Equivalence quantity of raw rapeseed per patty	45.90 g/patty
Rapeseed area per patty	0.14 m^2/patty
Total	
Required pea and rapeseed area per patty	0.41 m^2/patty
Required pea and rapeseed area per ton of "pea meat"	0.36 ha/t

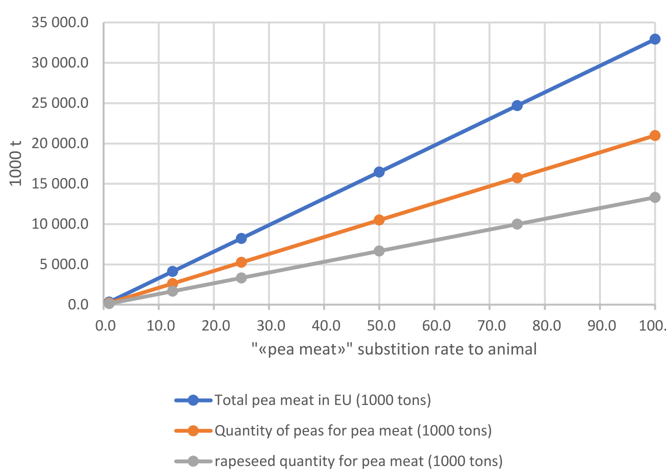

Fig. 1. Evolution of quantities of "pea meat" consumption in EU28 and needed pea and rapeseed quantities (1000 tons).

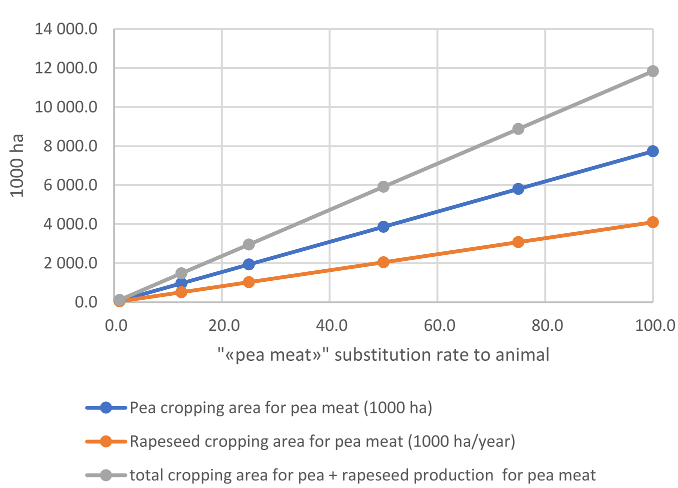

Fig. 2. Evolution of acreage for pea and rapeseed production for "pea meat" (1000 ha) according to "pea meat" substitution rate.

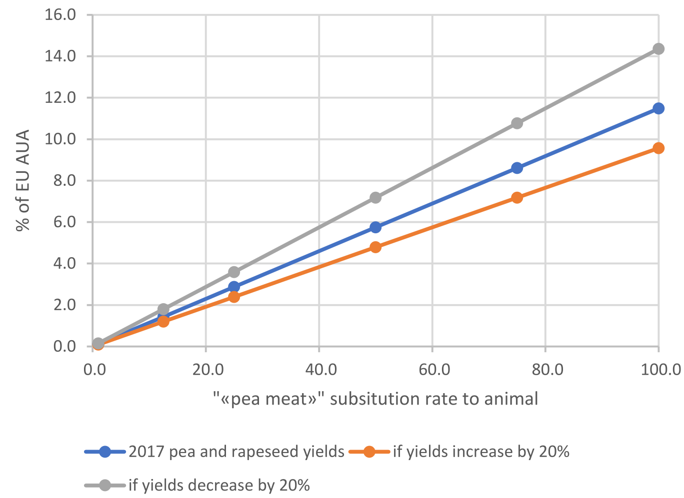

Fig. 3. Share of required cropping area of pea + rapeseed for "pea meat" in EU 28 arable utilized acreage (%).

to meat exports. Thereby we assume that self-sufficiency of 100%.

Table 8 details the next calculation steps: to convert tons of feed in ha, we use the 5 years average crop yield for the main concerned crops: common wheat, barley, maize, rapeseed, sunflower and soybean (average weighted with respective acreages), which reflects the average potential of arable crops in EU. Taking into account fodder crops is simpler since these surfaces are devoted to animal husbandry only. We assume that "pea meat" substitutes in an equal proportion all animal meats from different animal species: substituting 1% of EU meat consumption means substituting 1% of beef meat, of pork meat and poultry meat. We assume that 1% reduction of animal meat consumption leads to 1% reduction in animal production and feed consumption.

This rough calculation leads to a need of 0.570 million ha to produce 1% of the EU meat consumption. If we consider that "pea meat" production will engage 0.119 million ha, the net balance is −0.451 million ha, meaning that 100% substitution would be equivalent to 45.1 million ha, that is to say comparable to the present cereal acreage in Europe (56 Mha on 2015–2019 period, on a total arable area of 104 Mha). Of course, only a part of this land would be made free in Europe, since a large part corresponds to imported proteins as soybean or soybean meal, and imported maize (see Tab. 6), the EU being a net exporter of cereals, but a net importer of maize.

3.1.2 Producing soybean in Europe?

As shown by Guilpart *et al.* (2020), in terms of agronomy, 100% soybean self-sufficiency in Europe would be feasible even in a climate change perspective, and under the respect of basic agronomic rules (1 soybean every 3 to 6 years depending on the scenarios considered, priority choice to the best climatic zones).

Considering the present soybean yields in European Union of 2.9 t/ha (non GMO cultivars) (OilWorld, 2019/2020), 10.4 Mha would be needed to meet the needs of cattle, poultry

Table 5. EU compound feed use in million tons (from EU Agricultural outlook 2017–2030 graph 2.47).

2015/2016	Laying hens	Dairy cattle	Broilers	Beef Cattle	Pork	Total
Barley	0.6	6.4	3.9	10.6	17.0	38.5
Maize (grain)	4.5	5.2	13.6	11.5	19.4	54.2
Soy meal	0.6	3.0	8.0	7.3	7.6	26.5
Wheat	5.5	6.7	14.2	10.0	20.3	56.7
Other	7.3	19.4	12.7	13.7	24.2	77.3
Total	18.48	40.61	52.55	53.07	88.49	253.2

Table 6. Data from the EU28 Balance Sheet for protein feed 2015/2016.

Million tons	EU total use	EU origin	Imported	Sufficiency (%)
CROPS	177.8	161	16.8	91
Cereals	173.4	156.7	16.7	90
Wheat	55.5	51.3	4.2	92
Maize	57.3	47.1	10.2	82
Other cereals	60.6	58.3	2.3	96
Oilseeds	1.4	1.4	0	100
Pulses	2.9	2.9	0	100
Co-products	87.9	47.1	40.8	54
Oilseed meals	54.5	15.8	38.7	29
Soy meal	31	0.9	30.1	3
Rapeseed meal	13.5	11.4	2.1	84
Other co-products	36.6	31.5	5.1	86
Non-plant sources	8.8	8.6	0.2	98
Processed animal protein	2.2	2.1	0.1	95
Fish meal	0.5	0.4	0.1	80
Skimmed milk powder	0.2	0.2	0	100
Roughage	1266			
Grass	986			
Silage maize	227			

Table 7. EU compound feed use for meat production in million tons (from EU Agricultural outlook 2017–2030 and own calculation).

Allocation to meat	25%	15%	100%	100%	100%	
2015/2016	Laying hens	Dairy cattle	Broilers	Beef Cattle	Pork	Total
Barley	0.2	1.0	3.9	10.6	17.0	32.6
Maize (grain)	1.1	0.8	13.6	11.5	19.4	46.5
Soy meal	0.2	0.5	8.0	7.3	7.6	23.5
Wheat	1.4	1.0	14.2	10.0	20.3	46.9
Other	1.8	2.9	12.7	13.7	24.2	55.4
Total	4.62	6.09	52.55	53.07	88.49	204.8

and pork sectors (Tab. 7; 23.5 MT meal, equivalent to 29.4 MT seeds) for internal EU meat consumption, and 13 Mha would be needed −13.36 Mha including the quantities already produced in Europe – to meet the needs of all animal sector (Tab. 6).

For grain maize, 10.2 MT were imported in 2015/2016 (importations are growing) on a total need of 57.3 MT for the all animal sector (18%). The maize consumption for cattle, poultry and pork sectors only being 46.5 MT, the corresponding imported maize quantity would reach 8.28 MT, equivalent to 1.10 Mha in EU (5 years average 2015–2019 EU maize yield = 7.5 T/ha). As EU is a net exporter of other cereals, we may take into account soybean and maize only: 10.1 + 1.1 = 11.2 Mha are needed in Europe to compensate soybean and maize imports for cattle, poultry and pork meat internal consumption.

A complementary question is "what would be the substitution ratio of "pea meat" to animal meat which would allow to avoid soybean and maize imports and keep the same acreage devoted to feed production in EU?" We have estimated the total acreage devoted to feed production for cattle, poultry

Table 8. Calculation model for conversion of feed quantities in cultivated acreage in Europe.

	Value	Unit	Calculation formulas
EU compound feed consumption in 2017	204.8	Million tons	A
EU meat consumption/production ratio	0.929	%	B
Compound feed used for the production of the meat consumed in EU	190.4	Million tons	A × B
Average dry matter crop yield in Europe	5,390	t/ha	C
Acreage necessary for the compound feed production	35,321	Million ha	A × B/C*
Total fodder crops	21,700	Million ha	D
Total permanent grassland	58,200	Million ha	E
Total fodder and grassland	79,900	Million ha	D + E
Total arable land for feed + fodder	57,021	Million ha	A × B/C + D
Substituting 1% animal products on arable crops acreage	−0.570	Million ha	(A × B/C + D) × 0.01
Acreage necessary for "pea meat" (pea + canola) to substitute 1%	0.119	Million ha	F**
Difference of land occupation if 1% substitution	−0.451	Million ha	(A × B/C + D) × 0.01 + F
1% applied on permanent grassland	−0.582	Million ha	E × 0.01

Sources: A: Table 7, based on EU Balance sheet for protein and EU Agricultural outlook 2019; B: sum all kinds of meat; Tables 9.27 to 9.30 of EU Agricultural Outlook for the Agricultural markets ad income 2017–2030. EU Commission 2017; C: Eurostat, 5 years average 2015–2020 of cereals and oil seeds, weighted by acreages; source EU agricultural outlook 2019; *: fodder crops not considered; D: EU Agricultural outlook 2017–2030 for 2017; E: EU Agricultural outlook 2017–2030 for 2017; ** (Tab. 3)

and pork at 57.02 Mha (So) (Tab. 8) as EU acreage equivalent, of which 11.2(Si) correspond to soybean and maize imports. The real mobilized area in Europe is in fact Sm = 57.02–11.2 = 45.82 Mha European crops (E).

So the initial situation is So = Sm + Si.

If R is the reduction ratio of meat consumption, the future situation, keeping the same acreage (which will be used to produce feed and ingredients for "pea meat"), would be:

$$Sm = So - R \times So + R \times Si.$$

Giving R = (So − Sm)/(So-Si) = Si/Sm = 0.244, or a substitution of 24.4% of meat by "pea meat".

The reduction in "EU acreage equivalent" is Sm/So = 19.6%

We may calculate the reduction ratio of meat consumption in a different maner: we know that 1% reduction in meat consumption allows to spare 0.451 Mha as European acreage equivalent (Tab. 8). To spare 11.2 Mha, the reduction in meat consumption will reach 24.8% (11.2/0.451 = 24.8)

This result is nearly the same with the precision of the calculation.

Meaning that the substitution of about 25% of the meat consumption by "pea meat" would allow to provide the protein food equivalent with no extension of cultivated acreage in Europe and a cancellation of soybean and maize imports for feed.

We observe that these calculations are neutral regarding the EU exports of animal products, since only EU meat consumption is considered.

3.1.3 Focus on imported deforestation and land use

Instead of converting feed needs into European acreages on the basis of European yields, we can now focus on the case of imported ingredients for feed, whose the EU feed protein balance sheet gives an overview (Tab. 6)

Regarding potential deforestation, if we consider direct effects only, the attention should focus on Brazil whose production capacities in extension permit to follow a growing demand in commodities. Soybean meal is the most concerned commodity with a self-sufficiency ratio of only 3%, and at a lesser extent maize (EU imports between 13 to 17 MT/year from 2015 to 2020, almost 60% from Brazil in 2020). EU imported in 2015/2016 30.2 MT soybean meal for feed. Considering that soybean contains 18 to 20% oil, and including industrial losses, it corresponds to around 37.8 MT soybeans. According to OilWorld statistics (OilWorld, 2020), the average soybean in Brazil reaches 3.21 t/ha on the 5 years period 2014–2019. The land acreage needed to provide the soybean meal imported by the EU animal husbandry ranges by 11.8 million ha every year. According to the European Soy Monitor report (IDH and IUCN NL, 2019), only 13% of the soybean imported in EU in 2017 was guaranteed as deforestation free (and 22% compliant with FEFAC soy sourcing guidelines). This figure was only 6% for France in 2017; it would reach 20 to 25% in 2020–2021 according to Duralim platform.

The total soybean acreage in Brazil was 34.371 million ha on the same period, meaning that EU feed sector absorbs the equivalent of one third (34.2%) of the Brazilian soybean production and acreage (or 11.2% of the world soybean production).

A part of the imported maize should also be taken into account.

4 Discussion

4.1 EU feed consumption and land use

Concerning pea and rapeseed crops, the basic calculation shows that the development of "pea meat" could induce a significant enhancement of rapeseed oil use in food industry, the impact being limited considering the total land use in EU, but much more significant relatively to the size of the rapeseed oil sector itself (0.512 Mha in the 12.5% scenario, up to 4 Mha in the 100% scenario, compared to 6.749 Mha in EU28 in 2017 for a production of 21.9 MT; acreages and production decreased since then, mainly due to weather). Synergies between the two pea and rapeseed crops could be developed on both economic and agronomical aspects. For example, previous projects demonstrated that the nitrogen fertilization for a rapeseed crop following peas may be lowered, inducing a better carbon balance and sustainability for rapeseed itself (Véricel *et al.*, 2018)

Less than 12% of the EU 28 arable land would be needed in case of total substitution, meaning that "pea meat" can be easily absorbed in terms of production capacities. It varies from 9.5% to 14.4% in case of pea and rapeseed yields variations of ±20% (and consequently of protein and oil yields).

This result reflects also the choice of the "pea-meat" model, using pea and rapeseed: other ingredients could be chosen, offering tracks to optimization. If we consider the main component only (pea), variations in protein yield of the different crop sources would give rough estimates of incidence: when pea protein yield ranges by 0.79 t protein/ha, soybean reaches 0.93, faba bean 0.98, when lupin yields only 0.55 t protein/ha, lentils 0.38, rapeseed 0.69 and sunflower 0.36 (FAO sources reported in Pilorgé and Muel, 2016), meaning a variation on protein yield of approximately −50% to +25% compared to pea reference. Pea may be considered as a medium case, and acreage optimization would be possible with soybean and faba bean, also traditionally used for food. Lentils would necessitate more acreage but are traditionally consumed without transformation (and inherent losses).

We assumed that 1% reduction of animal meat consumption leads to 1% reduction in animal production and feed consumption, which could be a matter of discussion for further scenarios: the economical competition could lead to abandon firstly the less efficient animal production, whose consumption ratios may be higher (specially true for pork and poultry), or, at the contrary in case of meat reduction, the consumer might favor the highest quality of meat for the rest of their consumption, which may lead to less intensive production conditions and to a non-proportional decrease of feed consumption.

When assuming that 1% reduction applies indifferently to all kinds of meats, beef, pork and poultry, we also implicitly accept a reduction of meat from dairy cows, which can be estimated at about 10% of the total beef meat production in EU28 (7892 KT total beef production) and less than 2% of the total EU meat production, all types of meat included. Nevertheless, reducing dairy meat by 1% would lead to reduce dairy products in the same proportion and that could be compensated by other sources of proteins and fats, except if the cow life duration is extended proportionally (to produce more milk with the same animal). Due to the relatively intensive dairy production in Europe with relatively short dairy cows life, this lever could be used if meat reduction remains limited, probably until 10% at least. For greater reductions solutions should be found to compensate a drop in dairy production, mobilizing some acreage: our calculation tends to underestimate the acreage necessary to compensate the diminution of meat consumption.

So far we did not comment the reduction of permanent grassland linked to meat substitution, which in fact could reach similar values to arable crops acreage reduction if we apply a 1% reduction: it must be considered cautiously since these lands are often not proper to cultivation. The alternatives to grazing or hay production might be ecological succession and finally forest in many cases, as often observed. The real interest for carbon storage and biodiversity should be assessed, depending on management policies. If desired for biodiverisity reasons, preserving grassland could also be achieved by using the grass in biogas based energy production thereby reducing methane emissions from ruminants.

The 100% meat substitution scenario is not to be expected in future due to a partial but structural interdependence between arable crops sector and industries and animal husbandry sector: beyond being a major customer of arable crops commodities, the animal husbandry sector is also a user of many co-products/by-products of food or bio-energies industries which are not further processed for direct human consumption today. The immediate example is in "pea meat" itself: if the direct consumption of grain legumes does not generate co-products, the pea protein extraction starting from peas with 24% generates around 3 tons of co-product (pea starch and pea solubles) for 1 ton of pea protein isolate 85%. These co-products, already identified but not characterized on the online database Feedipedia (https://www.feedipedia.org) will probably find an outlet in feed industries in the short to medium term whereas in the medium to long term human food alternatives might be developed. Using organic resources not edible by humans, like co-products and fodders, is a traditional role of animal husbandry and contributes to the general balance of agricultural systems.

At last, our calculations did not consider the nutritional aspects to reach well balanced diets, which would be also a limit for the highest substitution rates of vegetable products to animal and would need a significant rebalancing of the diet to meet the requirements in specific nutrients like essential amino-acids and fatty acids. Specific studies like TYFA (Poux and Aubert, 2018, and ongoing works) have focused on the coherence between diets and agricultural production systems, which is a strategic field of investigation.

4.2 Producing soybean in Europe and ways to reduce dependency to imports

We show that the substitution of about 25% of the meat consumption by "pea meat" would allow to provide the protein food equivalent with no extension of cultivated acreage in Europe and a cancellation of soybean and maize imports for feed. This ratio gives a rough estimate of the efforts on food habits with respect to meat consumption to achieve if we wish to reduce imported deforestation without extending the cultivated acreage in Europe. It corresponds to a significant effort (for example 3 to 4 meals per week without meat), but not totally unrealistic if we compare the meat consumption in EU, 68.6 kg/capita in 2017, (to the FAO statistics (OECD/FAO Outlook 2020–2029, as retail weight) for the 2017–2019 data: 34.5 kg/capita at world level, 26.6 in developing countries and 69.3 in OECD countries. The R ratio of 0.25 would lead to 51.5 kg/capita, still 49% above the world average.

Other solutions than soybean production in Europe are also possible to meet the protein needs of animal husbandry in Europe, for example by using wheat and pea as main feed components instead of maize and soybean, better exploiting the diversity of fodder legumes crops or developing grass production in the case of ruminants. Better exploiting the specificities of European regions with the most adapted solutions to both production conditions and consumption patterns is the real challenge, far beyond our simple figures, and need specific studies, notably on feed systems.

A reduction of more than 25% in meat consumption would lead to a net release of arable land for feeding the European population, which may lead to social and economical consequences for the concerned territories: abandonment of the less fertile lands, planting forests for wood industry or carbon storage, production of biomass for energy or non food uses, or going on with agricultural production for food exports are options that are options that go beyond the agricultural sector alone and involve territorial strategies.

4.3 Imported deforestation

Meat is often criticized on two interconnected drawbacks: imported deforestation due to vegetable protein imports, mainly as soybean meal from Brazil, or in other terms the "carbon opportunity cost" (COC) (*cf.* Hayek *et al.*, 2021), and direct green house gas emissions of the animal production itself, including feed production. We show that the land acreage needed to provide the soybean meal imported by the EU animal husbandry ranges by 11.8 million ha every year in Brazil. According to the European Soy Monitor report (IDH and IUCN NL, 2019), only 13% of the soybean imported in EU in 2017 was guaranteed as deforestation free (and 22% compliant with FEFAC soy sourcing guidelines). This figure was only 6% for France in 2017; it would reach 20 to 25% in 2020–2021 according to Duralim platform. The development of monitoring imported deforestation is an encouraging evolution for Europe, but will hardly reverse the trend at global scale: Europe is becoming a secondary soybean importer, now far behind China.

5 Conclusions

A total substitution of meat consumption in EU by plant-based substitutes would mobilize around 12% of the EU arable land for "pea meat" production, and that a substitution of 25% of meat consumption would allow to provide the equivalent of food proteins without extending the cultivated areas in Europe, while avoiding soybean and maize imports for feed at the same time.

The Beyond Meat patty must be considered as a case study to evaluate the impacts of meat substitution by vegetable protein food, notably on land use in Europe and abroad, and on the potential synergies between grain legumes and oil crops productions. The direct consumption of grain legumes, as traditionally practiced in many countries, especially in Mediterranean region, is also an alternative which associates significant amounts of grain legumes and unsaturated oils. The impacts of direct consumption of grain legumes are probably similar: most grain legumes are even richer in proteins than the Beyond "pea meat" (18%).

The relative simplicity of our calculations must not hide the complexity of the substitution of animal meat by vegetable proteins: food systems are made of the interconnected subsystems of the food supply chains under the influence of different drivers like technologies, policies, demography, and socio-cultural aspects as shown in the diagram by Fanzo *et al.* (2020), where inertia, interdependency and feed-back interactions are numerous. The 100% substitution scenario is not to be expected in the near future due to a partial but structural interdependence between arable crops sector and industries and animal husbandry sector. Today, feed represents 58% of the cereal consumption in EU, and 52 to 57% of the production on 2015–2019 period; oilseeds production is also linked to feed outlets for the valorization of the meals (around 60% of the tonnage for rapeseed and sunflower). In the mid to long-term perspective these meals might be increasingly utilized in human food consumption.

In fact, animal and crops values chains have strong connections from land use and agronomy to the products valorization, with both synergies and competitions for resources especially land or markets for meat, vegetable proteins, milk or soy products. Thinking transitions and co-evolutions is preferable to thinking substitutions only. Even if the excessive meat consumption in Europe is a source of disequilibrium (for example, only 2% of grain legumes in European arable acreage when 6% is observed in Canada), regarding land use and agronomy, the main problems come more from the disconnection between animal husbandry and crops, permitted by the huge amounts of vegetable protein imports as soybean meals, leading to a growing specialization of cropping systems and heavy impacts on nitrogen and nutrients cycles (Billen *et al.*, 2014) than from a real competition for local resources. Reaching sustainable food systems will need new balances between animal and vegetable consumption and production in future. Important synergies could be developed also with the oilseed sector in Europe. At last, "pea meat" and more generally vegetable proteins for food form an important lever to decrease imported deforestation and improve the sustainability of the European food system.

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