The unbalanced development among legume species regarding sustainable and healthy agrifood systems in North-America and Europe

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Running Title: Legume diversity within American and European food product innovations

Title: The unbalanced development among legume species regarding sustainable and healthy agrifood systems in North-America and Europe: focus on food product innovations.

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1. Introduction

Ever since the International Year of Pulses in 2016 (the United Nations resolution A/RES/68/231), interest in legumes has increased in western countries regarding both their environmental and nutritional properties (Iannetta et al., 2021; Cusworth et al., 2021a; Semba et al., 2021; Balàzs et al., 2021; Weindl et al., 2020; Willett et al., 2019; Rawal et al., 2019; McDermott and Wyatt 2017). Studies have focused on those advantages of an increase in legume consumption (e.g., soya, peas, chickpea, dry beans) compared to their current low consumption. For instance, Poux and Aubert (2018) suggested reaching 11 kilograms/year/person in Europe (against the average of 4 kilo/year/person) whereas Willett et al. (2019) suggested 18 kilograms/year/person for a universal healthy diet. Indeed, increasing regular legume consumption contributes to healthy diets (Abdullah et al., 2017; Havemeier et al., 2017) thanks to their numerous micronutrients, antioxidants, and bioactive substances (Dahl, 2019; Bessada et al., 2019). Legumes as an alternative protein consumption can help reduce various diet footprints, particularly regarding deforestation, nitrogen, carbon impacts, and water use (see the reviews of Semba et al., 2021 and Cusworth et al. 2021a). There is a large consensus that increasing legume consumption is essential for achieving sustainable and healthy diets.

Yet, it is challenging to favour a balanced development among the various legume crops (Text Box 1) as crop diversification is a major part of the sustainability shift in diets (e.g., Iannetta et.

al., 2021; Beillouin et al., 2021; Bezner Kerr et al., 2021; Renard and Tilman, 2019; Gliessman, 2018; Altieri and Nicholls, 2018). It is crucial to develop crop diversification, even within legumes; thereby adapting legume species to appropriate pedoclimates which will increase yields in low-input systems and improve soil quality (Weindl et al., 2020). However, a balanced development of various legumes seems compromised for the moment. Semba et al. (2021) estimated (from FAOstats) that soya remains the main legume crop cultivated for food while other pulses represent very small amounts in proportion. When analysing scholarly publications on legumes at a global scale, Magrini et al. (2019) observed that over half of these publications over the last decades have dealt with soya; even in the field of Food Sciences & Technology (FST) that could be the roots of new knowledge in developing legume foodstuffs. Sonnino (2016) and Foyer et al. (2016) also pointed out that, for many decades, legumes (other than soya) had been weakened by low agricultural R&D investment. This has impacted production development, impeding the potential creation of a significant agricultural supply on which agrifood firms could rely upon to develop processed-food products. And so, even if the proportion of soybean production directly used as food is very small (6% reported by Samba et al., 2021, that is around 21 million tons) compared to its feed use, this soya supply for food alone remains more important than the different pulse supplies (peas, beans, lentils…) for which no detailed data exist concerning their share cultivated as foods in the world. Considering several studies, Magrini et al. (2019) approximated that the cultivation of all pulses for food represent 50 million tons.

For economists, we are facing a lock-in situation. Lock-in is the term used by economists to designate a well-established system that is not changing even though alternatives can bring improvements for society (for a review on lock-in in agrifood systems, see Conti et al., 2021). In the case of legumes, Magrini et al. (2016, 2018) used this concept and its socio-economic mechanisms to explain why, despite the numerous and various benefits of legumes, their production and consumption have been in steady decline since the second half of the twentieth century in western countries. Adopting a historic retrospective since the World War II, several studies converge in explaining this decline (see also Cusworth et al., 2021a, 2021b for a synthesis). In short, trade agreements and technological paradigm choices of western countries favouring agro-chemicals used with synthetic fertilisers and a preference for supplying protein based on animal products, led to a strong specialisation in crops and huge investments were made on cereals to the detriment of other crops. The global result is that cereals (such as wheat, rice, barley, maize, rye, and oats) are now the main crops, representing four times more cultivated ground than legumes. Cereal yields have nearly tripled over the past 50 years, while legume yields only increased by ~60% (Semba et al., 2021; Foyer et al., 2016). Legume consumption per person had decreased while general food consumption had increased; protein sources have been more and more animal-based. For instance, de Boer et al. (2006) calculated that legume protein consumption in the EU-15 member states ranges from 0.1 g to 3.7 g per person per day, out of a total protein consumption between 96 g and 119 g.

But whilst legume lock-in is mainly analysed through a comparison with cereal development, we must not forget that one legume in particular, has become a major worldwide crop thanks to feed development: this is soya. As mentioned above, soyabean production represents nearly three-quarters of grain-legume production (FAOstats), thereby catching over a half of scholarly publications all science fields considered – even food science and technology (Magrini et al., 2019). Nowadays, the development of soya for food is speeding up as benefiting from a larger knowledge-base. Until now soya was dominant crop for animal feed (Hartman et al., 2011), and is becoming more and more prominent in the food system (Foyer et al., 2018).

This path-dependency has created a competitive gap that is now very difficult to close up for pulses compared to major crops, particularly in Europe (Cusworth et al., 2021b; Magrini et al., 2018). The current dietary shift towards more plant-based foods, and particularly from animal-sources to legumes, is suggested as a new avenue for pulse development (Semba et al., 2021; Cusworth et al. 2021a, 2021b). Yet, several market studies pointed out that pulses are still rarely used in such food product innovations (Bashi et al., 2019; Euvepro, 2019; Radobank, 2017). In other words, on the one hand, some enthusiasts consider that the marginal position of legumes is shifting (e.g., Considine et al., 2017 used the term of "coming of age") thanks to a vaster range of legume productivity research and food processing potentials (as reviewed by Cusworth et al., 2021a). But on the other hand, whether a real balance is respected in the development of most common legumes, to maintain (and develop) their diversity, is much less certain.

In addition, we observe that those species are confronted to similar challenges concerning their uses in various food products. Whatever the legume species, studies in food sciences and technology converge on the fact that when the level of incorporation increase by more than 10% the acceptability decreases due to appearance, texture, odor, taste that are still too modified for consumers; and whatever the type of products, and in particular in bakery and pastry products, or pasta and meat-processed products (e.g. Monnet et al., 2019; Rababah et al., 2006). Therefore, pulses and soya are both confronted to impeding factors for their development in foods. But the fact that the knowledge-base for soya is greater in food science literature (Magrini et al., 2019) suggests that food innovations with soya ingredient are facilitated compared to other pulses; and as also suggested from some market studies (mentioned above) which retrieved more food product innovations with soya than with all other pulses.

According to innovation theories, tackling this question on a balanced development of legumes remains complex. On the one hand, we consider that the few firms investigating new products with those species constitute the roots of their development; and only a few new products would be sufficient to start a transition as only certain people are more open to adjusting to new food products (the early adopters) and then others will follow, progressively also start adopting more legumes to their diets (see the innovation adoption curve of Rogers, 2003). Hence, the current supply of food with pulses is under developed, probably contributing to their low consumption (Magrini et al., 2018; Schneider, 2002), and equally reinforced by an old-fashioned image and low consumption habits (Cusworth et al., 2021a; Jallinoja et al., 2016; Melendrez-Ruiz et al., 2019). Food production innovations could reverse this situation by creating a new and attractive foodstuff supply that would initiate a chain of events. On the other hand, we consider that this approach will not be sufficient for promoting legume-based products; for instance, institutional communication and nutritional education are also required to encourage their consumption, and their cultivation as the supply and demand of agricultural products are closely correlated (*"The diversity of marketing and processing opportunities manifest in legumes represent important macro-level shifts that stand to increase the economic viability of legume cropping for human consumption markets"* in Cusworth et al., 2021b:132).

In spite of this debate, no study currently explains how legumes are developing on food markets and what legume crop diversification could be associated to marketed food products in order to define sound policies for a sustainable development of food legumes in western countries. This situation needs to be better assessed and our objective is to measure this food market biodiversity concerning legumes through data information from markets. We began tackling this problem by using Mintel Global-New-Products-Database (GNPD)[1] which tracks food

[1] https://www.mintel.com/global-new-products-database

product innovations, considered as all new products launched on the market, in over 80 countries. Mintel-GNPD with more than 3,600,000 registered products, is currently the only database that has such a global coverage[2], with detailed information at product level (Solis, 2016), allowing us to focus on North America and Europe markets considered as central markets for food innovation in western countries. Based on these data, we identified around 100,000 products launched on markets between 2010-2019 which had at least one legume in their ingredients, based on soya and 14 pulses species (Text Box 1). By using those data, we evaluated food firms' interest in these various legume species through occurrence frequencies of those species in products. We also analysed the main market segments on which those food innovations were launched.

This original study, focusing on food product innovations with legumes launched on North America and Europe markets, highlights several important elements for people working in nutrition, food systems, agriculture, climate change, and food policy. In this study, we describe the types of food product innovations regarding the species used, types of innovations and market segments. Section 2 describes data and methodologies used for this analysis. Section 3 presents results. Section 4 discusses insights provided.

Text Box 1. Legume diversity in sustainable agrifood systems

Legumes are edible seeds of the Leguminosae family, the second largest family of seed plants comprising 600 genera and ~13,000 species (Foyer et al., 2016; Zohary et al., 2012). Legumes can be cultivated in a wide range of temperatures and altitudes, from cool temperate regions to the humid tropics. Some legumes are more tolerant to drought and/or poorer soils (Semba et al., 2021; Magrini et al., 2019). Worldwide, a distinction has been introduced regarding food uses of legumes rich in oil (such as soybean or peanut) and pulses with other dry seeds. This nomenclature provokes debates (Vollman, 2016); but adopting such distinctions highlights the unbalanced crop production of soya and pulses.

We refer to the recent review on legumes in diets by Semba et al. (2021), and the presentation of the most acknowledged genus and species in legume families by Foyer et al. (2016) for a more detailed description of those species. Combining those references, our analysis considered 15 main acknowledged legume species to measure their frequencies in recent food product innovations on markets. The following list of legumes considered shows in parentheses the most commonly-used English name associated with the scientific name: *Cicer arietinum* (chickpea); *Glycine max* (soya); *Cajanus cajan* (pigeon pea); *Lathyrus sativus* (grass pea); *Lens culinaris* (lentil); *Lupinus angustifolius* (lupine); *Phaseolus coccineus* (black bean, butter bean); *Phaseolus lunatus* (lima bean); *Phaseolus vulgaris* (dry bean); *Pisum sativum* (dry pea); *Vicia faba* (fava bean, faba bean, broad bean); *Vigna angularis* (adzuki bean); *Vigna mungo* (black gram); *Vigna radiata* (mung bean); *Vigna unguiculata* (cowpea). Note that the species *Vigna subterranean* (bambarra bean) and *Phaseolus acutifolius* (tepary bean) mentioned by Foyer et al. (2016) having no matches in the data used for our study (Mintel data hereafter, Section 2) are consequently not considered.

2. Data and Methods

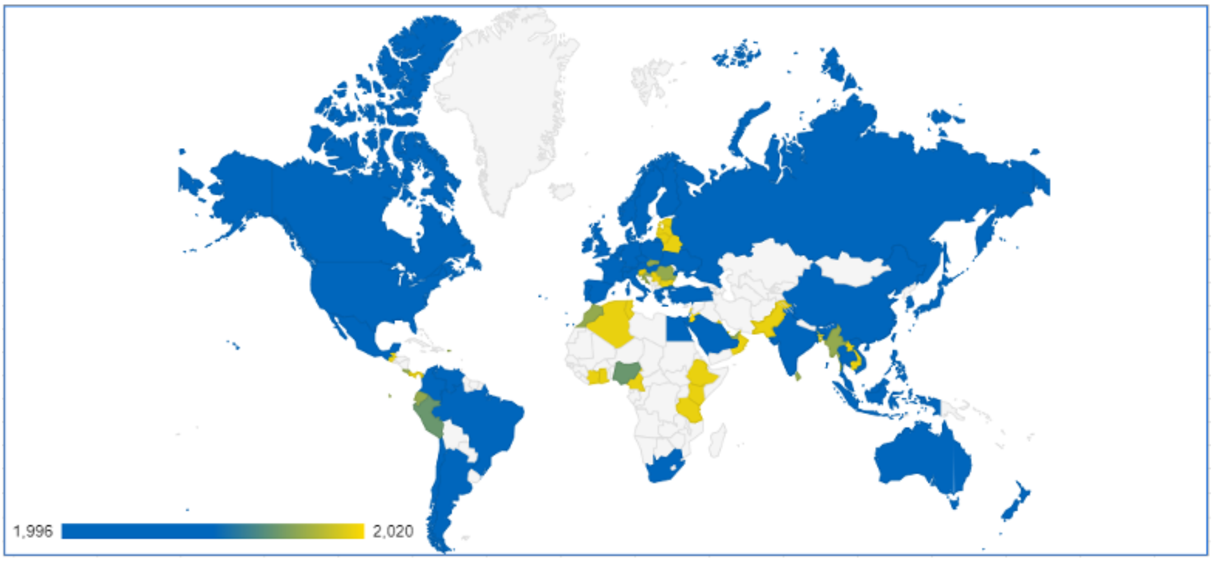
2.1 The food product innovation database used

[2] By comparison, the OpenFoodFacts database currently lists more than 1,800,000 products, and the USDA branded food database lists more than 1,100,000 products.

Mintel's GNPD (Text Box 2) is a data base in which food product innovations launched into a considered market are assigned into one of the five different categories: new product, new variety/range extension, new packaging, new formulation, and relaunch. Generally speaking, a new product refers to a product that is completely new to the firm introducing it, that is to say, the firm is positioning a new family of products (OECD and Eurostat, 2018). A new variety or range extension however refers to the development of a family of products already in place in the firm. After launching a new product or a new variety/range extension, if sales are not satisfactory, firms might adopt strategies involving new formulations, new packaging or relaunching the product. Each market's brand activity is treated independently, so if a range of products exists in the USA, any brand activity in another country is treated independently. Mintel staff (called 'shoppers') assigned a unique category of launch type, checked by the Mintel team (see Table 1 in Supplementary Materials for more details). We kept all those types of product innovations that constitute the new foodstuffs supply on western markets.

Text Box 2. The Mintel Global-New-Product-Database on foods and drinks

Mintel is a private company that collects data on all types of food innovations according to standardised and rigorous protocols involving a global network of expert shoppers across 86 countries in 2020. Most countries have been covered over the last decade as shown on the map here-below. New launches are added daily and the number of shoppers employed by Mintel regularly increases overtime, leading to a better coverage inside each country and through new countries included. Various channels are investigated: from supermarkets to specialised shops and various secondary sources of information are mobilised (trade shows, websites, press…). Even though these longitudinal data must be analysed with caution as each country's coverage is not exactly the same, they do show general trends on a global scale and at regions level worldwide.



Coverage country map by MINTEL shoppers from 1996 to 2020 (source: personal communication from Mintel).

Mintel-GNPD data contain over 80 information fields for each new product retrieved based on information printed on packaging (such as the company trading the product) and reported in their database. For our analysis we have focused on product subcategories and developed specific language processing methods to filter data and identify the various legume species used in these products.

2.2 Species identification in food products

When we retrieved data from MINTEL, there was no species category from Mintel GNPD for directly retrieving a dataset of food products containing pulses or soya. We then used queries to search products that Mintel linked to common terms on legume species in all Food and Drink product categories (except alcoholic beverages and mineral or source waters) and concerning launches from January 1st, 2010 to December 31st, 2019. The Figure 1 sums up the building of the datasets and hereafter explained.

Using the data search tool of Mintel, we firstly built two datasets on the worldwide area: one with 58,649 product innovations containing pulse species (caught up by key-terms like pea, bean, lentil, chickpea)[3] and another one with 243,827 product innovations containing soya. Secondly, each product in the Mintel database having a unique identifier, we matched the two datasets built and identified almost 29,000 products were common, ie. containing both pulses and soya.

Based on these datasets we applied text-mining filters to keep only products launched in North America (USA, Canada) and Europe (108,894 products retained, and among them around 12,000 have both soya and pulses ingredients). We then checked occurrence frequencies for soya and the 14 pulses species we selected (Text Box 1) in the ingredients data of those products. However, those species present several common names which increases synonymy, and consequently the risk of over or under representation of the diversity of species used. Moreover, we were confronted with methodological problems as there is no program that automatically decomposes products' ingredients lists. Therefore, we chose to match any expressions in the ingredients list referring to legumes through those key-terms: soy, pea, bean and the familiar names of the species we studied (Text Box 1). Then we identified 2,500 distinct expressions from which we built a species glossary indexing each legume expression with its scientific name, checked in the "Catalogue of Life"[4]. An extraction of this glossary is provided in the Supplementary Materials (Table 2). With this indexation we were able to detect 'fresh pulses' and around 500 'false friends' from which products were wrongly indexed in Mintel's database. For instance, the terms "lentil" or "lens" were sometimes associated in expressions that do not refer to *Lens Culinaris* species but to a specific process applied to other pulses such as "yellow split lentils"; a process applied to chickpea seeds that consists of dehulling and splitting them in order to obtain something similar to a lentil. Or another frequent case concerns the term "bean" associated with other species such as the expressions 'coffee bean' or 'cocoa bean' which were retrieved by the Mintel search request. This first methodological investigation suggests that delineation of data in Mintel GNPD according to their filters, contains a significant number of ambiguities, therefore it is advisable to pay careful attention when using those data without post data processing. Finally, a total of 750 expressions related to soya were identified and 1,500 expressions related to pulses species; those remaining concern "fresh pulses" use, other pulses or generic terms leading to undetermined legume species. We used this glossary to index all the products of our datasets. From this first indexation, we delineated a dataset of 107,266 products containing pulses ingredients and/or soya ingredients. Another delineation was created for the objectives of our analysis by excluding products with just one soya

[3] By comparison, when searching for new products containing cereals and not pulses in Mintel database, we retrieved 173,000 food products launched in the same period; nearly 10 times more. This simple result indicates how cereals are more present in foods compared to pulses.

[4] https://www.catalogueoflife.org

ingredient, that being soya lecithin; a well-known additive and minor ingredient that we excluded from our analysis[5]: 622 products were excluded.

Hence, the statistical results (Section 3) are presented from the two types of dataset built: (i) including products having both soya and pulses ingredients (12, 088 products), (ii) or by considering separately products with only soya and no pulse ingredients (80,290) and those with only pulse and no soya ingredients (14,266); all having been launched in North America and Europe over the last decade.

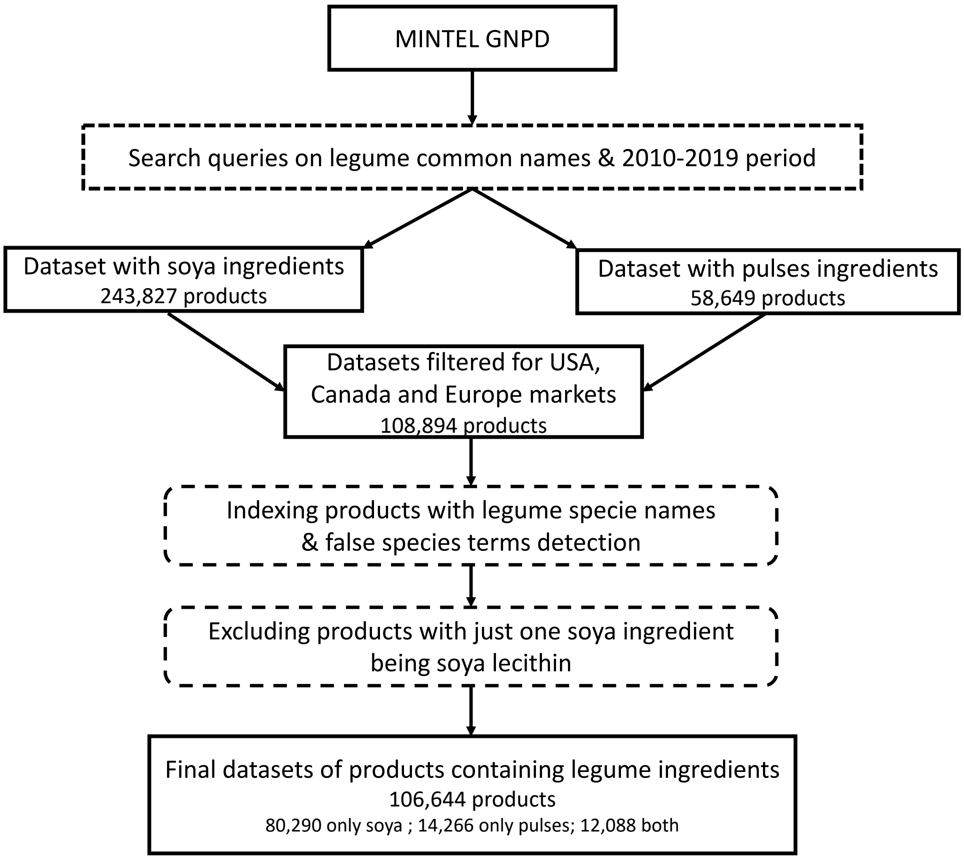


Fig. 1. The datasets building of food product innovations containing legume species

2.3 The market segmentation of food product innovations

Food product innovations concern a large variety of market segments according to their main uses and functionalities. We considered 12 main categories to identify various or common positions between species: 'Baby food and toddlers', 'Bakery', 'Breakfast products', 'Dairy products', 'Desserts (frozen and chilled), Ice creams and sweets', 'Drinks and soups', 'Fruit and vegetables', 'Meals and side dishes', 'Processed fish, meat, egg products', 'Snacks', 'Spreads', 'Sauces and seasonings' (see Table 3 in Supplementary Materials for more information on the types of products belonging to each category). The extent of investigation

[5] We found no studies explaining decision rules regarding the classification of ingredients according to the statement 'minor ingredient'. But as soya is much more developed than pulses regarding various technico-functional ingredients, in particular regarding additive ingredients, we decided to exclude the most frequent one which is soya lecithin. There is no official list of additives based on pulses.

into the different segment markets is a good indicator as to the extent the species in question is undergoing development.

3. Results

3.1 Type of food product innovations and top companies

When considering pulse and soya datasets separately, and at a global scale, we observed that product innovations with soya represent almost six times more than pulses. Nevertheless, the growth rate is not similar: over the last decade, the number of food innovations has tripled for those products using pulses and doubled for those using soya. But over recent years, those products using pulses continued to grow while ones using soya were more stagnant and even started to slow down. Therefore, even if pulses know a renewed interest, the food uses of legumes by firms remain largely on soya uses.

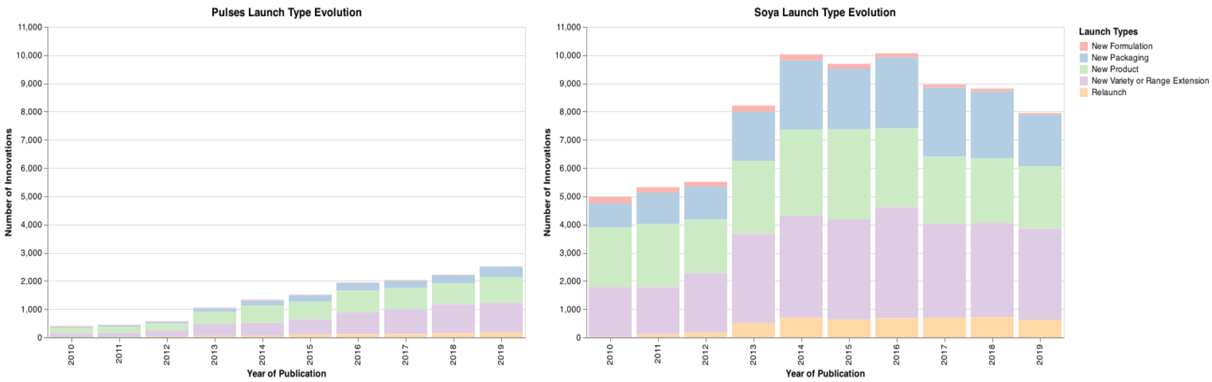


Fig. 2. Frequency of food product innovation types containing pulses and soya on a global scale 2010-2019

Range/extension innovations are more numerous (Figure 2). This could mean that more and more incumbent firms are investigating legumes, as extension of product families concerns more those kinds of firms. Consumer acceptance of strong innovative products (new to the market) is fairly limited, so these results confirm that most food innovations concern changes from similar products (new varieties, range extensions) or modifications of existing products (repackaging, relaunching).

When looking at North America and Europe, pulse innovations occurred more and more in Europe and less so in North America (Figure 3). Moreover, soya innovations have been decreasing in Europe over the past years when compared with pulse expansion. Nevertheless, over the last three years product innovations in Europe with soya are still twice those with pulses. In North America, evolution in both pulses and soya foods have been stagnating since 2014. While Canada is known to be the top exporter of pulse crops in the world, the number of food innovations launched in North America was not great compared with Europe.

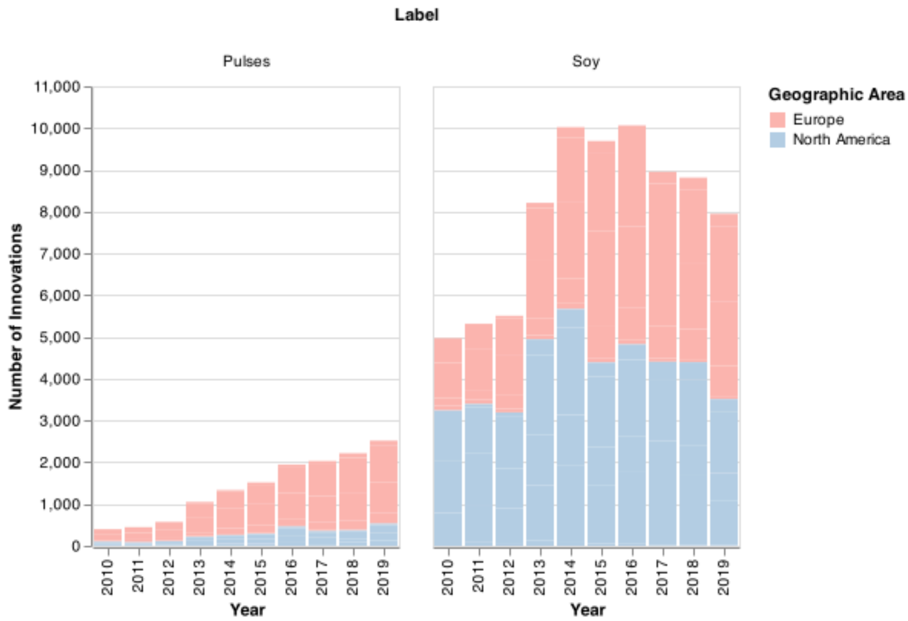


Fig. 3. Frequency of food product innovations containing pulses or soya in Europe and in North America 2010-2019

Besides we observed that the ranking of the top 10 companies launching these product innovations is different for soya or pulses (Fig. 4), some companies being also specialised in pulses (i.e., Bonduelle) or soya (i.e., Alpro). But quantitatively, even the 10th firm launching product innovations with soya launched more product innovations than the 1st firm launching product innovations with pulses over the decade.

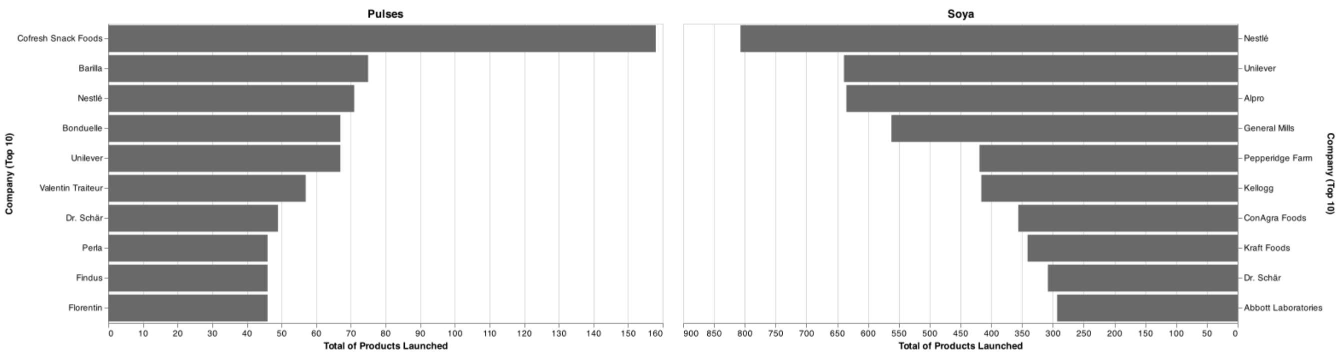


Fig.4. Top10 companies that launched food product innovations with pulses or soya ingredients over the last decade in North America or Europe.

3.2 Species diversity

When we looked at the diversity of pulses used, we observed that the top four are respectively chickpea, lentil, pea, and common bean (*Phaseolus vulgaris*) both for Europe and North America (Figure 5a). The chickpea has undergone an important increase, particularly in recent years. Other species are very little used (Table 4 in Supplementary Materials for frequencies by species). When comparing North America and Europe and excluding products with both pulse and soya ingredients (Figures 5b and 5c), we observed that the ranking of pulse species has shifted: there are less lentils than peas; we also noted that lupin is essentially used in Europe, as are faba-beans. Above all, we observed that species diversity in food products is low even though the development of chickpeas or lentils suggests progress. By confronting these results with those in scholarly publications on the FST field (Magrini et al., 2019), we observed that although the *Pisum sativum* is the pulse species most invested in R&D since many years, it is not however the top pulse species currently developed by agrifood firms.

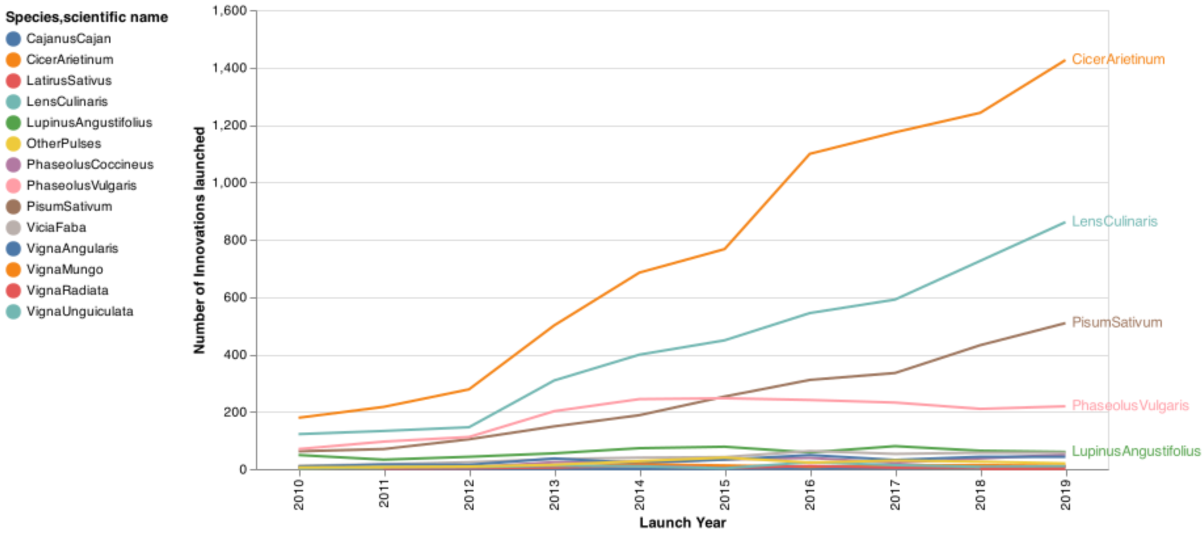


Fig. 5a. Number of main pulse species in product innovations over 2010-2019

Here products containing both pulses and soya ingredients are included.

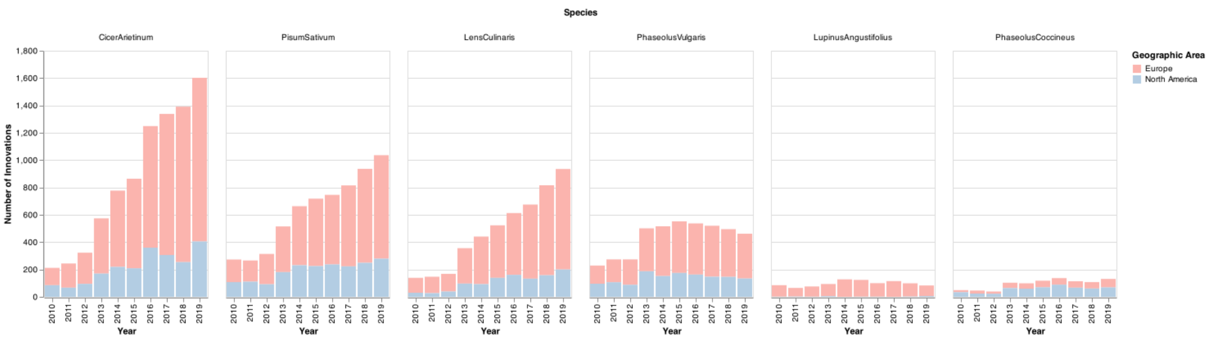


Fig. 5b. Number of the 6 main pulse species in product innovations in Europe and North America over 2010-2019.

Here, products containing both soya and pulses ingredients are excluded.

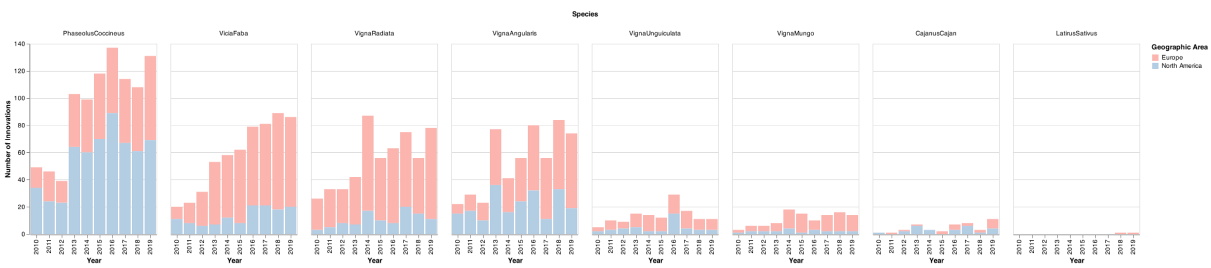


Fig. 5c. Number of the 8 pulse species less used in product innovations in Europe and North America over 2010-2019

Here, products containing both soya and pulses ingredients are excluded.

3.3. Food categories

Food markets are not invested in the same way for pulses and for soya (Fig. 6a, 6b, 6c). For soya the top four markets are: bakery, snacks, meal sides and dishes, and processed animal products (tofu being in this category). For pulses the top four are: meal sides and dishes, snacks, spreads (with a strong expansion of chickpea-based spreads like hummus), fruit, and vegetables (mostly canned pulses). Bakery is also invested for pulses but much less than for soya. There is much more investment in the animal processing products and meat-substitutes market for soya than for pulses, but this market has been rising significantly over the past years also for pulses (Fig. 6b). There is barely any investment for desserts and dairy products for pulses, and this situation remains stagnant for soya. Concerning the market for snacks (an expanding market), soya holds a stronger position, but pulses have definitely been on the rise the past few years. All in all, those results confirm that foodstuffs with soya are more developed and are applied to numerous foodstuffs (Rizzo and Baroni, 2018) compared to pulses.

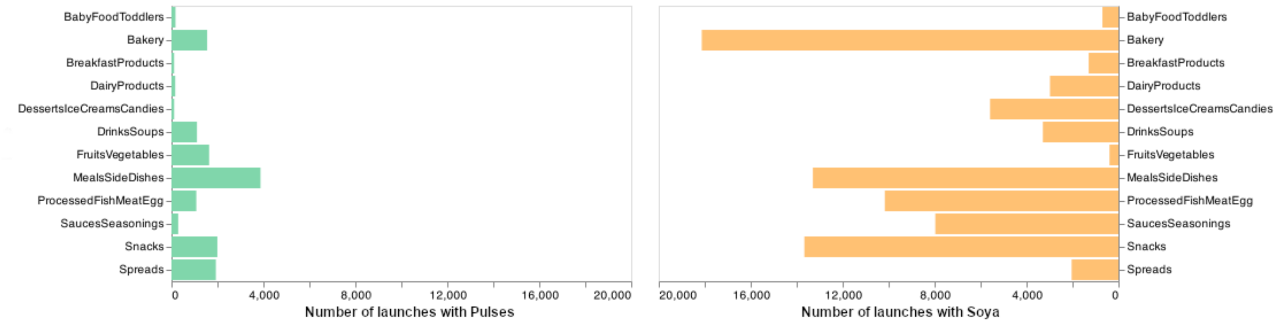


Fig. 6a. Number of product innovations by food categories for pulses and soya 2010-2019 in Europe and North America

Here, products containing both soya and pulses ingredients are excluded.

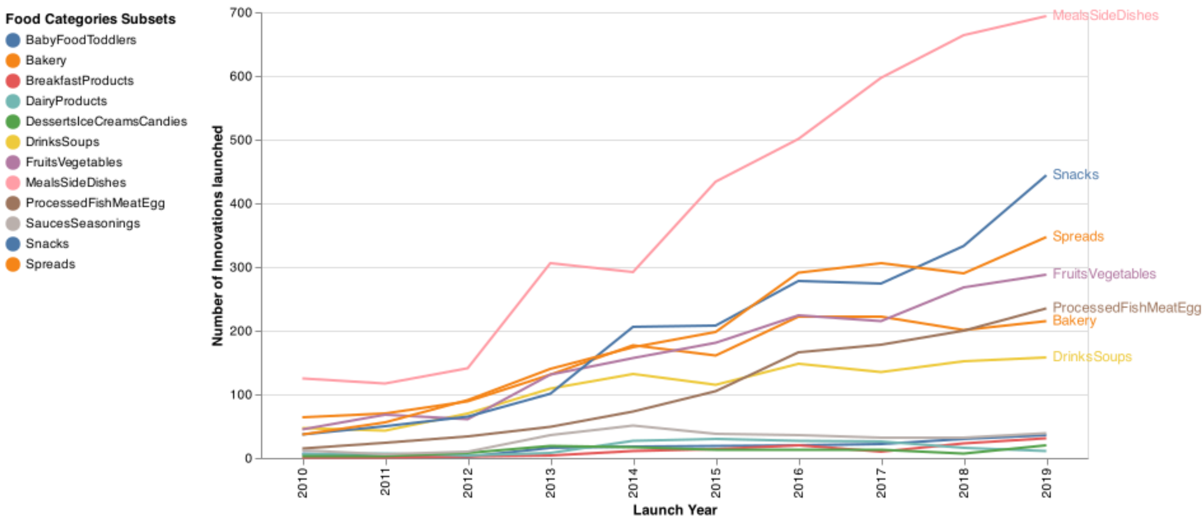


Fig. 6b. Time evolution of product innovations by food categories for pulses 2010-2019 in Europe and North America.

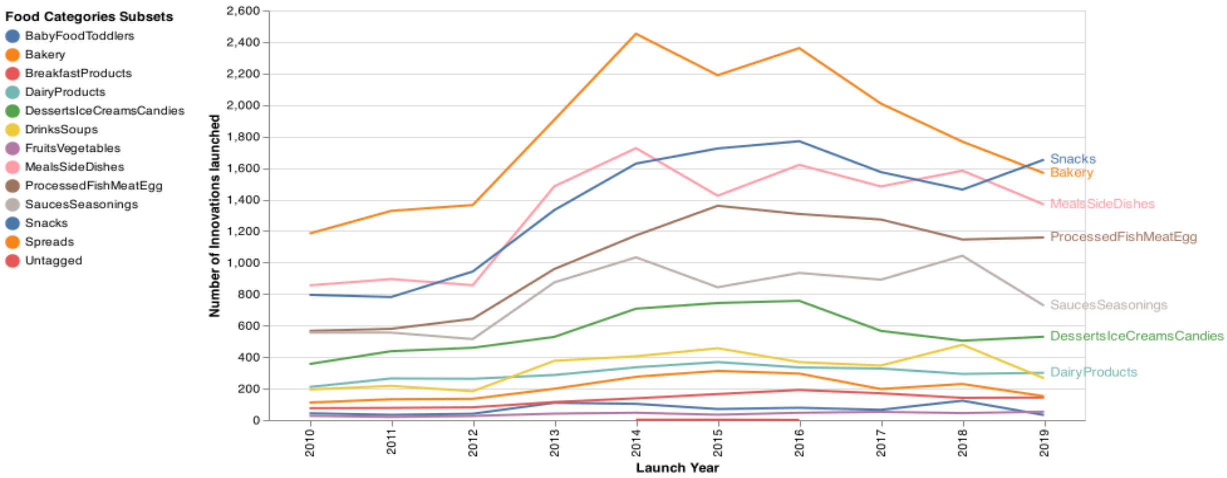


Fig. 6c. Time evolution of product innovations by food categories for soya 2010-2019 in Europe and North America.

4. Discussion

This study offers a broad overview on the current development of food product innovations with pulses compared to those with soya, comparing two main global markets: North America and Europe. Compared to the few market studies existing restricted to smaller geographical delineation and market segments, our investigation provides interesting insights discussed in the following sections.

4.1 Unbalanced development between soya and pulses calls for new science and innovation policies for food

We need to analyse how product innovations using legume ingredients are progressing on the market in order to define sound science and innovation policies in a view to sustainable developments of legumes for food (Semba et al., 2021). Our study reveals that there are many more food product innovations with soya than with any other pulses, confirming a strong path-dependency on markets even for food outlets. Crops that have always been subject to the most development in the past, continue to be so in the agrifood sector as they benefit from cumulated investment and knowledge. For example, outlets can potentially play a part in developing pulses as alternative protein markets, however even there, soya is clearly omnipresent. Even though we observed a slight decrease in soya food product innovations over the past years while pulses are still on the increase, these results suggest that soya is already established as the main legume crop for food, and as some studies suggested it (e.g. Foyer et al., 2018). From an economist point of view, firms lack the incentive to address such innovations with pulses. These crops have been under-developed and under-consumed in the past, so including them in innovations will be risky and will likely require major changes in firms' knowledge, skills and procedures. This challenge is all the more significant in the food sector where strong conservative attitudes prevail (Triguero, 2013; Galizzi and Venturini, 2012). Dijksterhuis (2016) also pointed out that most research programs of agrifood firms are *"running with a narrow window of minimal improvements to the existing ranges, rather than focusing on step change innovation"*.

Hence, to sustain balanced development for different legumes on food markets, public policies could develop more investment in sciences and innovation policies for pulses, particularly in the FST field. It is likely this investment would meet a strong leverage effect in Europe, as compared with North America, Europe benefits much more from product launches with pulses. The strong difference between these two western regions could be explained by the fact that soy consumption is already well implanted in North America, much more so than in Europe; therefore, firms are now looking to invest in pulses in Europe. Nevertheless, without public R&D support on pulses for food, achieving an equal level of development with soya is unlikely given the fact that the current more numerous innovations and market segments invested for soya reinforce soya knowledge-base in foods.

4.2 Developing such analyses reduces information asymmetries between firms competing on markets to stimulate innovation

This global analysis also helps to detect new developments on markets or alternative products that could meet consumer expectations, and firms looking for such information in order to reinforce their positions on the market. On the one hand, such analyses require expensive subscription data and methodological data-mining skills that small and medium firms cannot manage in the same way as major firms. On the other hand, existing market analyses on that subject are rare and costly, and more importantly they are not based on any particular strict methodologies to delineate the different pulse species as we did. This analysis highlights that agrifood firms are investigating many different market opportunities. But according to the segment market analysis, not all species currently benefit from the same depth of investigation within the agrifood sector, which opens the door to plenty of new food innovation possibilities for pulses that would consequently make them stand out in the market, fostering legumes in cropping systems

4.3 Research directions

This study aimed to identify agrifood firms' interest in how various legumes are used in products launched on the market. Beyond this specific case of legumes, this investigation also opens a research agenda on improving understanding food supply and demand on markets.

Our initial challenge is to improve our understanding of biodiversity on the food market regarding how various species are used in foods. We consider that analysing the presence of pulse ingredients in food products launched on the market is a way to reveal how agrifood firms give interest to pulses. This analysis required to develop links between plant thesauri and databases on food products such as Mintel-GNPD; and now to go further in parsing techniques from computing for implementing automatic processing and analysing deeply ingredient lists from packaging, so that products can be automatically indexed with species. Through parsing techniques this analysis could be improved in order to gain in efficiency and depth (Salord et al. *forthcoming)*. In particular, we can add a deeper analysis of the type of ingredients for distinguishing whole-grain uses, more refined ingredients and fractions (such as protein, fibre, starch ones) by mobilizing thesaurus on food processing like, for instance, the National Agricultural Library Thesaurus[6]. A systematic analysis of ingredients will reveal how food supply evolves regarding processing and formulation that are under many debates (Sadler et al., 2021)[7]. Detailed ingredient descriptions in a common ingredient thesaurus will contribute to clarify this debate and favour international comparisons on foods, informing how they can fit into sustainable diets. The study of Gilham et al. (2018: 8) with Mintel data for the Australian market suggested that most food innovations with pulses would not be significant for developing healthy habits as "*Most of the new products currently released onto the Australian*

[6] http://agroportal.lirmm.fr/ontologies/NALT/?p=classes&conceptid=root [accessed the 6th January 2021]

[7] By looking at the ingredient expressions associated to species we observed that high-processed ingredients such as protein isolates or other protein fractions concern essentially soya and pea. This suggests that two main technological paradigms could separate ways of development of food legumes. But further investigations are required to classify products according to the processing profile of legume ingredients.

market which contain vegetable and legume ingredients do not provide meaningful amounts of these ingredients, and tend to be highly processed and unhealthier options". According to the type and quantity of ingredients used by firms, science and innovations policies could also be adjusted to foster the development of sustainable and healthy legume supply. Therefore, beyond the measure of species biodiversity through marketed products, the current challenge is to evaluate the contribution of products to a nutritious and healthy supply according to the types of ingredient and formulation used.

Second, there could be further analyses regarding the main ways in which legumes are marketed as foodstuffs and which spaces they occupy in the general food landscape. The analysis of 'promising narratives' in food literature (both scientific and related to media) by Cusworth et al. (2021a:7) highlights two main pathways of development: *"They [legumes] can be the staples of the eco-pessimist who would prefer the revitalisation of unprocessed, traditional and whole foods to help minimise the negative environmental externalities of food production. They also serve as the fungible base materials for high-tech food processors who aim to produce convincing meat-simulacra to displace unsustainable meat and dairy products without fundamentally changing culinary practices."* Our study tends to indicate that for the moment the second pathway does not generally concern pulses; one reason being that meat-substitutes using pulses is still under-developed compared to soya. But again, only sophisticated techniques for analysing ingredient types could help answer those questions.

Third, additional information from Mintel data could be used, since any information found on packaging is available, such as claims on how products were marketed. Combining this with an analysis of ingredient lists will provide a better assessment concerning the 'reality' of sustainable and healthy claims. In addition, geographical information (if any) on the ingredients could help assessing links between production and consumption regarding the challenge of regional food systems development by adapting legume species to appropriate pedoclimates regions, and more largely by combining agricultural research and food research (El Bilali, 2019).

Fourth, we can also combine data on supply with demand. Further analyses on Mintel data can identify food products that attain the most sustainability goals as regards their ingredients and also the analysis of claims associated to products. But unless they are purchased by consumers and remain on the market long-term, these products are unlikely to have a significant impact on sustainability transition. Analysing real-world consumption of these products launched on the market is also essential to understand how demand is receptive or not to sustainable products, and identify the key enablers and barriers to any long-term success of these products in the marketplace. To do so, Kantar World Panel could be used: monthly purchases are declared by a panel of consumers in several countries[8]. But the ingredient list of the food products purchased are not reported in this database. Therefore, only analysis based on the "name of the product" could help to identify well-known products using legumes. Otherwise methods must be invested to match those data with others informing on the ingredient list of the products purchased (for instance, through the barcode identified in Mintel data) in order to retreive the various legume species. To our knowledge, no such study has been conducted on legume consumption from Kantar data or other data based on the purchases of consumers.

We conclude that dashboards resulting from such deep analysis, both of the supply and the demand, are essential to provide primary information on the evolution of food markets in order

[8] For US, the Nielson consumer panel could also be used https://www.library.hbs.edu/find/databases/nielsen-consumer-panel-and-retail-scanner-data [accessed the 6th january 2021].

to assess the speed of transition towards societal expectations, evaluate how demand meets supply in sustainability challenges, and conduct critical analysis on how to define sustainable products in link with agroecosystems. All these analyses will improve decision-making, in both public and private sectors, for placing agrifood production and trade on a sustainable pathway. However, to obtain such analysis, quantitative and computational methods on those data must still be developed: from data retrieval to data processing with a rising interest in automatic language processing, as much of those primary data are qualitative.

5. Conclusion

Crop diversification strongly depends on markets, and currently no study explains how crop diversity is developing among marketed food products; even less so in the case of legumes. Our study provides original insights on that subject showing that soya is becoming a major food crop for western food products while there are less food product innovations with pulses. Those results confirm a strong path-dependency process in agrifood sector that still benefits soya development. Further investigations need to be conducted to analyse which types of processed ingredients and food products are most widely used and purchased respectively, in order to assess the technological paradigms of soya and pulse development. This raises the question on how R&D could be reinforced on those species to favour knowledge transfer between species and encourage more balanced development of diversified legumes for sustainable and healthy agrifood systems. Beyond the case of legumes, those methods can be extended to measure biodiversity regarding any other species in food products.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Materials

Table 1. Launch types in Mintel's GNPD

Launch Type	Definition	Illustrative cases
New product	The product launched on the country's market by the firm corresponds to a new family of products that the firm has not traded on that market previously.	This could be a product totally new in one country but already traded in another one by the same firm. This could be a product totally new for the firm but already traded in the country by another firm.
New variety/Range Extension	The product launched is an extension of an existing range of products marketed by the firm since at least three months. Range extension is considered regarding Mintel food subcategories (Table 3).	A firm already trades in wet soups and launches a new wet soup based on a new recipe, not considered as a replacement of a former formula. However, if the same firm launches a dry soup (something it has ever previously traded), this would be considered as a new product as it comes under another subcategory of products.
New packaging	A visual change in design, mention of specific terms on the packaging or referring to a change in packaging such as 'new look', 'new packaging', 'new size', etc.	Change in the materials used for the packaging, change in design and information presentation, change in product size / proportions.
New formulation	When terms such as 'new formula', 'even better', 'tastier', 'great new taste', 'now lower in fat', 'new and improved', etc. are written on the	The name of the product is the same but extra marketing terms mentioned printed on the packaging suggest a new formulation.

	packaging; or if any secondary source information mentions such change. But Mintel team does not look at the ingredient list to check if there is a new formulation.	
Relaunch	When it is specified on the packaging, when it is known by secondary source information (trade shows, public relations, websites, press), when a product has been both repackaged and reformulated.	As the category of launch type is unique, if various types of change occurred or the product has been absent from the market for a long time, those cases are considered as relaunches.

Source: adapted by authors from Mintel Glossary 2020 and personal communication with MINTEL team.

Table 2. Illustration of the indexed legume species from legume expression in ingredient lists (authors' glossary extract).

Legume expression in ingredient list	**Legume indexation**
organic pigeon peas	*Cajanus cajan*
bengal gram flour	*Cicer arietinum*
whole chickpeas flour	*Cicer arietinum*
adzuki green beans	Fresh pulses
bruised soy	*Glycine max.*
chocolate lentils	False friends
rehydrated grass pea	*Lathyrus sativus*
beluga black lentil	*Lens culinaris*
bio lupin flour	*Lupinus angustifolius*
carob bean coating	Other pulses
black bean	*Phaseolus coccineus*
lima beans	*Phaseolus lunatus*
alubia beans	*Phaseolus vulgaris*
blue peas	*Pisum sativum*
legumes flour	*Undetermined*
broad bean	*Vicia faba*
azuki	*Vigna angularis*
urad flour	*Vigna mungo*
activated mung beans	*Vigna radiata*
asparagus bean	*Vigna unguiculata*

We retrieved all expressions associated to various terms designing legume names (all expressions associated with common terms like 'pea', 'bean', 'lentil' and species names from the Catalog of Life). Then, we indexed all the food products of the dataset with the Latin name of the legume when identified or other categories such as "fresh pulses".

Table 3. Categories of food product innovations considered

Category Group*	Category/subcategory names from MINTEL glossary
Baby food and toddlers	Baby formula, biscuits and rusks for babies and toddlers; growing up milk in the early stages of life for children
Bakery	Baking ingredients; bread products; cakes, pastries & sweet goods; biscuits/crackers/cookies
Breakfast products	Hot and cold cereals
Dairy products	Butter, cream, yogurts, milk, cheese, dairy alternatives (plant-based drinks or yogurts)
Desserts (frozen and chilled), ice creams and sweets	chilled desserts, frozen desserts; dairy-based or plant-based ice creams; dessert toppings; sweets and other confectionaries; jams; Chocolate products
Drinks and soups	Carbonated soft drinks; hot beverages; juices; beverage concentrates and mixes; meal replacements and nutrition supplements; special fermented drinks (kefir, kombucha); sport and energy drinks; dry and wet soups
Fruit and vegetables	All pre-packaged, canned, frozen, and dried vegetables, canned baked beans, pulses, mixed vegetables or pulses to be used for various dishes and canned products. Excludes loose vegetables in bags, unless they have been processed in some way. Most vegetables in brine or olive oil such as beans, corn (sweet corn), peas, mushrooms, asparagus, tomatoes or carrots. Those mixed with meat or fish come under Prepared Meals; and those to be spread on toast come under Spreads
Meals and side dishes	Instant noodles, pasta, rice; meal kits; pastry dishes; pizzas; prepared meals; prepared or ready to eat salads; sandwiches/wraps; side dishes such as noodles, pasta, potatoes, rice, polenta and stuffing; falafels
Processed fish, meat, egg products	Included meat substitutes
Snacks	Bean based snacks such as tofu and other processed pulse snacks; meat or vegetable snacks
Spreads	Dips; meat pastes and pâtés; vegetable pastes; sweet spreads
Sauces and seasonings	Cooking sauces; mayonnaise; oils; pickled condiments; all types of seasonings for enhancing flavours

* Food products are categorised by Mintel based on 25 main subcategories that we grouped to consider 12 main categories.

Table 4. Frequencies of pulse species in the ingredients of food product launches in Europe and North America over 2010-2019

Species	**Frequency**
Cicer arietinum	8574
Pisum sativum	6282
Lens culinaris	4813
Phaseolus vulgaris	4360
Lupinus angustifolius	969
Phaseolus coccineus	944
Vicia faba	582
Vigna radiata	549
Vigna angularis	542
Vigna unguiculata	133
Vigna mungo	110
Cajanus cajan	46
Lathyrus sativus	2