agronomy

Review

Innovative Pulses for Western European Temperate Regions: A Review

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Abstract: In Europe, there is an increasing interest in pulses both for their beneficial effects in cropping systems and for human health. However, despite these advantages, the acreage dedicated to pulses has been declining and their diversity has reduced, particularly in European temperate regions, due to several social and economic factors. This decline has stimulated a political debate in the EU on the development of plant proteins. By contrast, in Southern countries, a large panel of minor pulses is still cropped in regional patterns of production and consumption. The aim of this paper is to investigate the potential for cultivation of minor pulses in European temperate regions as a complement to common pulses. Our assumption is that some of these crops could adapt to different pedoclimatic conditions, given their physiological adaptation capacity, and that these pulses might be of interest for the development of innovative local food chains in an EU policy context targeting protein autonomy. The research is based on a systematic review of 269 papers retrieved in the Scopus database (1974–2019), which allowed us to identify 41 pulses as candidate species with protein content higher than 20% that are already consumed as food. For each species, the main agronomic (e.g., temperature or water requirements) and nutritional characteristics (e.g., proteins or antinutritional contents) were identified in their growing regions. Following their agronomic characteristics, the candidate crops were confronted with variability in the annual growing conditions for spring crops in Western European temperate areas to determine the earliest potential sowing and latest harvest dates. Subsequently, the potential sum of temperatures was calculated with the Agri4cast database to establish the potential climatic suitability. For the first time, 21 minor pulses were selected to be grown in these temperate areas and appear worthy of investigation in terms of yield potential, nutritional characteristics or best management practices.

Keywords: grain legumes; crop diversification; sustainable intensification; growing degree days

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1. Introduction

There is an increasing debate about the importance of plant-based proteins and the diversification of protein sources for food or feed [1]. Plant-based proteins originate in several botanical families but are mainly concentrated in legumes. Despite the importance of grain legume, their production and consumption are declining worldwide [2,3], whereas the acreage dedicated to soybean is continuously increasing due to the intensification of livestock production [3]. Although grain legume diversity is very high from a worldwide perspective [4], these species often have local patterns of production and consumption in several developed and developing countries [5]. Worldwide grain legumes production increased by 15% between 2016 and 2017. This increase in production occurred in each continent, except America where production remained stable. Soybean production also increased during this period. This increase was mainly due to the largest producers, North and South America. Based on the most recent available FAOSTAT data [6], there are four main pulses cultivated worldwide. Beans (all *Phaseolus* species included) were the most produced in 2019 (Table 1), half of which were produced in Asia. Peas are produced in Europe and in North America; however, 83% of chickpeas production (including the species *Cicer arietinum*) was harvested in Asia. Beyond these four common grain legumes, cowpea production reached 8.9 million tons, but was concentrated in Africa (97%) and pigeon pea production, which attained 4.4 million tons, was concentrated in Africa (15%) and Asia (83%). Broad beans (including *Vicia faba*, horse bean, broad bean and field bean) were also largely cultivated in 2019 with more than 5.4 million tons harvested. Lupins were produced mainly in Oceania (47%) and Europe (37%). Vetches with a production of 0.9 million tons were produced in Europe (31%) and Africa (43%) and Bambara bean was only cultivated in Africa, with an annual production of 0.2 million tons. The other pulses, grouped together for statistical purposes, accounted for 4.5 million tons worldwide. The only six pulses that are exchanged internationally are, in decreasing order of importation quantity, peas, with 37.6% of all world imports, representing 6.5 million, beans with 21%, lentils with 17%, chickpeas with 11%, broad beans with 5% and Bambara beans with only 0.01% according to the FAO data on 2016 market exchanges.

Table 1. World production of pulses in tons (T) and contribution percentage (%) of each continent (Faostat 2019).

	World (T)	**Africa (%)**	**America (%)**	**Asia (%)**	**Europe (%)**	**Oceania (%)**
Bambara beans	228,920	100.0	0.0	0.0	0.0	0.0
Beans, dry	28,902,672	24.4	24.4	49.7	1.3	0.3
Broad beans, horse beans, dry	5,431,503	27.0	4.0	33.6	29.4	6.0
Chick peas	14,246,295	4.9	6.1	83.4	3.6	2.0
Cow peas, dry	8,903,329	96.8	0.7	2.2	0.3	0.0
Lentils	5,734,201	3.3	42.7	42.5	2.2	9.3
Lupins	1,006,842	7.5	6.3	0.0	39.0	47.1
Peas, dry	14,184,249	3.9	39.3	18.1	37.0	1.7
Pigeon peas	4,425,969	15.1	1.8	83.2	0.0	0.0
Pulses, others	4,553,029	31.5	0.9	45.3	22.0	0.3
Vetches	762,795	42.6	12.7	12.4	31.4	0.9
Pulses, total	88,379,804	24.1	18.7	44.3	10.8	2.2

Minor pulses are produced and consumed locally worldwide, and there is no exchange between countries unless they are already cultivating and consuming these minor pulses [7]. This is more a consequence of food habits than because of pedoclimatic or agronomic constraints.

In 2018 in Europe, only 1.3% of the cultivated acreage was dedicated to pulses (Eurostat) where peas covered 37% of the surface followed by broad beans, field beans (26%) and sweet lupins (6%). The rest (26.4%) came from other dry pulses such as lentils, chickpeas and beans (Eurostat).

However, the production of pulses has decreased during the last five decades [8]. Several factors have driven this decrease. First, the reduction of human consumption of vegetal proteins was negatively correlated to the increase in the standard of living of the population and the substitution by animal proteins [9]. Besides, less time is devoted to cooking, which is essential to reduce the impact of antinutritional factors of pulses, leading to reduced consumption [10]. Second, the increasing import of cheap soybean meal to feed livestock from North and South America (2017) has induced a reduction in the price of meat. The availability of inexpensive proteins has supported the intensification of livestock production, which, at the same time, has dissociated livestock breeding from crop production for feeding [11]. The separation of protein and livestock production led to an intensification and a reduction of the number of cultivated crops, chosen for their economical performances. Moreover, as Watson et al. [8] argued, the yield increase of cereals in Europe since the 1970s was not followed by a similar yield increase of protein crops, leading to an expansion of cereal acreage while protein crops remained less attractive for farmers. However, since 2015, this trend has ended in Europe, probably because of both the increase in organic farming and the different policy instruments supporting protein crops [12].

European farmers, particularly those in arable systems, look to diversify the crop rotations to more sustainable and resilient cropping systems [13]. One of the major groups of crops targeted for diversification is grain legumes [13,14]. Several scholars have been interested in grain legumes because of their potential uses for food, feed and bioenergy/biomaterials but also because of the agroecosystem services they provide [2,3]. However, there is a general lack of knowledge and references regarding these grain legumes in terms of production potential in Northern countries and also about the diversity of their possible usage. Moreover, some scholars argue that the low adoption by European farmers of grain legumes compared with other crops is caused by low productivity and low profit margins, technological lock-in, and low temporal yield stability [15–17]. Reckling et al. [18] have underlined that in Northern Europe, the grain legume yield is as stable as that of other major spring crops, e.g., spring cereals or rape seed. Yield stability is also enhanced in the other crops of the cropping system by grain legumes, as demonstrated by Petrova Chimonyo et al. [19] in maize-based cropping systems. Mawois et al. [20] have studied the trajectories of farms that increased the proportion of grain legumes in their crop rotations, highlighting three levels for their successful introduction: the stability of the supply (both as on-farm consumption and in the food supply chain), the benefits of grain legumes as the preceding crop and/or the involvement of farmers in peer groups.

In this context, the increase in the use of grain legumes in European cropping systems can rely on two strategies. The first is to increase the current rate of cultivation of common pulses, e.g., lentils, chickpeas and common beans, in these countries, attempting to overcome the problems of lock-in at the supply chain level. This is the strategy that is currently analyzed in the mainstream literature regarding European temperate regions and in some European research and innovation projects, e.g., PROTEIN2FOOD or LEGVALUE. A complementary strategy could be to provide alternatives in the panel of grain legumes potentially cropped or processed by identifying new species from worldwide grain legume biodiversity and creating new niches for these species and a renewed interest in grain legumes. This strategy can rely, on the one hand, on the adaptability of grain legumes to new environmental conditions [21,22], and on the other hand, on the interest of the supply chain in new plant-based products, as occurred in the case of quinoa [23,24]. In this paper, our goal is to explore the latter strategy. Information on tropical grain legumes or minor pulses already exists in literature; however, it is often limited either to one species [25,26] or to a comparison of several species on a national/continental level, e.g., in India [27–29], Australia [30], Africa [31–33] or to a comparison of wild species [25,34,35]. The aim of this review is two-fold: on the one hand, it will provide insights about the agronomical and nutritional characteristics of a large panel of grain legume crops which are currently unknown and cultivated poorly or not at all in European temperate regions, and on the other hand, it will explore the potential matching of these pulses in temperate Western European climatic conditions. As we are interested in grain legumes as food, in this paper we will use the terms ‘pulses’ and ‘grain legumes’ as synonyms and distinguish them when the legume destination is not intended as food.

2. Materials and Methods

2.1. Literature Review and Data Collection

A systematic literature review was performed according to the 7 steps method formalized by the Centre for Evidence-Based Conservation [36]. The method adopted for this study is illustrated in Figure 1. The first step was the identification of the research question. We wondered about the global diversity of protein-based crops, namely of pulses, that could support a crop diversification in European temperate regions. To answer this question, we looked for a general overview of worldwide pulses diversity and characteristics. To this end, we first carried out a general literature survey in the Scopus database according to the Scopus Reference Guide [37] by selecting the advanced searches TITLE-ABS-KEY ((pulses AND ‘grain legumes’) AND crops) AND PUBYEAR > 1974 AND PUBYEAR < 2020 AND DOCTYPE (re) AND LANGUAGE (English) AND SUBJAREA (agri)) in the title, abstract and keywords with a focus on review articles, in the 1974–2019 time span in the Biological Sciences sub-database. We obtained a preliminary list of 231 reviews. Based on these reviews, we compiled a list of species to be checked. The eligibility criteria were to be cropped (not wild), used for human consumption and having a protein content in the grain equal or superior to 20 g/100 g. The species identified were double checked through a complementary search in three international databases: FoodData Central from the United States Department of Agriculture (formerly USDA National Nutrient Database for Standard Reference) [38], Prota4U hosted by Wageningen University [39] and the International Network of Food Data System from FAO [40]. A list of 47 species (common and scientific names) was finally established (Table 2). At this stage, since the information collected was too general on the agronomic and nutritional characteristics of grain legumes, in a second step we performed an in-depth literature review on the 47 previously selected species (Table 1). This second review was also performed in the Scopus database, focusing on scientific articles (therefore excluding reviews), in the 1974–2019 time span in the Biological Sciences sub-database. A grouped search including all the species was also performed in order to build a common database of minor pulses and delete duplicates. We considered minor and major pulses as separate searches.

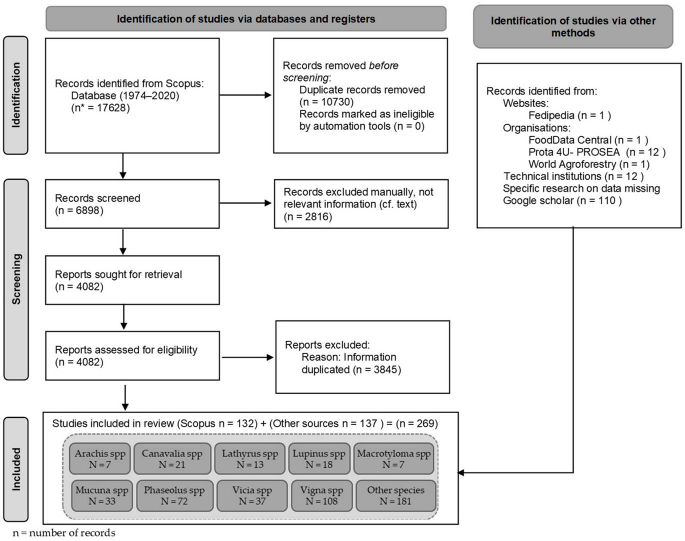

Figure 1. PRISMA 2020 flow diagram systematic review on pulses [41]. Details on the species included as well as on the number of papers retrieved are provided in Table 1.

Example of the Boolean string for this second search for one species is TITLE-ABS-KEY ((ervil OR 'Vicia ervilia' OR 'Bitter vetch') AND crop*) AND PUBYEAR > 1974 AND PUBYEAR < 2020 AND DOCTYPE (ar) AND LANGUAGE (English) AND SUBJAREA (agri) AND NOT ('cover crop*' OR 'green manure' OR intercrop*). By selecting the subject area 'AGRI' we tried to avoid the number of papers in ecology or natural sciences focusing on medical or beneficial properties of some of these species. Moreover, limiting the search to 'crop' helped us to select those papers that refer to cultivated species (not wild) and group both the common(s) and scientific names guaranteed to catch a maximum of the papers referring to a species. Finally, after a preliminary analysis of the database, we identified several papers dealing with the use of minor pulses as cover crops or green manure, along with their use in intercropping. As we were not interested in these topics, we excluded the papers including such words in the abstract, title or keywords. Even though we are aware that searching among the English literature limited the number of papers, we believed that this choice could ensure a common standard among the selected papers.

Table 2. Retrieved papers in the Scopus database for the period 1974–2019 for a sample of cultivated minor and major pulses (in grey) with a protein seed content above 20%, individual researches. In grey, a comparison with the same search was repeated for major pulses.

Common Name	Other Names	Scientific Name	Retrieved Papers in the Scopus Database (1974–2019)
Acacia leucophloea		*Vachellia leucophloea*	4
Adzuki bean	Azuki bean, aduki bean	*Vigna angularis*	102
African locust bean		*Parkia biglobosa*	31
African nut bean		*Ricinodendron heudelotti*	1
African oil bean		*Pentaclethra macrophylla*	5
African yam bean		*Sphenostylis stenocarpa*	27
Bambara groundnut	Earth pea	*Vigna subterranea*	99
Butterfly pea		*Centrosema pubescens*	16
Cowpea	Black eye bean, black eye pea	*Vigna unguiculata*	1348
Ervil	Bitter vetch	*Vicia ervilia*	40
Fenugreek		*Trigonela foenum-graecum*	145
Grass pea		*Lathyrus sativus*	131
Guanacaste		*Enterolobium cyclocarpum*	11
Horsegram		*Macrotyloma uniflorum*	43
Housa groundnut	Hausa groundnut, Kersting groundnut	*Macrotyloma geocarpum*	6
Itching bean		*Mucuna pruriens var. pruriens*	1
Jack bean		*Canavalia ensiformis*	36
Kedaung	Tree bean	*Parkia roxburghii*	2
Kidney bean		*Phaseolus vulgaris*	131
Lablab	Hyacinth bean	*Lablab purpureus*	125
Lima bean	Butter bean, Java bean, Madagascar bean, sugar bean	*Phaseolus lunatus*	113
Marama bean	Morama bean	*Tylosema esculentum*	8
Moth bean	Mat bean, Turkish gram	*Vigna aconitifolia*	63
Mung bean	Golden gram, green gram, Moong bean	*Vigna radiata*	811
Navy bean	Pearl haricot, haricot bean	*Phaseolus vulgaris*	66
Narbon bean	Narbon vetch	*Vicia Narbonensis*	43
Pigeon pea	Red gram	*Cajanus cajan*	590
Pinto bean		*Phaseolus vulgaris*	58
Pinto peanut		*Arachis pintoi*	70
Purple mucuna		*Mucuna atropurpurea*	0
Red moneywort		*Alysicarpus rugosus*	1
Rice bean		*Vigna umbellata*	55
Scarlet runner bean	Runner bean	*Phaseolus coccineus*	18
Sesban		*Sesbania sesban*	46
Sword bean		*Canavalia gladiata*	9
Tamarind		*Tamarindus indica*	45
Tarwi		*Lupinus mutabilis*	30
Tepary bean		*Phaseolus acutifolius*	46
Urad	Black bean, black lentil, mungo bean	*Vigna mungo*	357
Velvet bean	Cowitch	*Mucuna pruriens var. utilis*	25
Winged bean		*Psophocarpus tetragonolobus*	39
Yam bean		*Pachyrhizus erosus*	45
Broad bean	Faba bean, horse bean	*Vicia faba*	918
Chickpea	Bengal gram	*Cicer arietinum*	1795
Common bean	Field bean, bell bean, English bean, Windsor bean, pigeon bean	*Phaseolus vulgaris*	1988
Field pea		*Pisum sativum*	2014
Lentil		*Lens culinaris*	901
Lupin		*Lupinus* spp.	688

Then, a second search was performed in Google Scholar according to the same criteria as in the Scopus database in the case of absent or insufficient number of papers (e.g., Purple mucuna or Red moneywort), or in cases where the papers retrieved in the Scopus database did not target our goal, e.g., focusing exclusively on genetics, crop protection or agroforestry potential or looking only for a specific characteristic in growth, agronomy, nutritional or antinutritional composition. For minor pulses with a limited or local use, nutritional characteristics were obtained from research articles, of which a mean was calculated (protein, oil, carbohydrates and fiber content) or an interval was indicated.

The papers obtained from the Scopus searches for each pulse species were stored in a Zotero database, which contained a total of 17,628 articles, and 10,730 of them were discarded as duplicates. Among the duplicates, there were often papers comparing two or several pulses. An exhaustive screening on titles was performed in order to eliminate out-of-scope papers that did not provide useful information for our research (6661 papers). The most common reasons for deleting a paper from the list were the following: the name of a pulse was mentioned only as a comparison of one characteristic to another crop [42], the trial or analysis was performed in intercropping, thus evaluating the impact of the cover crop on the staple food yield [43] or there was no relation to the topic, e.g., papers dealing with biochemical [44] or genetic characteristics [45] or the use of pulse extracts as green fertilizers [46] or seed treatments [47] without any relation to pulse yield or seed quality. Papers with an historical or archeobotanical approach [48] and those stating consumer preferences [49] or the impact of the feed on the animal's health [50] were also excluded. For some crops, such as cowpea or Bambara bean, not all the articles found are cited in the present review, as for one topic, such as resistance to a fungus or an insect, dozens of articles could be found. Some cultivated legumes showed an interesting seed composition but they are not used as food. Brebra seed (*Millettia ferruginea*) was excluded from our analyses, even though the seed is edible. Other species from *Lathyrus* and *Vicia* with protein content above 20% were used as food but are either no longer cultivated [51] or are cultivated on a few hectares of a single Greek island for traditional dishes like *Lathyrus clymenum* [52]. Finally, papers dealing with consumer preferences for different varieties or for different cooking techniques were also excluded.

In the end, the final number of papers used for the review was 269.

2.2. Bibliographic Corpus Analysis

The file containing the Scopus extraction with information from 4082 documents assessed for eligibility was first analyzed to describe the papers in terms of sources (journals), years of publication and origin. For these analyses, we calculated the absolute, relative and cumulative frequencies. Then, the corpus was uploaded and analyzed using the CorTexT platform, already used for agronomic literature reviews [53,54], throughout the CorTexT Manager (INRAE-LISIS, Noisy-le-Grand, Seine-Saint Denis, France) (http://manager.cortext.net/) (accessed on 30 November 2021).

A term-extraction algorithm was first performed using the title, abstract and keywords of each document to identify the 100 most cited terms. With those terms, several functions have been tested in the default proposed form such as the contingency matrix, geospatial exploration and network mapping to see the relationships between species, countries, journals and other agronomical terms.

2.3. Descriptive Analysis

The aim of the descriptive analysis was to characterize both the agronomic and nutritional characteristics of the selected species. Both are essential to select candidate species diversifying cropping systems in temperate regions to be used in the food industry. On the one hand, for the agronomic characteristics, we analyzed the environmental requirements (optimal, minimal and maximal temperature, average water requirement, duration of crop cycle), fertilizer inputs, potential yield, fixed nitrogen and symbiotic bacteria. On the other hand, for the nutritional characteristics, we analyzed the nutritional profile (calories, protein content, carbohydrates, vitamins, minerals, micronutrients) and the most common antinutritional characteristics (phytic acid, total tannins, saponins, trypsin inhibitors, lectins and other antinutritional molecules).

2.4. Species Selection for Temperate Regions

The most promising crops for arable systems in temperate regions were selected from the database mainly according to the environmental requirements. Focusing on arable systems, only annual crops that could rotate with other crops were considered. For a preliminary evaluation, we also excluded crops that require special harvesting techniques such as those that produce grains underground. For annual species we considered those having varieties with maximum crop duration of 120 days, thus corresponding to summer crops in temperate regions. We also excluded species with optimal temperatures higher than 25 °C or where those data were absent. We hypothesize for the annual crops a growing period from 1 March to 15 October. We could not consider the crop heat units to reach maturity, the sensitivity to day length and the precocity because of a lack of data in the literature. We considered as candidate species those that can potentially grow in continental European temperate regions under oceanic influence (by excluding temperate areas in Ireland) according to the European environmental stratification proposed by Metzger et al. [55]. Climatic data (1998–2018) were extracted on the Agri4cast database provided by the European Joint Research Centre (https://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx) (accessed on 11 January 2021) in the area between latitudes 47.56° to 53.44° and longitudes −0.017° to 7.28°. The spring sowing date (date to start accumulating growing degree days (GDD)) was considered as the last of three consecutive days with daily mean air temperatures equal to or greater than 12.8 °C based on the Corn Heat Units Index used to characterize climatic regions [56]. The potential season-ending date (date to stop accumulating GDD) was considered as the earliest date when the daily mean air temperature dropped to 12 °C, excluding dates included in the 90 days following the sowing date. The sum of temperatures was calculated within those dates considering base temperatures of 6 °C and 10 °C. Given the lack of data on the grain legumes investigated, those climatic data were compared to the requirements of already cultivated spring crops such as corn or soybean, to establish preliminary conformity of the criteria.

3. Results and Discussions

3.1. Descriptive Analysis of the Bibliographic Corpus

The selected corpus on pulses was composed of 4081 documents. More than 50% of the research was published since 2010 (data not shown). The observed bibliography shows that the interest in pulses has been increasing, especially in the last 15 years, reaching more than 250 documents per year (data not shown). An analysis of the country of origin of the first authors shows that affiliations from 116 countries are represented; of them, more than 50% are from two countries, Brazil and India. Papers from European temperate areas are poorly represented. Finally, more than 600 individual journals are represented in the corpus, and 55 account for 50% of the articles. Of these latter journals, mostly are in the agronomy and crop science area, e.g., *Crop Science*, *Field Crop Research* or *Experimental Agriculture*, and have partially regional coverage, e.g., *Indian Journal of Agricultural Sciences* or the *Australian Journal of Crop Science* (data not shown). The matrix of contingence obtained from the CorTexT platform (data not shown) also confirmed that almost 40% of the retrieved papers were published in two Indian journals (*Indian Journal of Agricultural Sciences* and *Indian Journal of Agronomy*) and more than 40% on *Phaseolus vulgaris* (or common bean, data not shown). This was confirmed by geospatial exploration which identified India as the main producer of references on pulses, ahead of other countries in the world.

The most cited terms were *Phaseolus vulgaris* (in different written forms) with 537 occurrences which corresponded to more than 25% of all the literature, followed by *Vigna radiata* 407, *Cajanus Cajan* 238, Experimental field 155, *Triticum aestivum* 152, *Vigna mungo* 142, Common bean 95, *Pisum sativum* 70 and *Arachis hypogaea* 69. This confirms the large disparity that exists between main pulses and minor pulses in the literature. Those terms are also entered into evidence on the network map of the 100 most cited terms in the abstract (Figure 2). We can also identify other terms associated with the yield (height of the plant, seeds dry weight or leaf area), management practices (P fertilization) associated with the impact on other crops (like wheat or mustard) or on the pulse studied and resistance to biotic or abiotic stresses (drought, moisture, weeds, diseases and insects).

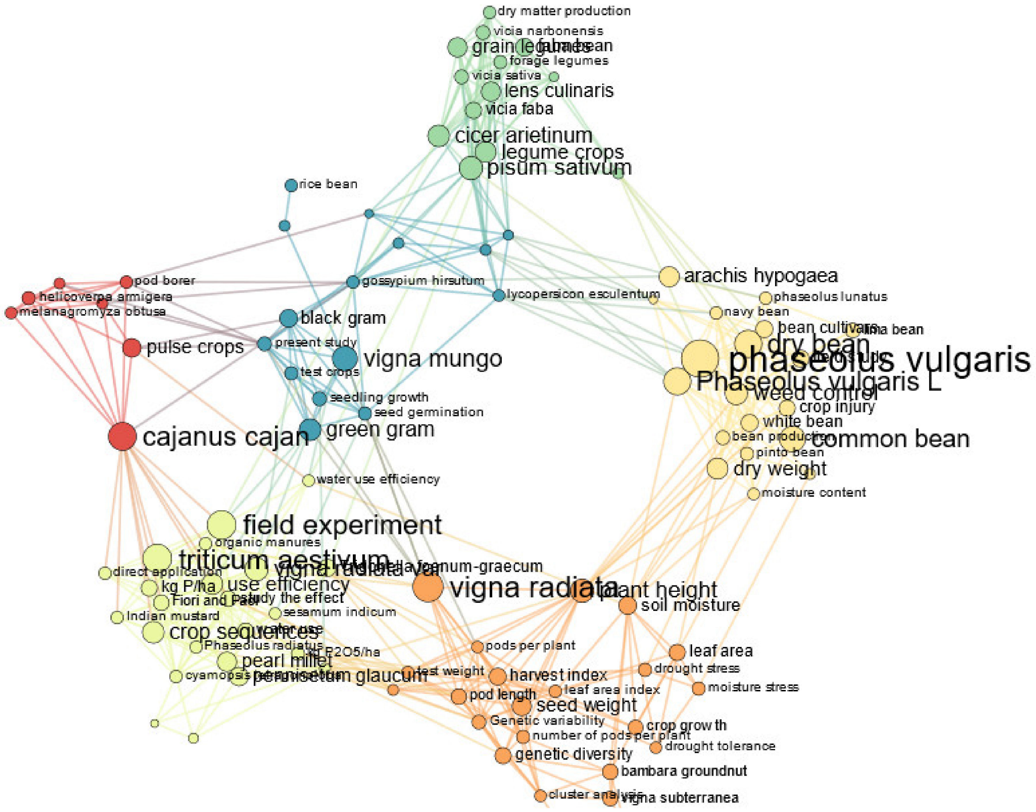

Figure 2. CorTexT Manager—script network mapping. The size of the dots reflects the occurrence frequency: the larger the dot, the higher the occurrence. Analysis was performed on the 4082 documents identified in Scopus based on the 100 most recurrent terms.

These data also confirm the existing gaps in knowledge and research interests between the common bean, pea, other major pulses like cowpea, mung bean or urad and the other minor pulses.

3.2. Types of Pulses and Agronomical Needs

Pulses are found worldwide, and some of them are adapted to temperate climates (kidney bean, lupins) (Table 3, Appendix A) whilst a larger number can be found in tropical or subtropical areas (adzuki bean, cowpea) and a few can be found in both areas (soybean, broad beans). Crops such as the common bean that can grow under both temperate and tropical climate conditions are grown during the spring–summer period and in cold (winter) periods in temperate areas, or at high altitudes in tropical areas [57–59]. In soybean, on the other hand, several maturity groups adapted to different pedoclimatic conditions have been developed [60,61]. Most of them have a crop length between 2 and 6 months, but it is highly variable even within a species. However, those crop lengths have been observed in tropical conditions allowing a high GDD, and the exact GDD is not precisely defined in the literature. Some crops have longer cycles that can reach nearly a year (i.e., cowpea and sword bean [39]), and others can be cultivated as an annual plant (i.e., urad, tepary bean [62]) or as a perennial (i.e., pigeon pea [63], morama bean, *Mucuna atropurpurea* [39] and yam bean [64]). The perennial pulses could also be cultivated as annuals depending on the agronomical practices of the country. Despite the in-depth research conducted it was difficult to identify the intra species genetic diversity available that may be conducive to a larger potential for one species to spread to other climatic conditions or agronomical practices.

In temperate climates, pulses are mainly cultivated as main crops or in association with cereals [65], whereas in tropical countries, we can find associations with corn [66], coffee [67], cassava [68] and other diverse crops [69,70]. In the latter crop, little or no fertilization or pest management is required. Two pulses are cultivated not for their grains but for their tuber production, making the grains a coproduct (yam bean and African yam bean [71,72]). Among the studied species, minimal temperature has been retrieved in 25 species over 57. Among them, a few minor pulses resist cold temperatures (Tarwi bean, pigeon pea, kidney bean and fenugreek). Among the major pulses, five over six tolerate negative temperatures. The other pulses require positive temperatures during their entire life cycle, and in most cases, above 10 °C. The optimal growing temperature is characterized in the literature only in 33 out of 47 species, but the temperature intervals are often wide. The maximal temperature is retrieved in 23 species over 47 but it will not be a constraint in temperate climates of Western Europe.

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3.3. Nutritional Characteristics

Pulses have an interesting nutritional profile (Table 4, Appendix B), because they have high protein content with a mean value in our sample of 23% (rice bean has the lowest content with 19.7% [75] and tarwi [40] has the highest content, 51%), low fat content with a mean value of 3.8% and a small percentage of saturated fatty acids. Pulses also provide fiber, vitamins and minerals which are important for human health. Table 4 and Appendix B show the nutritional characteristics of pulses, not taking into account genetic or pedoclimatic variability between species. Vitamins and minerals, when present, were included in Appendix B. It is interesting to note that the values of protein content in minor pulses were comparable to or higher than those of the common pulses already cultivated in North-West Europe.

Table 3. Pulses' agronomic requirements and potential yields, extracted from Appendix A.—indicates that no data were retrieved from the literature.

Pulses—Common Name	Temperature (°C) Min; Max; Optimal	Crop Length	Water Requirements (mm)	Yield (t/Ha)	Kg N Fixed (kg/ha)
Adzuki bean	5–10; 34; 15–30	60–190 d	500–1700	0.5–3.5	100
Butterfly pea	5; 35; 20–28	120–194 d	400–1750	0.7	-
Cowpea	15; 35; 25–35	60–340 d	500–1500	0.2–7	12–50
Fenugreek	−4; -; 18–27	90–100 d	300–400	-	-
Grass pea	20; -; 10–25	90–180 d	400–650	0.3–10.5	25–50
Horse gram	-; 40; 20–32	120–150 d	380–900	0.5	-
Itching bean	-; -; 19–27	-	400–3000	0.2–2	-
Kidney bean	−1; 30;15–20	65–105 d	300–600	2.2	20–44
Lablab	-; -; 18–30	54–220 d	650–3000	1.4–4.5	20–140
Lima bean	>0; >37; 16–27	115–180 d	900–1500	0.4–5	40–60
Moth bean	25; 45; 24–32	70–90 d	200–750	0.07–2.6	-
Navy bean	12; 35; 22–30	53–300 d	400	0.5–5	125
Pigeon pea	0; 40; 18–29	3–5 y	600–1400	0.6–5	69–134
Pinto bean	-; 36; 21–25	90–100 d	-	0.5–3.9	-
Rice bean	10; 40; 25–35	120–150 d	700–1700	0.2–2.7	-
Sword bean	-; -; 25–30	150–300 d	900–1500	1.5–5.4	75–230
Tarwi	<0; -; -	150–330 d	-	0.6–4.8	100
Tepary bean	8; >32; 17–25	60–120 d	400–1700	0.4–1.7	-
Urad	-; -; 25–35 no frost	60–140 d	600–1000	0.3–2.5	18
Velvet bean	5; -; 19–27	-	1200–1500	0.5–3.4	60–330
Winged bean	-; -; 20–30	120–180 d	1000	0.7–1.9	-
Broad bean	−12; 30; 18–27	90–220 d	700–1200	1.1–2.2	33–550
Chickpea	−11; >32; 10–29	90–180 d	500–1800	1–5.5	35–140
Common bean	−9; 38; -	70–110 d	274–550	0.9–2.6	465
Field pea	<0; -; 7–30	90–180 d	400–1000	1–4	30–96
Lentil	2; 35; 6–27	80–130 d	300–2400	0.8–7	50
Lupin	<0; -; 18–24	115–330 d	400–1000	0.5–5	90–400

d means days (annual crops) and y years (pluriannual crops), °C degrees Celsius. In grey, a comparison with the same search was repeated for major pulses.

Other current and largely cultivated crops are also rich in proteins (Appendix C) but often they also have high fat content, making them less nutritionally valuable. Appendix C describes in the same way as Appendix B the nutritional characteristics of other protein-rich crops cultivated or not in temperate regions. For cotton and rapeseed, there are nearly no data concerning their nutritional composition as they are mainly used to obtain fiber and oil or oil and proteins, respectively, with no direct use as food or feed. A common protein supplement, spirulina (*Arthrospira maxima*) was also included because of its interesting nutritional profile, highest content of proteins and third lowest level of oil content by comparison.

Table 4. Nutritional profile of pulses, extracted from Appendix B.

Pulses—Common Name	Energy (kcal/100 g)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)
Adzuki bean	329	19.9	0.5 (0.2)	62.9	12.7
Butterfly pea	-	25.2	3.7	19.9	9.2
Cowpea	343	23.9	2.1 (0.5)	59.6	10.7
Fenugreek	323	23.0	6.4	58.0	25.0
Grass pea	-	24.4	2.8 (0.8)	55.94	11.4
Horse gram	280	22	0.6	37.5	5.7
Itching bean	382	27–37	6.6–8.8	46–53	6–10
Kidney bean	333	23.6	0.8 (0.1)	30.0	24.0
Lablab	344	21–29	1.7 (0.3)	60.74	25.6
Lima bean	338	21.5	0.7 (0.2)	63.4	19.0
Moth bean	343	23–26	1.6 (0.4)	61.5	5
Navy bean	337	22.3	1.5 (0.2)	60.8	15.3
Pigeon pea	343	13–26	1.5 (0.3)	62.8	15
Pinto bean	347	21.4	1.2 (0.2)	62.6	15.5
Rice bean	338	18–19	0.5 (0.3)	59.1	7.1
Sword bean	361	24–30	2.6–9.8 (-)	41–59	7–13
Tarwi	440	41–51	14–24 (19)	28.2	7.1
Tepary bean	353	19–24	1.2 (-)	67.8	4.8
Urad	341	25.2	1.6 (0.1)	59.0	18.3
Velvet bean	373	20–29	6–7	50–61	9–11
Winged bean	428	30–35	16.3 (2.3)	41.7	11–26
Broad bean	341	26.1	1.53 (0.3)	58.3	25
Chickpea	378	11–31	6.0 (0.6)	63.0	12.2
Common bean		20–24	0.8 (0.6)	75.5	-
Field pea	352	23.8	1.2 (0.2)	63.7	25
Lentil	352	24.6	1.1 (0.2)	63.4	10.7
Lupin	371	36.2	9.7 (1.2)	40.37	18.9

In grey, a comparison with the same search was repeated for major pulses.

3.4. Antinutritional Characteristics

All pulses contain one or more antinutritional compounds (Appendix D) and although the concentration is under the lethal dose, a regular or almost exclusive consumption may induce certain medical problems, such as the lathyrism caused by grass pea in European populations after the wars [76] that led to a law forbidding the consumption of grass pea grain or its derivatives in Spain [77]. Efforts have been made to breed new varieties with reduced content of the neurotoxin [78].

Appendix D reports data from research articles that analyzed one or several compounds. The other columns indicate the presence of other toxic molecules that are only present in some crops, even in a single crop, such as β-ODAP (beta-oxalyl-diaminopropionic acid) in grass pea or gossypol in cotton. Itching and velvet bean present the highest content of phytic acid, with some varieties reaching between 53 and 57 mg/g [28], whereas the other pulses varied from 0.5 to 41 mg/g. In the case of tannins, some varieties of African yam bean contained up to 18.1 mg/g [79], while other pulses contained from 0.01 [80] to 96 [81] mg/g. Saponins reached the highest values in some varieties of navy bean, but have lower values than some varieties of lentils or chickpea [82]. Trypsin inhibitors were found in high quantities in sesban seeds, reaching 140 mg/100 g [83]. Finally, lectins were less abundant in a few species of pulses; mung bean seeds contained the highest quantity, with 15.8 mg per 100 g [84].

No pulse exceeded the lethal dose estimated at 50–60 mg/kg for phytates, 30 mg/kg for tannins, 2.5 g/kg for trypsin inhibitors, 50 mg/kg for lectins, 50–60 g/kg for hydrogen cyanide or 20 mg/100 g and 2–5 g/kg for oxalates [85]. Nevertheless, the presence of these antinutritional compounds may cause some troubles. Phytic acid chelates with several minerals, limiting their bioavailability for the organism. Tannins reduce the absorption of nutriments and vitamin B12, reducing the efficiency of energy conversion [86]. Cooking or transforming these pulses inactivates the negative effects of these antinutritional factors on health or wellbeing [87].

3.5. Potential for Minor Pulse Cultivation in European Temperate Regions

Analyses of the meteorological data showed that in the considered European temperate regions between 1998 and 2018, the total number of observed situations was 7456. The minimal duration of good cropping conditions was 121 days, and the average maximum was 140 days. The most frequent duration was 120–125 days (18.5%) followed by 125–130 (15.3%) and 130–135 days (10.5%). The daily temperature varied from 14.9 to 20.0 °C, with a mean of 17.1 °C. Sowing was possible in 12.6% of the situations in March, 54.1% in April, 34.0% in May and only 1.8% in June, whereas the possible harvest day was concentrated between September (64.7%) and October (33.6%). The GDD in base 6 °C varied from 1102 to 2430 °C day, the most frequent being 1500 to 1600 °C day (19%), 1600–1700 °C day (18.3%), 1400–1500 (16.2%) and 1700–1800 (13.2%). The GDD in base 10 °C varied from 615 to 1654 °C day with a mean of 994 °C day being the most frequent, 1000–1100 (25.5%), followed by 1100–1200 (20.6%) and 900–1000 (20.2%) (Figure 3).

By applying the criteria of crop needs and the possibility of reaching the GDD necessary to attain crop maturity, compared to other spring crops already cultivated in those regions, almost half the selected grain legume crops (21) appeared to be of interest for temperate cropping systems. Those species are the ones listed in Tables 2 and 3.

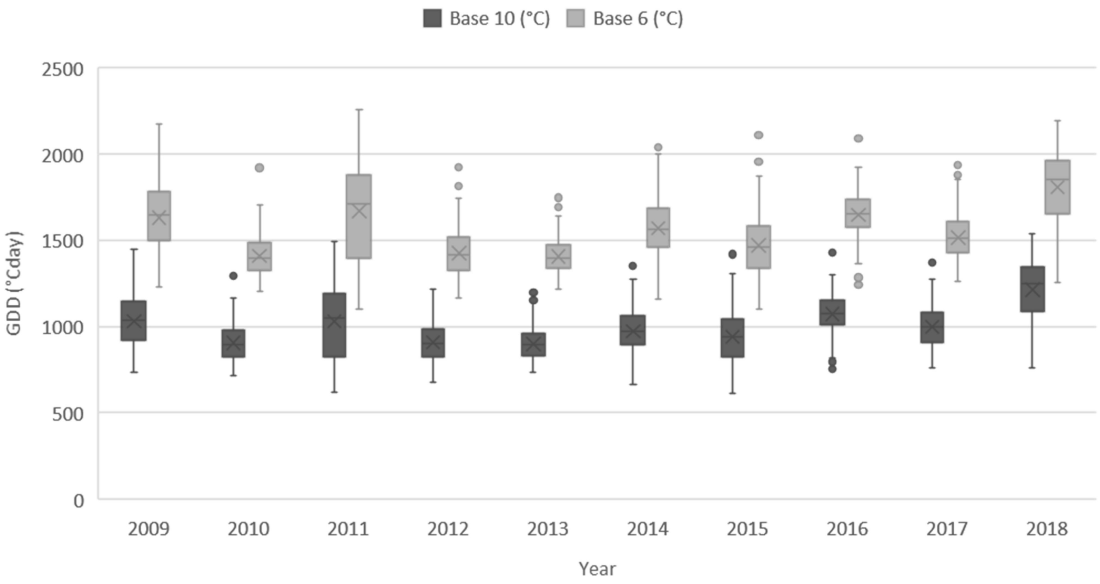

Figure 3. Bow whispers of the growing degrees days (GDD, °C day) cumulative distributions in several locations in European temperate regions (see Section 2.4) within the last 10 studied years for a base temperature of 6 and 10 °C (source: own calculation from the Agri4cast database).

4. Conclusions

The present systematic review has revealed the agronomic and nutritional interest of almost 20 pulses beyond the major ones which could be cultivated in Western European temperate regions. At this stage, this possibility is theoretical as there are several gaps in the literature. Firstly, there is a lack of physiological data, especially for minor pulses, whereas for major pulses information could be retrieved but only for the current cultivation area. Particularly, data concerning the optimal and minimal growing temperatures, the GDD requirements to reach physiological maturity as well as the minimal water requirements are missing. Secondly, there is little information about soil constraints such as the soil structure, soil depth, pH or soil water availability. Pests and diseases are described for most pulses, even for those species with few references. Thirdly, beyond the species level, there is a lack of knowledge about the genetic diversity that could be useful to extend the cultivation area, as the characterization that is retrieved in scientific literature is not sufficient to the best of our knowledge. Probably, in seedbanks, the information available will be more exhaustive for assessing certain traits such as crop length or disease resistance but this information will not be enough to establish the potential crop length in climatic areas other than those where genetic material has been collected. Among the 20 pulses with the highest cultivation potential in temperate areas, we have found that both their nutritional and antinutritional characteristics are comparable to those of the major pulses already cropped and consumed in these areas. Technological characteristics, processing potential and consumer preferences were outside of the scope of this review; however, all the retrieved species are already consumed as raw food or food components in different parts of the world. The potential of these species for uses other than as food, i.e., feed (grain or forage) or non-food (bioplastic) were also outside of the scope of this literature review but they can be considered worthy of investigation when contemplating the development of a new supply chain.

From these conclusions, we can highlight three main research perspectives when addressing the introduction of these pulses in Western European temperate areas. These are traditional perspectives when considering the introduction of a new crop to different environments, as occurred for example with quinoa. Firstly, a characterization of the requirements of the pulses in a controlled environment is necessary to identify their growing needs in order to adapt the crop management to obtain the maximum potential yield. Then, multisite and pluriannual field trials are required to establish the optimal pedoclimatic conditions and management practices. In parallel, a second perspective concerns the great effort that must be undertaken to study the existing genetic diversity in order to find the varieties that are most adapted to temperate conditions. This effort will require a large collaboration with seedbanks in order to characterize this diversity. Finally, a third perspective will concern a breeding program to improve the existing varieties. These three perspectives are a necessary first step before considering adoption by local farmers and introduction to cropping systems in temperate areas.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Agronomic requirements of minor and major pulses in grey major pulses.

Pulses—Common Name	Climate Region	Countries Where Cultivated	Temperature (°C) Min; Max; Optimal	Crop Length [a]	Water Requirements (mm)	Mineral Requirements	Pest Risk [b]	Yield (t/Ha)	Kg N Fixed (kg/ha)	Bacteria Associated	References
Acacia leucophloea	Tropic	Bangladesh, India, Indonesia, Pakistan	6; 49; -	Y (tree)	400–1500		F; I				[88]
Adzuki bean	Tropic	China, Japan, Korea, Nepal	5–10; 34; 15–30	60–190 d	500–1700	N, P, K	B; F; I	0.5–3.5	100	*Bradyrhizobium* spp.; *Sinorhizobium fredii*	[89–97]
African locust bean	Tropic	Sudan, Uganda	0; 45; 21–36	Y (tree)	500–1500		B; F; I				[98,99]
African nut tree	Tropic	West and Central Africa, Madagascar	-; -; 18–32	Y (tree)	1000						[39,99]
African oil bean	Tropic	Sub-Saharan Africa	18; -; 25	Y (tree)	1000–2000		I				[39,99]
African yam bean	Tropic	Ghana, Nigeria, Togo	0; -; 19–27	150–240 d	900–2000		F; I	3 A *			[90,98,100]
Bambara groundnut	Tropic	Australia, Cameroon, Nigeria, Sudan	15; 40; 20–28: no frost	90–180 d	600–1200	N, P, K	F; I; N; V	0.1–6	100	*Bradyrhizobium* spp.	[90,101–109]
Butterfly pea	Tropic	Brazil, Colombia, India, Mexico, Philippines, Venezuela	5; 35; 20–28	120–194 d	400–1750		F; I; B	0.7		*Rhizobium*	[110–114]
Cowpea	Tropic	Burkina Faso, Ghana, Mali, Senegal	15; 35; 25–35 no frost	60–340 d	500–1500	N, P, K	F; I; P; PW; V	0.2–7	12–50	*Rhizobium* spp. NGR234; *Bradyrhizobium* spp.; *Sinorhizobium fredii*	[39,62,100, 115–124]
Ervil	Temperate	Australia, Iran, Morocco, Turkey		134–154 d	200–500			0.6–4			[125–129]
Fenugreek	Temperate	Morocco, Tunisia, Spain	−4; -; 18–27	90–100 d	300–400	N, P, S				*Rhizobium* spp. NGR234	[130,131]
Grass pea	Temperate/subtropic	India, Iran, Italy, Middle East, Spain	20; -; 10–25	90–180 d	400–650	N, P	F; I; V	0.3–105	25–50		[39,63,98,132, 133]
Guanacaste	Tropic	Brazil, Costa Rica, Mexico, Venezuela	-; -; 23–28	Y (tree)	750–2000						[134]
Horse gram	Tropic	Australia, India, USA	-; 40; 20–32: no frost	120–150 d	380–900	N, P	F; I	0.5		*Bradyrhizobium*	[39,90,100,118, 135,136]
Housa groundnut	Tropic	Cameroon, Nigeria, Senegal	18; 34; 25–32	70–180 d	500–600	Few	F	0.5	42	*Bradyrhizobium* *Rhizobium* spp.	[39,137,138]
Itching bean	Tropic	India	-; -; 19–27		400–3000			0.2–2			[139]
Jack bean	Tropic	Brazil	-; -; 13–27	180–300 d	800–2000		N	4.5			[100,140,141]
Kedaung	Tropic	Bangladesh, India, Egypt, Malaysia				N, P, K	F, I				[142]
Kidney bean	Temperate	Brazil, China, EU, India, Mexico, USA	−1; 30;15–20	65–105 d	300–600	N, P, K, S, Zn	F; I; N; V	2.2	20–44	*Rhizobium*	[98,130,132, 143]
Lablab	Tropic	Cameroon, India, Madagascar	-; -;18–30	54–220 d	650–3000	Few	F; I; N; V	1.4–4.5	20–140	*Rhizobium* spp. NGR234	[63,90,98,116, 144–146]
Lima bean	Temperate	Brazil, Mexico, Peru	>0; >37; 16–27	115–180 d	900–1500	N, P, K, Zn	B; F; I; N; V	0.4–5	40–60	*Bradyrhizobium* *Rhizobium* spp.	[39,90,98,147–149]
Morama bean	Tropic	India	-; 37; -	Y	100–900						[39,137]
Moth bean	Tropic	Australia, India, Pakistan, Thailand, USA	25; 45; 24–32	70–90 d	200–750		I; N; V	0.07–2.6		*Bradyrhizobium* *Rhizobium* spp. NGR234	[39,116,150–152]
Mung bean	Temperate	China, India	12; 40; 28–30	50–120 d	600–1000	P, K, Ca, Mg, Zn	B; F; I; V	0.3–2.2	14	*Rhizobium inoculums*	[39,92,98,102, 153–156]
Navy bean	Temperate/Tropic	Australia, EU, USA	12; 35; 22–30	53–300 d	400	N, P, Zn	B; F; I	0.5–5	125	*Rhizobium phaseoli*	[39,130,157, 158]
Narbon bean	Temperate	Australia, Iraq, Italy, Jordan, Portugal, Spain, Turkey	30; -; -	170 d	200–500		PW; F; I; N; V	0.5–2			[30,126,127, 159–161]
Pigeon Pea	Tropic	India, Kenya, Malawi, Myanmar, Nepal, Tanzania, Uganda	0; 40; 18–29: no frost	3–5 y	600–1400	P	I; N	0.6–5	69–134	*Bradyrhizobium* spp.	[63,92,98,102, 141,162–164]
Pinto bean	Temperate	USA	-; 36; 21–25	90–100			B; V	0.5–3.9			[165,166]
Pinto peanut	Tropic	Argentina, Brazil, Colombia, USA	-; -; 21–30		1100–1500	K, Al, Mn	F; N; V	0.3–3			[63,167–169]
Purple mucuna	Tropic	India	-; 19–27; -	Y	400–3000						
Red moneywort	Temperate/Tropic	Australia, Asia, Madagascar			600–1500			3–7.5		*Bradyrhizobium*	[170]
Rice bean	Temperate-Tropic (Alt≈2000 m)	Bangladesh, China, India, Nepal	10; 40; 25–35	120–150 d	700–1700	P	B; F; I	0.2–2.7		*Rhizobium* spp. NGR234	[39,90,102,118, 171–174]

Table A1. *Cont.*

Pulses—Common Name	Climate Region	Countries Where Cultivated	Temperature (°C) Min; Max; Optimal	Crop Length [a]	Water Requirements (mm)	Mineral Requirements	Pest Risk [b]	Yield (t/Ha)	Kg N Fixed (kg/ha)	Bacteria Associated	References
Scarlet runner bean	Temperate-Tropic (Alt≈2000 m)	Africa, Central & South America, EU	5; >37; 25	120–150 d	1500	F	F;	0.9–12.5		*Rhizobium*	[39,149,175]
Sesban	Tropic	Chad, Egypt, Kenya, Uganda	7; 45; 17–20	Y (tree)	500–2000	P, K	F; I; N; V			*Rhizobium leguminosarum*, *Bradyrhizobium*	[98,170,176–178]
Sword bean	Tropic	India	-; -; 25–30	150–300 d	900–1500		F; I; N	1.5–5.4	75–230		[39,98]
Tamarind	Tropic	Australia, Cameroon, China, India, Mexico, Nigeria	4; 41; 15–28	Y (tree)	32–3800	P	B. F; I; N				[179–183]
Tarwi	Temperate (Alt≈3000 m)	South America	<0; -; -	150–330 d		N, P	F; I; V	0.6–4.8	100		[90,184]
Tepary bean	Temperate/Tropic	Guatemala, Mexico, USA	8; >32; 17–25	60–120 d	400–1700	P	B; F; I; N; V	0.4–1.7		*Bradyrhizobium*, *Rhizobium leguminosarum bv. phaseoli*	[39,90,130,149,185]
Urad	Tropic	India, Pakistan	-; -; 25–35 no frost	60–140 d	600–1000	P, B	F; I	0.3–2.5	18	*Bradyrhizobium yuanmingense*	[62,153,154,186]
Velvet bean	Tropic	India	5; -;19–27	D or Y	1200–1500		I; N	0.5–3.4	60–330	*Bradyrhizobium* sp.	[90,98,187–191]
Winged bean	Tropic	India, Indonesia, Philippines, Sri Lanka	-; -;20–30	120–180 d	1000		F; I	0.7–1.9		*Rhizobium* spp. NGR234	[116,192]
Yam bean	Tropic	Costa Rica, India, Mexico, Peru	-; 35–40; -	2 Y		N, P, K	N; I	A *	165–215	*Rhizobium* spp. NGR234	[64,116,193,194]
Broad bean	Temperate/Tropic	Australia, China, Ethiopia, EU, Jordan, USA	−12; 30;18–27	90–220 d	700–1200	N, P, K, Ca	F; I; N; V	1.1–2.2	33–550	*Rhizobium Leguminosarum*	[39,92,98,130,132,195,196]
Chickpea	Temperate/Tropic	EU, Middle East, South Africa	−11; >32; 10–29	90–180 d	500–1800	P, Zn, S, B	F; I; N; V	1–5.5	35–140	*Rhizobium cicerii*	[39,92,98,130,153,195,197–201]
Common bean	Temperate	Australia, Africa, Canada, EU, Middle East, USA	−9; 38; -	70–110 d	274–550	N, P, S, Mo	F; I; V	0.9–2.6	465	*Rhizobium leguminosarum*; *Rhizobium tropici*	[202–213]
Field pea	Temperate/Tropic	Canada, China, EU, India, Russia	<0; -; 7–30	90–180 d	400–1000	N, P, K, Mg	F; I; N; V	1–4	30–96	*Rhizobium leguminosarum*	[39,92,98,130,132,156,195,214]
Lentil	Temperate	Australia, Canada, EU, Middle East	2; 35; 6–27	80–130 d	300–2400	N, P, K	F; I; N; V	0.8–7	50	*Rhizobium*	[39,92,98,102,130,153,195,215,216]
Lupin	Temperate	Australia, EU, Middle East, Ukraine	<0; -;18–24	115–330 d	400–1000	P, Fe	F; I; V	0.5–5	90–400	*Rhizobium lupini*	[39,92,98,132,195,217–220]

[a] Crop length: days (d), years (Y); [b] pests: fungi (F), insects (I), bacteria (B), nematodes (N), virus (V), parasite weeds (PW); * A: the tuber of the plant is the main crop use.

Appendix B

Table A2. Nutritional composition of minor pulses, in grey major pulses.

Pulses—Common Name	Energy (kcal/100 g)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)	Vitamins	Minerals	Reference
Acacia leucophloea	382	27	5	58	7		Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[88,221]
Adzuki bean	329	19.9	0.5 (0.2)	62.9	12.7	B_1, B_2, B_3, B_6, B_9, A	Ca, Fe, Mg, P, K, Na, Zn	[38,222]
African locust bean	414	24–34	19–23	67	11.7	C	Ca, Fe, Mg, K, Na, Zn, Cu, Mn	[99,223–227]
African nut bean	649	26.3	58.1	4.6	2.7		Ca, Fe, Mg, P, Zn, Cu	[99]
African oil bean	206	48.5	33.4	8.9	6.3	C, B_1, B_2, B_3	Ca, Fe, Mg, P, K, Na, Cu, Mn, Pb	[71,99,226,228]
African yam bean	365	20.5	1–12.2	65–78	7–12		Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[71,79,229,230]
Bambara groundnut	408	18–30	6.2 (2.0)	33.4–68.5	1.9	C, B_1, B_2, B_3,	Ca, Fe, Mg, P, K, Na, Se	[40,104,231–235]

Table A2. *Cont.*

Pulses—Common Name	Energy (kcal/100 g)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)	Vitamins	Minerals	Reference
Butterfly pea	-	25.2	3.7	19.9	9.2		Ca, P	[236]
Cowpea	343	23.9	2.1 (0.5)	59.6	10.7	C, B_1, B_2, B_3, B_6, B_9, A	Fe, Mg, Zn, Cu, Mn, Cr, Ni, Al, Pb	[38,40,237,238]
Ervil	324	20–28	11–16	61			Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[239–243]
Fenugreek	323	23.0	6.4	58.0	25.0	C, B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn, Mn	[38,244,245]
Grass pea	-	24.4	2.8 (0.8)	55.94	11.4	C, B_1, B_2	Ca, Fe, Mg, P, Zn	[155,221,246]
Guanacaste	-	33.9	2.8 (0.1)	56.8	1.3		Ca, Fe, Mg, K, Na, Zn, Cu	[236,247]
Horse gram	280	22	0.6	37.5	5.7		Ca, Fe, Mg, P, Zn, Mn, Cu	[248–250]
Housa groundnut	367	19–21	1.1	67–74	5.5	C, B_1, B_2, B_3	Ca, Fe, P, K	[38,40]
Itching bean	382	27–37	6.6–8.8	46–53	6–10	C, B_3	Ca, Fe, Mg, P, K, Na, Cu, Mn	[28,251,252]
Jack bean	389	21–27	3.5 (0.3)	60.6	2–8	-	Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn, Pb	[40,253,254]
Kedaung		20.1	20 (13)		0.98		Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[255,256]
Kidney bean	333	23.6	0.8 (0.1)	30.0	24.0	C, B_1, B_2, B_3, B_9, K, E	Ca, Fe, Mg, P, K	[38,237,257]
Lablab	344	21–29	1.7 (0.3)	60.74	25.6	B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn	[38,40,258,259]
Lima bean	338	21.5	0.7 (0.2)	63.4	19.0	B_1, B_2, B_3, B_6, B_9, K, E	Ca, Fe, Mg, P, K, Na, Zn	[38,230]
Morama bean	635	29–38	32–42 (10)	18.9	19–27	E	Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[260,261]
Moth bean	343	23–26	1.6 (0.4)	61.5	5	C, B_1, B_2, B_3, B_6, B_9, A	Ca, Fe, Mg, P, K, Na, Zn	[38,40]
Mung bean	347	15–28	1.2 (0.4)	62.6	16.3	C, B_1, B_2, B_3, B_6, B_9, A	Ca, Fe, Mg, P, K, Na, Zn	[38,40,235,262,263]
Narbon bean	271	26.9	10–15	52–53			Ca, Fe, Mg, P, K, Zn, Cu, Mn, S	[241,264,265]
Navy bean	337	22.3	1.5 (0.2)	60.8	15.3	B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn	[38,266]
Pigeon pea	343	13–26	1.5 (0.3)	62.8	15	B_1, B_2, B_3, B_6, B_9, A	Ca, Fe, Mg, P, K, Na, Zn	[38,40]
Pinto bean	347	21.4	1.2 (0.2)	62.6	15.5	C, B_9, K, E	Ca, Fe, Mg, P, K, Na, Zn	[38,266]
Pinto peanut		27.1	49.7 (9.4)	21.4				[267]
Protein pea	352	23.8	1.2 (0.2)	63.7	25	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Purple mucuna	417	23.9	13.3 (5.3)	51.7	8.1	C, B_3	Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[268]
Red moneywort	439	16–27	14.0 (2.8)	54.6	4.25		Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[269,270]
Rice bean	338	18–19	0.5 (0.3)	59.1	7.1	C, B_2	Ca, Fe, P, Zn, Cu, Mn	[38,40,75,172]
Scarlet runner bean	338	20.3	1.8 (-)	62.0	4.8	C, B_1, B_2, B_3	Ca, Fe, P	[231]
Sesban	459	30–40	5–6 (1–2)	45–47	11–16			[83,271]

Table A2. *Cont.*

Pulses—Common Name	Energy (kcal/100 g)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)	Vitamins	Minerals	Reference
Sword bean	361	24–30	2.6–9.8 (-)	41–59	7–13	C, B_1, B_2,	Ca, Fe, Mg, P, K, Na, Zn, Cu, Pb, Hg	[40,253,272,273]
Tamarind	239	24–25	8–12.5	10–19	3–4	C, B_1, B_2, B_3	Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[179,274–276]
Tarwi	440	41–51	14–24 (19)	28.2	7.1			[40,184,277]
Tepary bean	353	19–24	1.2 (-)	67.8	4.8	B_1, B_2, B_3	Ca, Fe, P, K, Na	[40,231,262,278]
Urad	341	25.2	1.6 (0.1)	59.0	18.3	B_1, B_2, B_3, B_6, B_9, A	Ca, Fe, Mg, P, K, Na, Zn	[38]
Velvet bean	373	20–29	6–7	50–61	9–11		Ca, Fe, Mg, P, K, Na, Zn, Cu, Mn	[38,39,279–285]
Winged bean	428	30–35	16.3 (2.3)	41.7	11–26	B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn	[38,40,281]
Yam bean	390	10–32	24–26	31–33	7–8	C, B_1, B_2, B_3, B_6	Ca, Fe, Mg, P, K, Na, Zn, Mn, Se	[72,286,287]
Broad bean	341	26.1	1.53 (0.3)	58.3	25	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38,288]
Chickpea	378	11–31	6.0 (0.6)	63.0	12.2	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38,40,289–291]
Common bean		20–24	0.8 (0.6)	75.5		B_9, A	Ca, Fe, Mg, K, P, Na, Zn, Mn, Se, S, B	[292–294]
Field pea	352	23.8	1.2 (0.2)	63.7	25	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Lentil	352	24.6	1.1 (0.2)	63.4	10.7	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn, Se	[38,295–297]
Lupin	371	36.2	9.7 (1.2)	40.37	18.9	C, B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn	[38,298]

Appendix C

Table A3. Nutritional composition of grains of non-pulses crops.

Other Crops—Common Name	Latin Name	Energy (Kcal)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)	Vitamins	Minerals	References
African walnut	*Tetracarpidium conophorum*		30.1	43.4	16.9	2.6		Ca, Fe, Mg, K, Mn, Ni, Pb, Na, Cu	[299,300]
Almond	*Prunus dulcis*	579	21.2	49.9 (3.8)	21.6	12.5	B_1, B_2, B_3, B_6, B_9, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Cashew	*Anacardium occidentale*	552	18.2	43.9 (7.8)	30.2	3.3	C, B_1, B_2, B_3, B_6, B_9, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Castor bean	*Ricinus communis*	579	20.2	45.0		3.1		Ca, Fe, Mg, P, K, Na, Zn	[226]
Chia	*Salvia hispanica*	486	16.5	30.7 (3.3)	42.1	34.4	C, B_1, B_2, B_3, A, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Conophor nut	*Tetracarpidium conophorum*	590	22.8	4902		5.5		Ca, Fe, Mg, P, K, Na, Zn	[226]
Cotton	*Gossypium hirsutum*		26–46	30–38		17.3		Ca, Mg, P, K, S	[301–303]
Cram Cram	*Cenchrus Biflorus*	370	17.8	8.5	62.3		B_1, B_2, B_3	Ca, Fe, P	[231]
Egusi melon	*Citrullus colocynthis*	537	31.4	43.9		6.6	B_1, B_2, B_3	Ca, Fe, Mg, P, K, Na, Zn, S	[226,304]
Flaxseed	*Linum usitatissimum*	376	24.4	30.9 (2.9)	0	38.6	B_1, B_2, B_3, K	Ca, Fe, Mg, P, K, Na, Zn, Mn	[305]

Table A3. *Cont.*

Other Crops—Common Name	Latin Name	Energy (Kcal)	Protein (%)	Oil (Saturated FA) (%)	Carbohydrate (%)	Fiber (%)	Vitamins	Minerals	References
Groundnut [a]	*Arachis hypogaea*	570	25.1	47.6	20.9	8.7	B_1, B_2, B_3, B_6, B_9	Ca, Fe, Mg, P, K, Na, Zn	[38]
Hazelnut	*Corylus avellana*	628	15.0	60.8 (4.4)	19.2	11.2	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Hemp	*Cannavis sativa*	553	31.6	48.8 (4.6)	8.7	4.0	C, B_1, B_2, B_3, B_6, B_9, A, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Kalahari white bautinia	*Bautinia Petersiana*	371	22.9	13.1(3.0)	40.2	13.0	B_1, B_2, B_3	Ca, Fe, P	[39]
Linseed	*Linum usitatissimum*	534	18.3	42.2 (3.6)	28.9	27.3	B_1, B_2, B_3, B_5, B_6, B_9, B_{12}, E, K	Ca, Fe, Ni, P, K, Na, Zn, Mn, Se, Co, Cu, Cr	[38]
Millet	*Pennisetum glaucum*	378	11.0	4.2 (0.7)	72.9	8.5	B_1, B_2, B_3, B_6, B_9, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Pistachio	*Pistacia Vera*	560	20.2	45.3 (5.9)	27.2	10.6	C, B_1, B_2, B_3, B_6, B_9, A, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Quinoa	*Chenopodium quinoa*	368	14.1	6.1 (0.7)	64.2	7.0	B_1, B_2, B_3, B_6, B_9, A, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Rapeseed	*Brassica napus*		18–20	43–45		23–27			[306,307]
Sesame	*Sesamun indicum*	573	17.7	49.7 (7.0)	23.5	11.8	B_1, B_2, B_3, B_6, B_9, A, E	Ca, Fe, Mg, P, K, Na, Zn	[38]
Soybean	*Glycine Mac Merrill*	446	36.5	19.9 (2.9)	30.2	9.3	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Spirulina (dried)	*Arthrospira maxima*	290	57.5	7.7 (2.7)	23.9	3.6	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]
Sunflower (kernel)	*Helianthus annuus*	584	18–21	51.0 (4.4)	20	8.6	C, B_1, B_2, B_3, B_6, B_9, A, E	Ca, Fe, Mg, P, K, Na, Zn, Se	[38]
Walnut	*Juglans* spp.	654	15.2	65.2 (6.1)	13.7	6.7	C, B_1, B_2, B_3, B_6, B_9, A, E, K	Ca, Fe, Mg, P, K, Na, Zn	[38]

[a] Equivalent to peanut.

Appendix D

Table A4. Antinutritional constituents of pulses and other crops with high protein content, in grey major pulses.

Crops—Common Name	Phytic Acid (mg/g)	Tannins Total (mg/g)	Saponins ()	Trypsin Inhibitors (mg/100 g)	Lectins (mg/100 g)	Others [a]	References
Acacia leucophloea	Presence	0.01		Presence			[221]
Adzuki bean		2.9					[308]
African locust bean	0.6	0.81		19.4		HCN; OX	[224–226]

Table A4. *Cont.*

Crops—Common Name	Phytic Acid (mg/g)	Tannins Total (mg/g)	Saponins ()	Trypsin Inhibitors (mg/100 g)	Lectins (mg/100 g)	Others [a]	References
African nut bean	Presence	0.07–0.3				OX	[309]
African oil bean	41	7.9	17.8			HCN	[99,226]
African yam bean	4.3–14.9	18.1	1.2	6.7		HCN; OX	[79,310]
Bambara groundnut	0.5–14.8	tr-5.0	1.4	6.7		OX	[232,311–313]
Butterfly pea	11.5	8.7				HCN; L-DOPA [i]	[236]
Castor bean	0.89	0.11				OX; A	[226]
Conophor nut	2.1	0.21				OX	[226]
Cotton		0.1				GO	[302]
Cowpea	1.4–3.8	1.4–10.2	0.3	26.4 [b]		HCN; OX	[82,311,314, 315]
Egusi melon	4.1	0.8				OX	[226]
Ervil		Presence		Presence		PA	[239,241]
Fenugreek			0.1–0.9				[244,245]
Grass pea	3.0	0.2–0.8		19.64 [b]		β-ODAP; CTI	[246,316–319]
Groundnut [h]	4.18	0.04		80.8 [b]		OX; HCN; AL; AI	[87]
Guanacaste	9.5	3.7				HCN; L-DOPA	[236]
Horse gram		2		865			[248,250]
Housa groundnut	Presence	Presence			Presence		[320]
Itching bean	4.7–56.8	1.8–3.3	1.2–1.3	43.2–43.7 [b]		HCN	[28,251,311]
Jack bean	12.0–13.7	Tr-0.7	1.8	16.4 [b]		HCN; CV; OX	[230,311,314, 321,322]
Kedaung		98.3	0.3	6.94 [b]			[81,142]
Kidney bean	17.3–24.1	5.4–28.8	0.9–23	4.6–29.3 [b]	1.92–9.98 [c]	HCN; OX	[82,323]
Lablab	6.1–15.7	0.2–0.4	1.3	19.7 [b]		OX	[230,258,311, 314,322]
Lima bean	13.6	6.5–9.1	1.2–1.5	2.1–17.2 [b]		HCN; OX	[230,308,311, 322]
Linseed						HCN	[324]
Morama bean			0.08	Presence			[263,325]
Moth bean	3.8–4.2	4.8–13	33	28.3–31.4 [b]		HCN	[82,311]
Mung bean	5.8–7.4	4.4–8.0	2.8–35	15.8 [b]	2670 [d]	OX	[82,84,308, 326]
Narbon bean		Presence		Presence		PA	[239,241,327]

Table A4. *Cont.*

Crops—Common Name	Phytic Acid (mg/g)	Tannins Total (mg/g)	Saponins ()	Trypsin Inhibitors (mg/100 g)	Lectins (mg/100 g)	Others [a]	References
Navy bean	12.9–15.8	39.9	20–160	5.9 [f]	3.8 [c]	OX	[82,328–330]
Pigeon pea	7.3–16.2	3.8–17.1	0.04–1.4	4.1–19.2 [b]		HCN; OX; CTI; PA	[40,82,230,311,331]
Pinto bean		2.6			2.3 [c]	OX	[82,266,308,330]
Pinto peanut		Presence					
Purple mucuna	3.8–4.5	1.8–3.4		39.2–44.1		HCN	[311]
Rapeseed	Presence	Presence				Glucosinolates	[324]
Red moneywort		Presence					[269]
Rice bean	3.3–20.3	2.4	2.3	34.3–40.6	Tr	HCN	[75,172,311,332]
Scarlet runner bean				Presence *	Presence *		[333,334]
Sesban	18–51	19	5.2–14.6	50–140	Presence	PA	[83,272]
Sword bean	3.5–21.4	0.01–570	1.7–5.2	17.4–26.8 [b]		HCN; OX	[80,230,311,322,335]
Tamarind	Presence	Presence		Presence			[180,336]
Tarwi				T		AL; HCN	[184]
Tepary bean			1–37	11.5–18.0 [b]	1.4–18.2 [e]		[82]
Urad	11.2–14.6	5.4–11.9	0.2–23	94.2 [g]			[82,308,314,337]
Velvet bean	5.0–53.6	1.8–3.1		43.2–52.8		AL; HCN; L-DOPA	[28,311,321,338–342]
Winged bean	7.8–12.3	0.3–12.6		0.01–0.14 [e]	76 [e]	CTI	[343,344]
Yam bean	Tr	Tr		0.01	0.0003	HCN	[287]
Broad bean	6.4	0.1–24.1	0.4–370	1.7–3.3 [b]	25–100 [d]	CTI; L-DOPA	[82,87,311,345]
Chickpea	1.2–12.1	08–5.9	0.09–600	11.9 [b]	6.22 [d]	HCN; OX; PA; CTI	[40,82,311,346]
Common bean	8.2			0–4.64 [g]	8.57	CTI; AI	[82,294,347]
Field pea	2.2–7.4	0.2–13	18–110	1.5–108	5.1–150.6	OS; PA; AI; HCN; CTI	[82,348]
Lentil	2.4–12.4	12.8	0.04–0.13	2.8		OX; AI	[349,350]
Lupin	1.4–3.5	ABS	ABS	ABS	ABS	PH; AL	[351–353]
Soybean	10.0–23.0		0.2–5.6	0.2–1.12 [b]			[230,311,354]

[a] Presence of: OS: oligosaccharides; PA: phenolic acid; AI: amylase inhibitor; HCN: hydrogen cyanide; CV: canavanine; OX: oxalate; A: allergens; PH: phomopsine; GO: gossypol; CTI: chymotrypsin inhibitors; GC: γ-glutamyl-β-cyanialanine; VC3: vicianine + vicine + convincine; CA: caravanine; AL: alkaloïds; β-ODAP (beta-oxalyl-diamino-propionic acid); TAN: tannins; [b]: units trypsin units inhibited TUI/mg protein; [c]: units g/kg PHA: lectin as PHA (*P. vulgaris* lectin); [d]: units HU/mg sample; [e]: units HUA/g proteins; [f]: units TIA/g sample; [g]: units IU/g seed; [h]: data reported in groundnut oil; [i] l-3,4-dihydroxyphenylalanin; ND: non-detected; Tr: traces; ABS: absence; * presence: molecules detected but unquantified.

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