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SYSTEMATIC MAP

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Evidence of development of underutilised crops and their ecosystem services in Europe: a systematic mapping approach

Todd Jenkins[1*], Sofie Landschoot[2], Kevin Dewitte[2], Geert Haesaert[2], John Reade[1] and Nicola Randall[1]

Abstract

Background Growing interest in agrobiodiversity and sustainable agricultural practices has stimulated debates on diversifying cropping systems, furthering the potential for the reintroduction of underutilised crops. These crops may support multiple ecosystem services and enhance food security and agricultural value chains. This study used a systematic mapping approach to collate and summarise the state of research literature addresses the research question: What is the evidence for ecosystem service provision and economic value of underutilised crops? We focused on oats, triticale, hull-less barley, narrow-leaved lupin, buckwheat and faba beans due to their limited use in Europe, their broad gene pool, ecological benefits, and nutritional value.

Method Three academic databases were used to identify research articles investigating the impacts of using the six underutilised crops of interest on outcomes including breeding, agronomic traits, nutrition and health, and economic values. In addition, current and recently completed European projects were searched to identify ongoing relevant research. After screening for relevance, data was extracted from all included articles and projects and imported into a spreadsheet for cross-tabulation and to produce descriptive statistics.

Results From an initial 34,522 articles identified by the searches, 1346 relevant primary research articles containing 2229 studies were included. A total of 38 relevant European projects were identified, with 112 research results or goals relating to the six underutilised crops. Faba bean was the most common crop in both European projects and published literature. No current projects had a focus on hull-less barley. Agronomic traits were the most common primary research topic across the crops (56.39%), with oats and faba bean being well researched. Hull-less barley was the least studied crop across all topics. Within sub-topics related to specific ecosystem services, desirable traits, disease, weed and pest control all ranked highly, whilst invertebrate diversity and nitrogen fixation ranked lowest.

Conclusion Primary research varies between crops and topics, with hull-less barley receiving the least interest. Key knowledge gaps were identified in all crops across all topics relating to breeding tools, breeding for desirable traits, agronomic traits of buckwheat, narrow-leaved lupin and hull-less barley, inclusion of the crops in human nutrition and health, and the socioeconomics of these crops. Evidence presented in this map could inform further research areas with these crops and aid future policy making for the inclusion of these crops in rotations and practices that could benefit all stakeholders along the food systems value chain.

Keywords *Avena sativa*, *Lupinus angustifolius*, *Fagopyrum esculentum*, *Vicia faba*, Naked barley

*Correspondence:
Todd Jenkins
tjenkins@live.harper.ac.uk
Full list of author information is available at the end of the article

Background

Agricultural land, including natural grassland, accounts for almost half of the European territory (48%) (European Commission 2021), and global cultivated land has increased by about 12% since the 1960s (FAO 2022). Historically, the focus has been on the intensification of agricultural systems for increased outputs (Thies et al. 2011; Emmerson et al. 2016) including enhancing food production and increasing yields. However, this focus has often overlooked the role of agricultural land in providing ecosystem services (Thies et al. 2011; Emmerson et al. 2016). Recently, there has been a growing awareness of the need for sustainable agriculture, with agricultural biodiversity playing a crucial role. Agricultural biodiversity, or agrobiodiversity as it is more commonly coined, can be defined as "*The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry, and fisheries.*" (FAO 2021). Agrobiodiversity is a valuable tool for facilitating ecological intensification and acting as a bridge between traditional and modern agricultural systems, thus promoting contemporary development, social integrity, and ecological health (Johns et al. 2013). The evolving discourse surrounding food production systems has prompted policy exploration and the need for more sustainable agricultural practices (Béné et al. 2019). One such approach involves the diversification of cropping systems, which can enhance the provision of ecosystem services, including pollination services and soil stabilisation (Tamburini et al. 2020), as well as providing services for diversifying nutrition and health for humans. Improving nutritional and agronomic value of crops can be achieved by understanding and utilising modern plant breeding techniques. Exploring the introduction of new or underutilised crops in arable rotations offers alternative solutions to reducing inputs and enhancing food security.

Crop diversification can provide key provisioning services (such as food production) and enhance important ecosystem services and biodiversity (Power 2010), benefitting agriculture, with simplification showing an adverse effect on these wider services (Deguines et al. 2014). Diverse crop rotations, intercropping and alternative crops increase floral/faunal diversity, including pollination services (Bavec 2015). Such diversification sustains biodiversity, especially increasing natural pest enemies (Rusch et al. 2013), emphasizing its role in sustainability and ecosystem service improvement. Implementing these rotations can also enhance crop production and soil health, as well as biodiversity and natural pest control (Beillouin et al. 2021). Diversification strengthens robustness, boosts soil health, and improves productivity, counteracting the impact of agricultural intensification (Li et al. 2019). Studies have shown that adding diversification can enhance soil health and crop productivity (Chahal et al. 2021). Diversification may also elevate soil microbial activity and organic compound sequestration when coupled with conservation practices such as low tillage (Eerd et al. 2014) increase carbon storage as well as soil health and crop yield (Sainju et al. 2017).

Ecosystem services extend to improved human and livestock health and increased economic value in agriculture. Diversified agriculture is key for nutritional stability in food systems (Nicholson et al. 2021). Crop diversifications offer opportunities to combat poverty, hunger, and malnutrition in affected regions (Li et al. 2020), but slow adaptation is linked to yield concerns, necessitating improved growing practices for food security and nutrition (Grovermann et al. 2018). Introducing nutrient-rich legumes may cost-effectively aid poor and undernourished populations (Bhat and Karim 2009). Plant breeding, including traditional methods like crossbreeding and hybrid breeding as well as advanced techniques like CRISPR and speed breeding, is pivotal for developing crops with desirable traits (Fahey 2015; Swarup et al. 2021; Ahmar et al. 2020). For example, breeding programmes in the US have combined different varieties to improve fibre and protein content within the vegetable Amaranth (Shukla et al. 2010). Recent scientific advancements in breeding techniques also enable rapid and more varied trait expression within crops (Varshney et al. 2006). They have addressed various issues including reducing free asparagine in wheat via CRISPR/Cas9 (Raffan et al. 2021) and improving leaf rust resistance with DNA markers linked to known genes (Riaz et al. 2017). Rapid breeding methods expedite desired trait integration compared to traditional breeding, aiding in the creation of environmentally resilient crop varieties that have the potential to meet growing food demands. These techniques, however, currently require specialised infrastructures and have high-cost considerations (Li et al. 2018), but support the development of high-yielding crop varieties and offer opportunities for targeted breeding to enhance ecosystem services, including pest and disease resistance often compromised in traditional yield-focused breeding (Ficiciyan et al. 2018). The choice between modern varieties and landraces depends on farmers' priorities and the social-ecological context (Ficiciyan et al. 2018). These breeding techniques and the push towards diversifying cropping systems offer a unique opportunity to re-introduce underutilised crops into cropping system around the world.

Underutilised crops are wild or domesticated plant species, which were once important for food, fibre, fodder, oil, or medicinal properties, but have been replaced by economic crops (Li et al. 2020). Re-introduction of these crops has the potential to increase soil biodiversity, and support pest control, and disease management when integrated into crop rotations (Bavec et al. 2018). Diversifying cropping systems with underutilised crops may also offer benefits such as nutrient fixation, weed control, and stable yields, promoting long-term agricultural sustainability (Bavec 2015). Alongside the potential to contribute to increase agrobiodiversity, their adoption may also help contribute to food security, in particular in relation to climate change (Mayes et al. 2012; Massawe et al. 2015; Mustafa et al. 2019) and could potentially improve livelihoods and nutrition in impoverished regions (Jamnadass et al. 2011).

The six underutilised crops studied in this review are: oats (*Avena sativa*), triticale (*x triticosecale*), hull-less barley (*Hordeum vulgare* L. var *nudum* Hook. f.), buckwheat (*Fagopyrum esculentum*), narrow-leaved lupin (*Lupinus angustifolius*), and faba beans (*Vicia faba*). These crops were decided upon by key stakeholders of the EU, Horizon 2020 funded project, CROPDIVA (https://www.cropdiva.eu/), and were identified and, in addition to their relatively low use in Europe, were chosen for three reasons: each is characterised by a broad gene pool, their ecological benefits, and high nutritional value.

Possessing a broad gene pool is valuable for a crop as it will allow the crop to possess an extensive genetic diversity that will allow it to both withstand environmental variability (for example more readily adaptable to climate change) and facilitate breeders to develop varieties more easily to suit the most important traits to them and the wider value chain within food systems.

Some examples of the ecological benefits associated with a sustainable crop management system containing the underutilised crops studied in this review include, but are not exclusive to, oats demonstrating biomass production which increase ground cover and rooting systems to support water protection (Maltais-Landry et al. 2014). triticale reducing soil erosion (Blanco-Canqui et al. 2015) and hull-less barley contributing to adaptability and yield stability in varying climatic conditions (Sturite et al. 2019). Buckwheat (Wauters et al. 2021), shows various mechanism of weed suppression (Wauters et al. 2021) via resource competition and allelopathy (Falquet et al. 2015). Buckwheat (Falquet et al. 2015) also demonstrates benefit to pollinators (Clark 2007) as, being a self-incompatible species, it secretes nectar that is highly attractive to pollinator species to ensure pollen is transferred between individual plants for fertilisation (Taki et al. 2009). Narrow-leaved lupin is known to support pollinators, including providing nectar when availability is limited in agricultural landscapes (Fijen et al. 2021). Faba bean is a nitrogen fixer, and—compared to other legumes faba bean can maintain high rates of biological nitrogen fixation in the presences of high nitrogen availability in the soil (Köpke and Nemecek 2010). Faba bean is reported to be able to symbiotically fix between 15 and 648 kg N/ha in field conditions (Köpke and Nemecek 2010).

Each of the underutilised crops explored in this review also possess a high nutritious and food technology value. Oats provide more overall protein, fibre, iron and zinc than other whole grains (such as whole-grain wheat, cornmeal, brown rice, whole-grain rye, pearled barley and sorghum (Webster 2011)) and are therapeutically active against metabolic diseases such as diabetes (Sangwan et al. 2014). The biological value of Triticale protein (typically crude protein varies between 90 and 200 g per kilogram of dry matter) has been shown to be greater than that of wheat protein (Heger and Eggum 1991; McGoverin et al. 2011) this coupled with the growing knowledge of health benefits of including a range of cereal grains in diets (McGoverin et al. 2011) has increased the interest in using triticale. Hull-less barley when compared to hulled barley has been shown to have better nutritional value, containing more proteins, lipids and soluble dietary fibres (Soares et al. 2007; Škrbić et al. 2009). Buckwheat has been shown to be nutritionally valuable due to its protein, lipid, dietary fibre and mineral content, as well as having positive effects on diseases such as high cholesterol, hypertension and diabetes (Yilmaz et al. 2020). Faba bean is rich in proteins, fibres and carbohydrates, as well as being low in fats and sodium and being cholesterol-free (Etemadi et al. 2019). Faba bean also accumulates a large amount of *L*-Dopa which is currently used as a major ingredient in treating diseases such as Parkinson's disease (Etemadi et al. 2019). Narrow-leaved lupin has shown to be a source of nutraceutical proteins with health benefits making them useful function foods (Jimenez-Lopez 2020). The health benefits of this crop are also notable showing to have effects on cholesterol lowering, anti-cancer and anti-inflammatory effects (Lemus-Conejo et al. 2023), as well as protection against the symptoms of menopause and osteoporosis (Lemus-Conejo et al. 2023; Farag et al. 2018).

Despite their potential value to agricultural landscapes and the agri-food chain, at present, these crops are not a part of a traditional crop cycle in many countries in the EU. To fully ascertain the potential value of these crops it is important to understand the services they provide in relation to key topics of environmental and anthropogenic significance, including crop breeding, agronomic traits (including ecosystem services for nature), nutrition and health, and socioeconomics. The previously identified crops will hereby be referred to as 'the six underutilised crops' collectively in this study, unless further specified.

This study aims to assess the current state of research into the agronomic and socioeconomic importance of six currently underutilised crops in European agriculture (oats, triticale, hull-less barley, buckwheat, narrow-leaved lupin, and faba bean). To achieve this, a systematic mapping approach was undertaken to ascertain the knowledge gaps associated with the underutilised crops in the key topic areas: crop breeding, agronomic traits (which will be assessed agronomy, agroecology, biodiversity, and other ecosystem services related to these crops), nutrition and health, and socioeconomics.

Objectives of the systematic map

The aim of this systematic mapping approach was to assess the current state of research regarding the six underutilised crops with regards to their agronomic, nutritional, and socioeconomic value, and to identify gaps in research. An overview of research efforts in the adoption of underutilised crops has been undertaken as part of the Crops for the Future project (Gregory et al. 2019) and some efforts to study the opportunity for underutilised crops has taken place in southern Africa (Mabhaudhi et al. 2016, 2017). However, there has been no specific review of research into the use and potential benefits of underutilised crops in Europe. The objectives of this review were set by European stakeholders as part of an EU Horizon 2020 project, CROPDIVA.

Primary question

The primary question explored within this review was: '*What evidence exists relating to the ecosystem service provision and socioeconomic value of six underutilised crops: oats; triticale; hull-less barley; narrow-leaved lupin; buckwheat; and faba beans?*'.

Secondary question

A secondary question was also explored, considering the extent to which this research focusses on how these crops offer such ecosystem services.

Methods

A three-stage approach was undertaken for this review:

1. Identification of recent and ongoing European projects relating to the underutilised crops, by searching within the CORDIS (https://cordis.europa.eu/projects/en) database.
2. Carrying out a rapid review of primary research relating to ecosystem services and the socioeconomic value of oats; triticale; hull-less barley; narrow-leaved lupin; buckwheat; and faba beans. A rapid review, following systematic map principles (James et al. 2016) was undertaken to establish current knowledge and gaps.
3. Topic modelling of wider literature relating to the six underutilised crops.

Systematic mapping approach

The review was conducted in a rapid manner using a systematic mapping approach and aimed to identify, collate, and describe relevant published, primary research relating to ecosystem services and the socioeconomic value of the six underutilised crops (ROSES form for systematic maps completed in Additional file 1). The ecosystem service research relating to these crops covered a wide variety of purposes, including but not limited to agronomic traits such as the enhancement of biodiversity; the enhancement of natural pest enemies; the enhancement of pollination services; relative nutritional value to both human and animal feed; crop yield; environmental impact; and crop breeding. This was investigated alongside any potential socioeconomic value of all six of the crops. The systematic map covers all geographical regions (considering Europe and the rest of the world in individual graphics) in which research on these crops has been undertaken and consists of a report describing the review process, a searchable database describing the identified relevant studies, and heat maps of the scope of the research under relevant categories.

Definition of the question components

PICO analysis Population: Agroecosystems and food systems (farmland environments, humans, and wildlife—flora and fauna).

Intervention: Any of the following crops: oats; triticale; hull-less barley; narrow-leaved lupin; buckwheat; faba beans.

Comparator: Alternative, "traditional" crops.

Outcome: Any outcomes relating to topics of breeding, agronomic traits, nutrition, and socioeconomics.

PO analysis Within the review, multiple topic areas were included in the search criteria. The PICO question above covered topics relating to all research areas where it was relevant. Select breeding and nutritional topics were assessed by PO criteria, as stated below, when there was not a relevant comparator or outcome within the PICO framework.

Population: Six underutilised crops (as identified above).

Occurrence: Specific plant traits—These include but are not limited to research relating to articles focusing on nutritional content or those research breeding for desired plant traits.

A-priori protocol

An a-priori protocol was produced prior to commencing the review, in order to guide the process. The components of the review process were simplified to facilitate producing information in a short period of time (Tricco et al. 2015).

Search strategy

Bibliographic databases and searches In November and December 2021, specific search term combinations with Boolean search operators were entered into three online databases to capture an un-biased sample of the relevant published literature.

Searches were designed to capture an un-biased sample of literature relating to the underutilised crops and their ecosystem service and socioeconomic value. The following academic literature databases searches were undertaken for studies using English search terms for the systematic mapping approach:

Academic databases:

1. CAB Abstracts (https://www.cabdirect.org/)
2. Scopus (http://www.scopus.com/)
3. Web of Science (https://www.webofscience.com/wos/woscc/basic-search).

All articles found from Web of Science, and a subset of articles (based on relevance) from CAB Abstracts (10,000 articles) and Scopus (2000 articles), were included in the screening process. Relevance was assessed by the authors using a percentage selection of 200 papers every 1000 papers. Once the percentage relevance dropped below 10% the cut off for the subset was defined. Duplicate articles were removed, and articles were screened at title level and then again at abstract. Figures were produced using Microsoft Excel (version 2201) and EviAtlas (Haddaway et al. 2019) (https://estech.shinyapps.io/eviatlas/).

European projects

As the purpose of this map was to inform primary research being conducted as part of an EU research project (CROPDIVA), the CORDIS database (of EU funded projects) was used to collate information on projects involving any of the six named underutilised crops. Each crop name and synonyms were searched for individually within the database.

Search string

The following search string was used as a basis for searches within the three academic databases listed above for the systematic mapping. This search string was formatted to the Web of Science format:

(oat OR oats OR "Avena sativa" OR triticale OR *triticosecale OR "hull-less barley" OR "naked barley" OR buckwheat* OR "Fagopyrum esculentum" OR "narrow-leafed lupin*" OR "Lupinus angustifolius" OR "faba bean*" OR "Vicia faba") AND (nutrition* OR health OR diversity OR biodiversity OR *biodiversity OR yield OR environment* OR "ecosystem service*" OR pollinat* OR "natural enem*" OR insect OR invert* OR "water protection" OR "soil protection" OR "water quality" OR "soil quality" OR leach* OR erosion OR runoff OR "nitrogen fix*" OR *economic OR economic* OR trait* OR resistan* OR breed*).*

Search terms were firstly identified by stakeholders (all contributors to the review) and the final search string was clarified by a scoping process with all key words assembled and evaluated both individually and in combination (Additional file 2 for search string development). Terms that resulted in exceptionally large numbers of results and assessed as yielding "too broad" results were excluded from the final search string.

To cover topics related to "agronomic traits", and the six underutilised crops value in agronomy, search terms were identified to find articles that assessed the six underutilised crops and their relation to key agronomic traits. These include searches relating to the topics of agronomy, agroecology, biodiversity, and other ecosystem services (including soil and water health). For example, from scoping the search term "pollinat*" will find all studies relating to pollination, pollinators, pollinator, pollination services and anything relation to words begin with the search term. These terms were used to focus the review on the agronomical trait benefits of the six underutilised crops. Throughout the analysis of the data this category will be referred to as "Agronomy" to fit better within graphical representation of the data.

To cover topics related to "socioeconomics" in this review the term "*economic" was used. This term in the scoping showed to capture topics related to socioeconomics, as well as wider economic value of the six underutilised crops. Though this term covered "socioeconomic" within the search, some social aspects relating to the crops may have been missed as they were not included within the search string.

For the CORDIS searches, each crop name and synonyms were searched for individually within the database.

Screening strategy

All articles identified through searching were screened at title and abstract for relevance using predefined inclusion criteria (detailed below) and any duplicates across the initial search were disregarded. EPPI-Reviewer-web (EPPI-Centre Software 2022) was used to remove all duplicates by assessing all studies and removing those with a calculated similarity score of 0.7 or greater. EPPI-Reviewer-web was subsequently used for screening in two stages: titles, then abstract.

For projects listed in the CORDIS database, deliverables relating to one or more of the underutilised crops were recorded separately and categorised by topic area.

Consistency in the application of the inclusion criteria was assessed by comparing agreement between two reviewers at abstract level screening, using a subset of 2000 abstracts. Disagreements were discussed, justified and the inclusion criteria was refined where necessary and required. Agreement was evaluated formally using a kappa test (Cohen 1960), and if agreement score fell below 0.4, indicating fair agreement, a further review was conducted on a further 500 abstracts. These were screened, following resolutions of previous disagreements, and rescored to ascertain if the agreement score raises above 0.4 for this subset of abstracts. Consistency checking results were as follows: first abstract level screening, n = 2000 kappa = 0.066, this was discussed by the reviewers and one category of articles (63% of all disagreements) were said to be "false positives" from one reviewer. These articles were not included in the final criteria. Second abstract level screening, after discussions and clarifications made, n = 500 kappa = 0.71.

Inclusion criteria

Articles that met predefined inclusion criteria were then included for data extraction. Data from accepted articles were coded from their abstracts, using a simplified coding tool (Additional file 3). Where articles had more than one study within the research, each study was recorded individually.

Relevant subjects Farmland environments, humans, and wildlife.

Relevant interventions: Underutilised crops, as defined above, either introduced into a diversified cropping systems or studies relating to the ecosystem service provision, nutritional or socioeconomic value of the crop.

Relevant comparators: Traditional crops, as defined above, either as part of a diversified cropping system with the underutilised crop or in comparison to the ecosystem service provision, nutritional or socioeconomic value of the underutilised crop.

Relevant outcomes: Outcomes will be included iteratively as they were identified during screening of the literature and will be coded accordingly. Outcomes will include but are not limited to nutritional value; desirable breeding outcomes; effects on both human and livestock health via feed; yield impact; environmental impact (including that of biodiversity); ecosystem service provision (including effects on pollinators); socioeconomics.

Relevant types of study design: Primary research.

Relevant languages: All languages included where possible. Studies in languages not able to be translated will be included in a separate supplementary database.

Date: No date restrictions were applied to initial searches.

Critical appraisal

The intention of this systematic mapping was to assess the current breadth of information and status of six underutilised crops, not to examine the validity of the conclusions of those studies, as such, critical appraisals were not conducted.

Data coding strategy

Meta-data (the descriptive data describing the methods and setting of each study) was extracted from each included study and entered in a spreadsheet (Microsoft Excel). This database was populated with several variables, each given a category set out in coding tool provided by the authors (Additional file 3)—examples of each type of information are provided within the file. These parameters were tested out on a subset of 100 studies to ensure all complex data was extracted reliably. This information was entered into a database for all included studies that were available and passed screening as a relevant study at full text.

Synthesis

An access database was used to apply the coding and create a searchable database describing the scope of the research. This database was used to generate simple descriptive statistics, graphs, and complex cross-tabulations of key variables. The heatmaps were produced using EviAtlas online software with conditional formatting to visually represent knowledge gaps and clusters.

Topic modelling

Topic modelling is an unsupervised machine learning technique that seeks to find hidden semantic structure in text documents and is an efficient method to analyse large volumes of articles. Topics can be conceived of as networks of collocation terms that, because of the co-occurrence across documents, can be assumed to refer to the same semantic domain (or topic). This assumes that, if a document is about a certain topic, one would expect words that are related to that topic, to appear in the document more often than in documents dealing with other topics (Chaney and Blei 2021). Latent Dirichlet Allocation (LDA) is one of the most popular algorithms in topic modelling. It was initially proposed by Pritchard et al. (2000), later on, LDA was improved by Blei et al. (2003). For LDA, it is considered that data instances are being generated from a latent process, which is dependent on hidden variables. To run this model, the number of topics K needs to be defined. To find a "good" number of topics, four different metrics were calculated. Arun et al. (2010) and Cao et al. (2009) which need to be minimized and Griffiths (Griffiths and Steyvers 2004) and Deveaud et al. (2014) which need to be maximized. These measures select the best number of topics using a symmetric Kullback–Leibler divergence of salient distributions which are derived from the factorization of the document-term matrix (Marin Vargas et al. 2021).

Before the algorithm was run fully, a pre-processing screening was undertaken. Punctuation, stopwords (and, or the, etc.), numbers, Latin names, etc. were removed to reduce unnecessary noise within the dataset. This process identified any themes that may not have been considered during the systematic mapping process.

To investigate additional themes and patterns relating to the underutilised crops within the wider literature, the full results from the search string were used for topic modelling of broader topics that were not directly searched for or coded. In addition, a separate topic modelling exercise was also conducted for two specific sub sections on of the primary topics (agronomic traits and socioeconomics). These were conducted in SWIFT-Review (Howard et al. 2016).

Broad themes within the entire literature base, that were obtained from the initial searches (prior to inclusion criteria being applied), had a topic modelling algorithm (Latent Dirichlet Allocation) run on selected publications.

Knowledge gap and cluster identification

Knowledge gaps (subtopics that are un-represented or under-represented in the evidence base) and knowledge clusters (subtopics with sufficient numbers of studies to allow meaningful synthesis) were identified by the lead author by cross-tabulating key meta-data variables in heat maps. The team discussed, once identified by the lead author, all knowledge gaps and clusters, including those that they felt of key relevance to decision makers and readers.

For the projects collated using the CORDIS database, a heatmap showing the distribution of research relating to each of the underutilised crops was produced using EviAtlas (Haddaway et al. 2019) (https://estech.shinyapps.io/eviatlas/).

Results

European projects

38 European projects were identified from the CORDIS database that investigated one or more of the six underutilised crops. Within the 38 projects, there were 112 separate relevant deliverables identified.

Faba bean was the most common deliverable (56 of 112—within 15 projects) (Fig. 1). There are several projects (e.g., EUFABA, EUROLEGUME, FABASHAPE, TRUE and LEGATO) that focus either specifically on faba bean or on legumes. Within the literature there is a precedent for studying legumes as alternative crops in

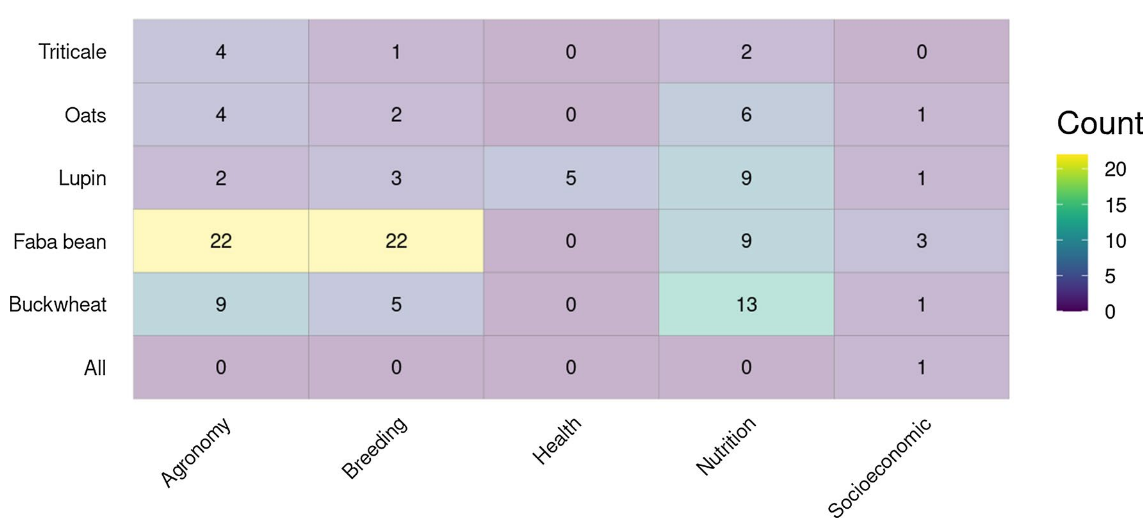

Fig. 1 Distribution of research topics (along the x-axis) recently completed or currently on going within EU funded projects in relation to the relevant crops within the six underutilised crops (along the y-axis). "All" refers to the fact that all six underutilised crops were included within the project. Hull-less barley was not included within this graphic due to featuring in no projects or work packages as a standalone study crop

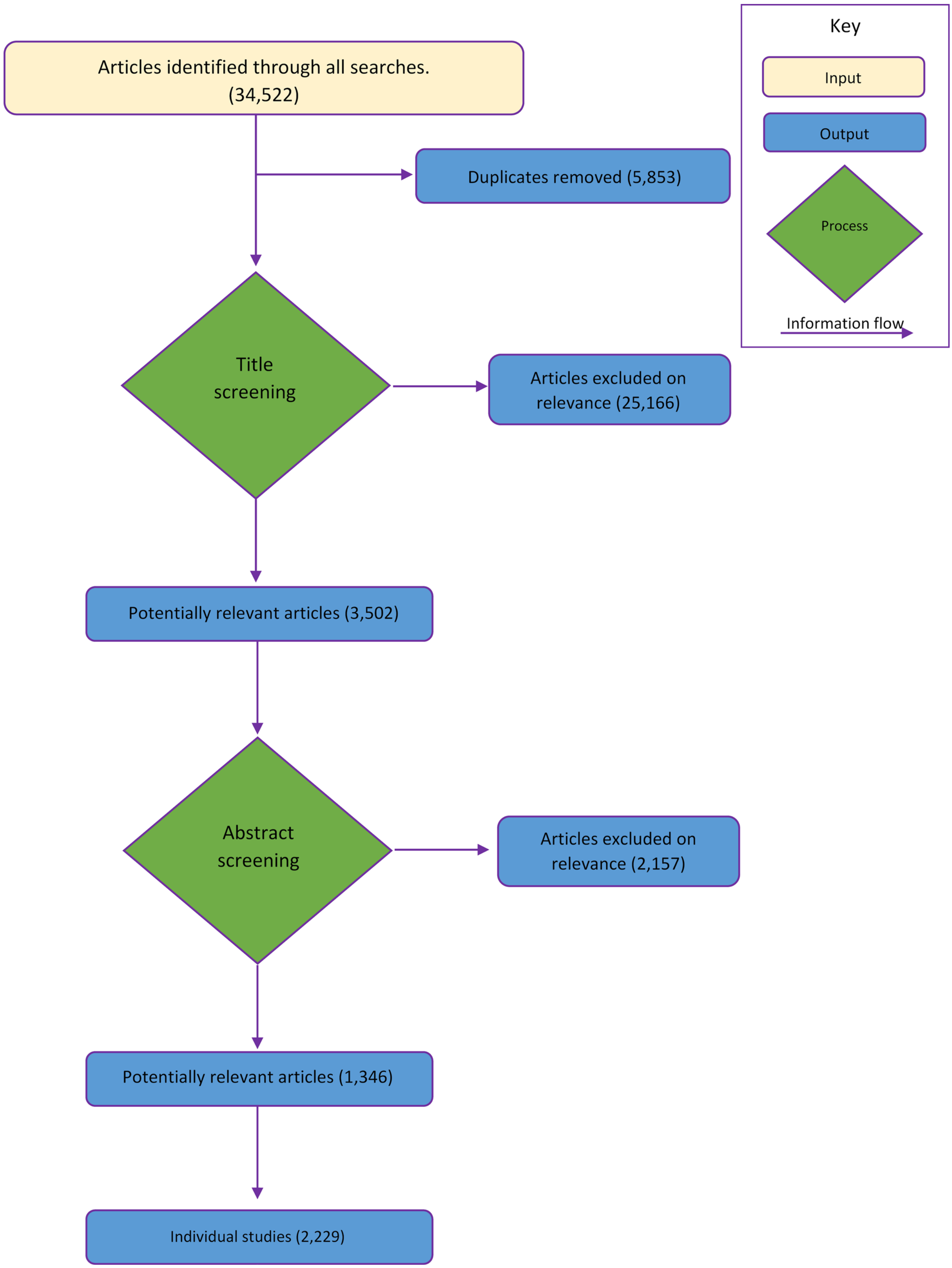

Fig. 2 Schematic of screening stages for the rapid review that lead to 1346 articles with 2229 studies from those articles that were obtained and subsequently mapped with regards to six underutilised crops within the European Union

diversified cropping systems, and for protein sources and breeding tools (Magrini et al. 2016; Ditzler et al. 2021). These studies show the importance of legumes to ecosystem services and animal nutrition, but also illustrate the agronomical benefits of utilising these crops.

No current (or recently terminated) European project has focused any resources on hull-less barley.

Oats are currently a focal point in 12 EU projects, but the focus on many projects appeared to be on diets for human disease control, such as that of coeliac disease (e.g., projects GLUTEN EPITOPES IN C and CD-CHEF, which characterised regions causative for coeliac disease and ELISA kits to detect the causative region e.g., gliadins). Four projects dealt with oats and agronomy (e.g., REMIX) and two projects focused on breeding (e.g., HEALTHYMINORCEREALS). Furthermore, there are also more regional projects on oats, not included in the Cordis database e.g., the 'Healthy Oats' project. This project has been granted from the European Regional Development Fund as part of the Ireland-Wales Cooperation Programme, which will help farmers and industry prepare for the changes pending under the EU Green deal, including reduced use of fertilisers and pesticides.

Primary research from academic databases

The search yielded a total of 22,522 results in Web of Science Core Collection. Abstract and title level screening demonstrated that a subsample of the search results had a proportional relevance of 37% (n = 100).

Articles were screened for inclusion according to the schematic in Fig. 2. A total of 34,522 articles were identified from the three databases searched. Of these, 5853 duplicates were removed, and 28,669 articles were screened at title level for inclusion for further screening. The 3503 articles that passed screening at title level were further screened using their abstract and all the accepted articles were simultaneously coded for inclusion. Articles were not read at full text, therefore certain information (such as exact geographic location) was not extracted. The coding tool (Additional file 3) was used to code each relevant study from the included articles. A total of 1346 articles were included and from these 2229 individual studies were identified, because one article contained more than one study in them (Additional file 4 for database of all studies included).

Figure 3 shows the yearly distribution of all studies within the primary research related to the six

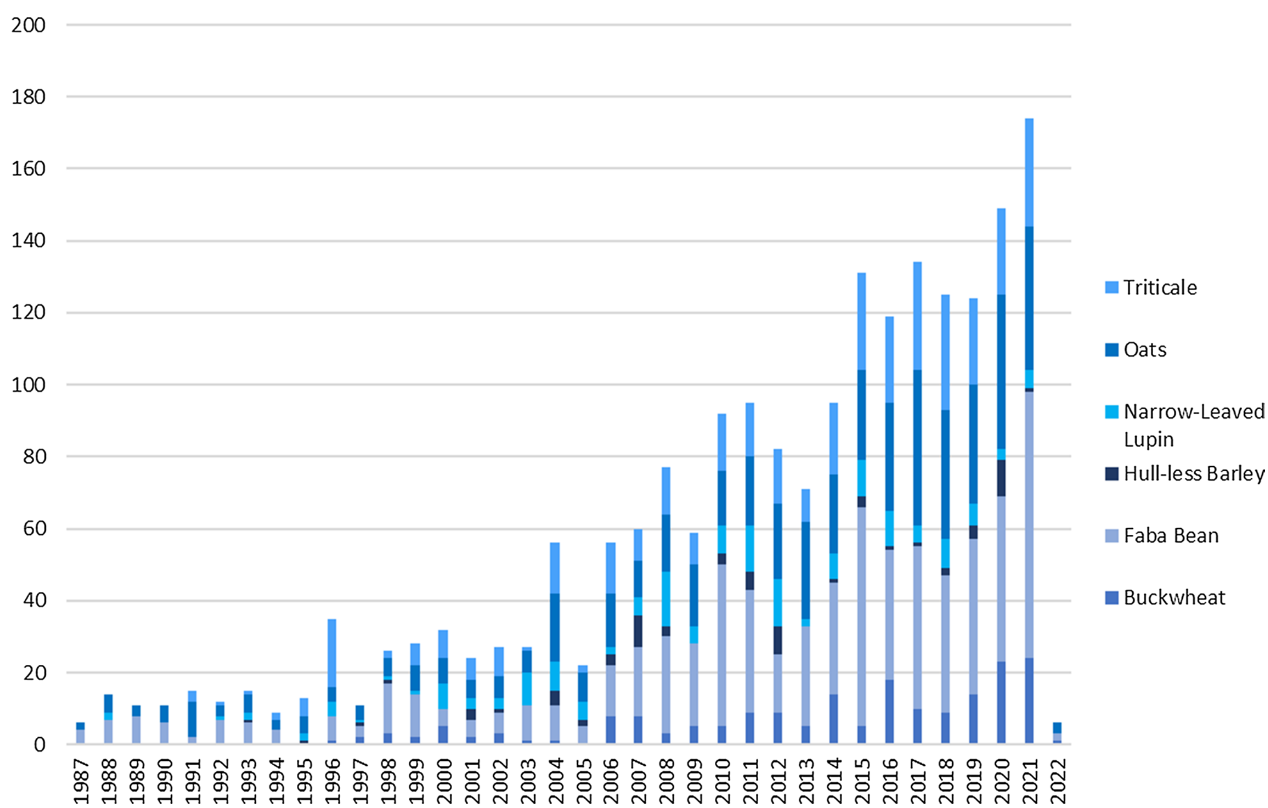

Fig. 3 Yearly distribution of all studies within articles relating to the six underutilised crops from the academic database searches performed for the rapid review. Each year is divided into the individual crops. Some studies are represented more than once as some mention more than one of the underutilised crops

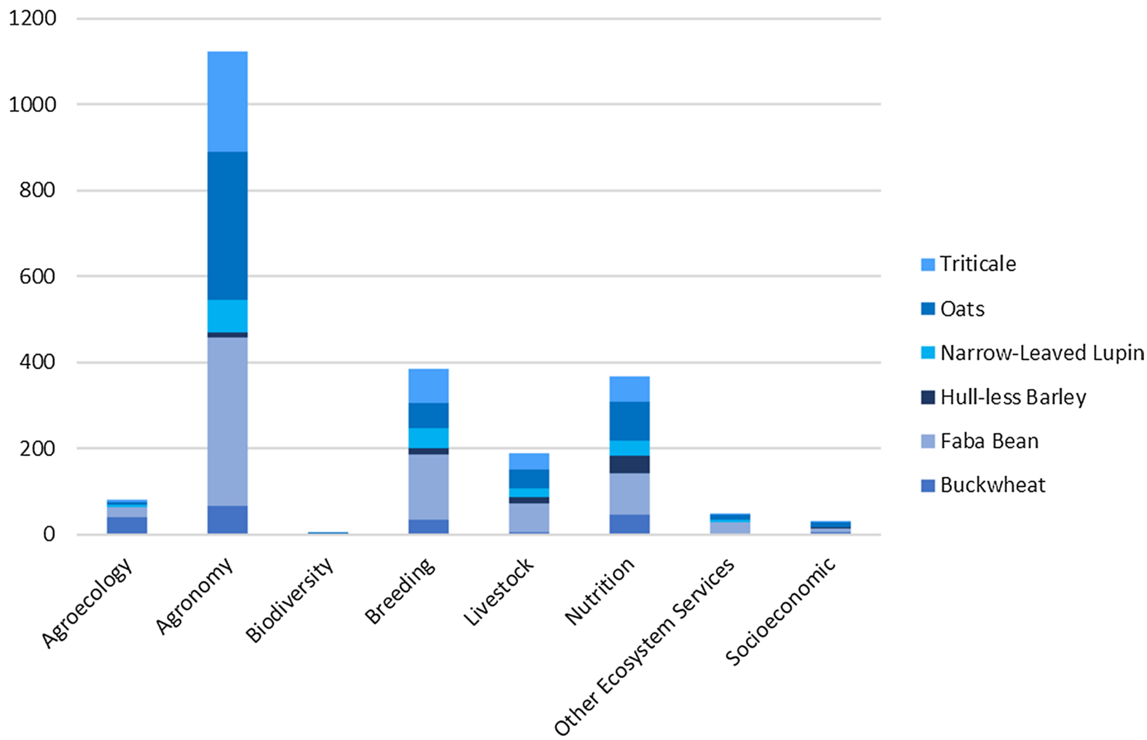

Fig. 4 Total distribution of studies by topic relating to the six underutilised crops from the academic database searches performed for the rapid review. Each topic is divided into the individual crops. Some studies are represented more than once as some mention more than one of the underutilised crops

	Agroecology	Agronomy	Biodiversity	Breeding	Livestock	Nutrition	Other Ecosystem Services	Socioeconomic
Triticale	2	113	0	52	10	21	1	0
Oats	0	127	1	13	18	39	7	2
Narrow-Leaved Lupin	2	40	0	29	13	23	2	1
Hull-less Barley	0	6	0	8	3	11	0	0
Faba Bean	6	180	0	53	45	62	12	2
Buckwheat	11	32	0	12	2	21	0	1

Fig. 5 Distribution of article topic (along the x-axis) research studies in relation to the six underutilised crops (along the yaxis) within European countries. A total of 983 outputs were extracted from literature originating from within Europe

underutilised crops with a clear upwards trend in total number of studies. The research was not distributed evenly for each crop. Faba bean was the most studied (34.7% of all studies), followed by oats (25.5%) and triticale (19%). Buckwheat (8.8%) and narrow-leaved lupin (8.4%) were much less studied, with research into hull-less barley being sparse (3.6%).

Figure 4 shows the overall distribution of topics in all studies from the included literature. Agronomy was the most studied area (> 1000 studies), followed by studies relating to breeding and nutrition.

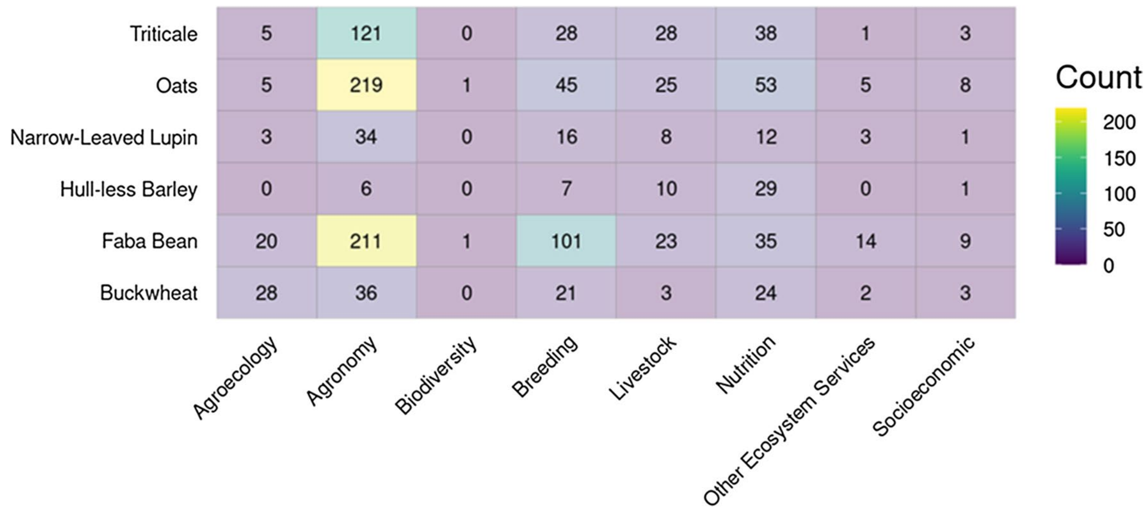

Fig. 6 Distribution of article topic (along the x-axis) research studies in relation to the six underutilised crops (along the y-axis) I within countries in the ROW. A total of 1236 outputs were extracted from literature originating from outside of Europe

The distribution heat maps of literature on the six crops for European countries (Fig. 5) and for the rest of the world (ROW) (Fig. 6) show similar trends, agronomy related topics (made up 56.39% of studies across all countries, 55.14% of European studies, and 57.38% of ROW studies), followed by breeding (17.27% across all countries; 16.99% European; 17.5% ROW) and nutrition (plus livestock) (24.94% across all countries; 27.26% European; 23.11% ROW).

Crop breeding

Of the 2229 studies, 385 (167 Europe and 218 ROW) of those were categorised within the "Breeding" topic. Faba bean study within relation to breeding covered 40% of all

Table 1 A breakdown of the total number of studies relating to the breeding of each of the six underutilised crops

	Total	European	ROW	Key research areas within breeding					
Oats	58	13	45	Breeding for yield	Agronomic traits	Disease resistance	Breeding costs	Development of speed breeding	
				15	11	10	1	1	
Triticale	80	28	52	Breeding for yield	Agronomic traits	New Cultivars	Genetic variability	Disease resistance/severity	
				17	28	6	6	8	
Hull-less Barley	15	8	7	Breeding for yield	Genetics	Adaptability	Agronomic traits	Disease resistance	Breeding potential
				5	5	2	1	1	1
Narrow-leaved Lupin	45	29	16	Disease resistance	Yield and agronomic traits	Plant characteristics			
				9	12	7			
Buckwheat	33	12	21	Genetic resources	Nutritional and protein content				
				11	11				
Faba Bean	154	53	101	Yield traits	Genetic diversity	Disease resistance	Drought tolerance		
				24	17	12	10		

A further breakdown is provided of studies that were undertaken within Europe as compared to ROW. Key, interesting subtopic numbers are provided for five of the crops with faba bean not included due to the high variety and wide range of breeding studies relating to this crop. Faba bean breeding studies made up 40% of all studies categorised as breeding studies categorised as "breeding" studies. This further equated to 31.7% of all studies within European studies and 46.3% of all studies within ROW. Table 1 shows the breakdown of total studies with regards to all six underutilised crops in total and within European and ROW studies. It also provides an insight into the most studied subtopics relating to each crop with regards to breeding.

Agronomic traits

The agronomic traits, and associated topics, of these crops are the most widely studied of all topics (56.39% of articles across all countries).

Oats and faba beans are more regularly included in agricultural systems compared to the other underutilised crops (trends realised during screening literature). Whilst narrow-leaved lupin, buckwheat and hull-less barley can often be considered as orphan crops. Despite their more extensive use, oats and faba bean are included as underutilised crops because they are regarded as underutilised when compared to more "traditional" crops such as wheat, soybean, maize. Often these are considered rotational/break crops rather than focal, cash crops.

Topic modelling for agronomic traits

Within the inclusion criteria, husbandry topics related to agronomy, such as fertilizer and pesticide application, were not considered for analysis. These applications were deemed supplementary to the underutilised crops, and not a direct effect of the crop itself. However, topic modelling of the entire article database was conducted via SWIFT-Review (Howard et al. 2016) to see the distribution of these husbandry topics in relation to the target crops. Topic modelling groups words that appear together within articles. Topics of interest for potential future investigation included "Topic 94: nitrogen, yield, application, fertilizer, fertilization, grain, increased, effect, phosphorus, fertilizers" and "Topic 20: weed, wild, control, weeds, orobanche, herbicide, crenata, herbicides, broomrape, infestation", which returned results of 2112 and 725 articles, respectively. This demonstrates that, without discerning which of the six crops it is related to, both fertilizers and herbicides are a well-studied area of research. Although, as there is a good knowledge of the crops, "Topic 20" is in relation to faba bean research, as the species *Orobanche crenata* is a parasitic herb that is commonly found attacking the crop.

Traits that support ecosystem services

All main topics were categorised into sub-topics to demonstrate further detail on each included studies research. Figure 7 shows the distribution of sub-topics classified as supporting ecosystem services for each of the six underutilised crops.

Studies that investigated how one or more of the six underutilised crops could provide desirable traits valuable in agroecosystems [e.g., high temperature resistance in buckwheat (Aubert et al. 2020)] represented 22.1% of the studies when consider those attributed to ecosystem service provision. Studies that investigated the impact by one or more of the six underutilised crops on the control of disease [e.g., management of chocolate spot in faba bean (Wubshet and Chala 2021)], pests (e.g., effect of intercropping faba bean with canola to reduce cabbage aphid (Mollaei et al. 2021)) and weeds (e.g., intercropping

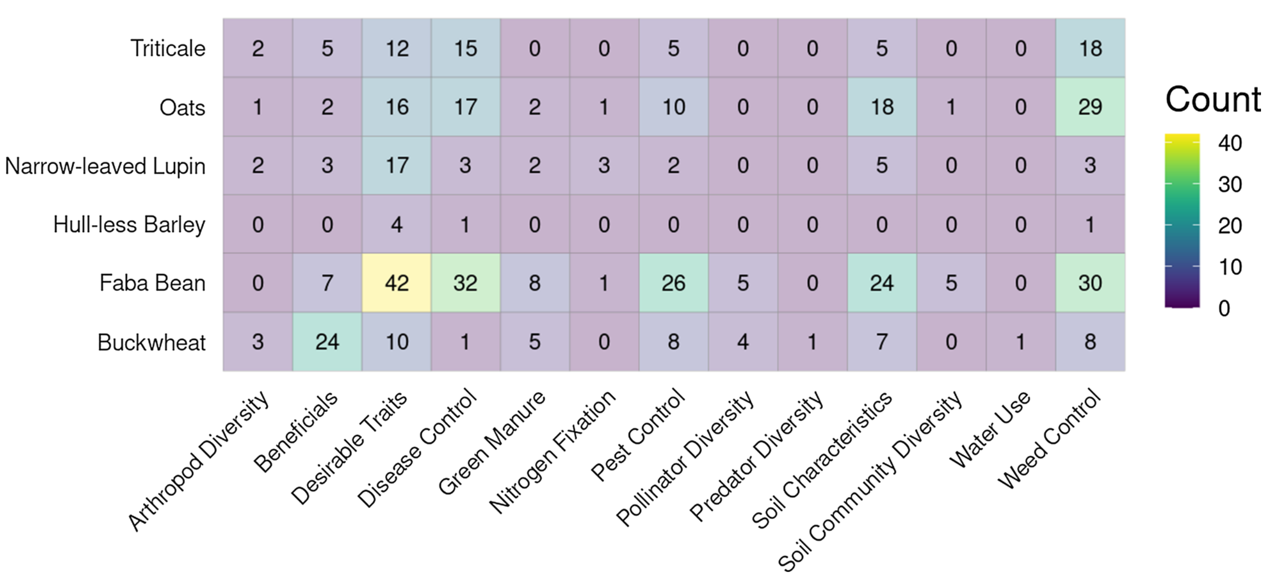

Fig. 7 Distribution of sub-topics (along the x-axis) that relate to ecosystem services across all major topics in the systematic map in relation to the six underutilised crops (along the y-axis). A total of 457 outputs were extracted from literature relating to different ecosystem services

lupins and triticale to increase weed suppression (Carton et al. 2020)) were also comparatively well studied (15.1%, 11.2% and 19.5% respectively). Research investigating nitrogen fixation and invertebrate diversity (arthropod, pollinator, predator and soil community) was the least commonly studied within the sub-topics (0.1% and totaling 5% respectively). Faba bean and buckwheat were the crops studied the most when it came to ecosystem services, whilst hull-less barley is the least studied of the six crops.

Nutrition and health

Nutritional studies related to narrow-leaved lupin are rarely found (Figs. 5 and 6), most of them are related to inclusion in animal diets—namely for pigs' diet or chicken feed [e.g., (Kasprowicz-Potocka et al. 2016; Hejdysz et al. 2018)]. This crop has comparable properties to a more traditional protein crop, for example soybean (widely researched, data not shown) and faba bean. In studies related to oats there is already a lot of knowledge on the inclusion in food/feed products for humans. For buckwheat, a gluten-free (pseudo) cereal less research is done, although its potential as a food source for humans is beginning to be investigated (Kılıç and Yeşİm 2018), as well as its gluten-free product potential (Arcangelis et al. 2020).

Fodder and animal feed related studies were found to be the most widely researched with the six underutilised crops, with around 50% of the studies in the nutrition topic also relating to them. There are several examples for all other crops of the investigation of use for animal feed, for example: oats [e.g., (An et al. 2020)]; faba bean [e.g., (Proskina et al. 2021)]; buckwheat [e.g., (Er and Keles 2021)]; triticale [e.g., (Kokoszyński et al. 2018)]; hull-less barley [e.g., (Janocha et al. 2020)].

Socioeconomic

The topic "*socioeconomics"* was rarely assigned from the primary literature relating to the crops. As shown in Figs. 5 and 6 a total of 31 (6 European, 25 ROW) out of 2,229 studies were considered purely "socioeconomic" from the conducted search.

Topic modelling for socioeconomics

To enhance the socio-economic section, we used topic modelling within SWIFT-Review (Howard et al. 2016) to search for topics that related to this topic area from the entire database of 34,522 articles. One model (Topic 99) was concerned with "economic, production, cost, etc." which incorporates 2,022 articles in it. This shows that the economics of certain aspects of the value chain are being studied, but not necessarily in the terms of socio-economic research rather a pure economic outlook.

Topic modelling of the entire database

The most frequently appearing topic, topic 10, deals with "economy" and the development of food products in relation to climate and environment. Although these studies deal with "economy", the term "social" does not occur in the key words. This indicates that most articles focus on the economic aspect environmental aspects when developing new products, but that the sociological aspect is often neglected.

Topic 2 deals with cover crops rotation tillage for the reduction in weed, but maize is the main crop mentioned within this topic. This indicates most publications dealing with cover crops still focus on the main crops in the world, e.g., maize.

Topic 9 seems to focus on faba bean breeding for increased number of pods and weight of pods. As mentioned above, there has been a lot of research on faba bean breeding. However, this research seems to deal mostly with increasing the yield, but not on the "intercropping", i.e., combining "ability" and "biodiversity" (attraction of pollinators) traits. The fourth most important topic deals with insects and pollinators, but not directly in relation to the crops. Topics 15 and 13 deal with cereals and yield. Indicating that the current literature focusses on yield and not on the other ecosystem services.

Discussion

The key aim of this systematic mapping review was to assess the current research of each of the six underutilised crops and identify research gaps relating to each. Our results found various themes with each of the crops relating to different topics such as breeding, agronomics and agroecology, nutrition and health, and socioeconomics. These results highlight ongoing research gaps, even in well-studied underutilised crops, suggesting opportunities for future research.

General observations regarding underutilised crops

Generally, across the EU projects and primary literature there is a wide disparity in the research conducted into each of the crops. More widely studied crops, such as oats and faba beans, contain a wider range of research areas focussed on them. This is shown in Fig. 5 (studies within Europe) with over 200 studies for oats and over 350 studies in the case of faba bean. With 8.5 million tonnes of oats grown (2.5% of cereals grown) in the EU in 2020 (Eurostat 2022) and faba beans being a valuable crop for both nutrition, ecosystem services and good capability to adapt to diverse climates (Duc et al. 2015), these crops already appear to be important within crop rotations and increasing cropping diversity. This could explain why these two crops are more regularly studied than the others. However, these are underutilised in comparison to other crops when considering in 2020 9.5 million tonnes of Rye, 54.7 of Barley, 67.8 of grain maize and 119.1 of grain wheat and spelt were produced (Eurostat. 2022) and the fact that approximately 14% of those oats produced were used in human consumption within the EU show it is an underutilised crop within certain markets.

Triticale is another relatively well studied crop with just under 200 studies within the European primary literature being assigned to this crop. Over 55% (Maknickienė and Ražukas 2007) of these studies are attributed to "agronomy", which can be explained by the hybrid and commercial nature of the crop and its high use in animal feed (Zhu 2018).

Buckwheat and narrow-leaved lupin research are namely focused on cover cropping and nutrition (often for livestock). These crops are important protein crops and can be viable alternative food sources for specific diets such as those that are gluten free. They both also provide a good nectar and pollen resource for pollinators, thus their inclusion as cover crops.

The least studied of the crops, which does not currently feature within any European project, is hull-less barley. With the lack of inclusion in research projects and only 30 studies within Europe included in the meta-data this crop is understudied, and thus it is underutilised in cropping rotations. Much of the research included dates from 2012 onwards (some research does come from the early to mid-1990s) showing that increased focus on this crop has only started in the past decade.

Notable patterns across the evidence base

Crop breeding

Oats Very few of the studies focused on breeding tools specifically relating to stress tolerance, milling or nutritional quality, but instead focused on breeding for yield and agronomic traits, with recent examples in Ethiopia and Turkey ((Tessema and Getinet 2020; Çalişkan et al. 2020), respectively). With regards to research into disease resistance, much of the literature is focused on evaluating genotypes and oat germplasm for resistance to stem rust (JunHai et al. 2014) and crown rust (Klos et al. 2017).

There is limited research into abiotic stressors of oats, but these are all pre-2000, bar one study on drought tolerance (Sadras et al. 2017). The studies on various nutritional qualities focused on oat varieties provisions of mineral content (Mehta and Jood 2018), protein content and beta-glucan content (Ahmad et al. 2015).

Overall, the focus of existing research is on breeding for desirable, agronomic, and economic traits and the genetic analysis and evaluation of varieties of oats. Research into breeding tools to enhance abiotic stress tolerance and nutritional quality is limited in comparison, however, highlighting a need to focus on increased resilience and nutritive qualities in oat breeding.

Triticale Disease resistance research in triticale is primarily focused on Fusarium Head Blight (FHB) (Ittu and Ittu 2008; Góral et al. 2013; Kalih et al. 2015) and rust resistance [e.g., (Kwiatek et al. 2015)]. A recent study researched the effect of substitution lines and their ability to infer stripe (yellow) rust resistance (Kang et al. 2017). Another recent study suggests an influence of plant growth traits and environmental factors on susceptibility of triticale to yellow rust (Rodriguez-Algaba et al. 2020). Despite this knowledge and further research into breeding strategies, such as fast generation cycling and optimal breeding strategies using genomic selection (Liu et al. 2016, Marulanda et al. 2016), respectively), there is a gap in the research for the development of targeted resistance and desirable traits within triticale.

No studies within the literature have directly dealt with stem digestibility within triticale breeding, with most focusing on either yield [e.g., (Diordiieva et al. 2020)] or on quality for forage (Bilgili et al. 2009). Within the parameters measured in Bilgili et al. (2009), stem component measurements were included, but stem digestibility was not directly measured.

Due to the hybrid and commercial nature of triticale, the majority of the research into breeding strategies for disease resistance and desirable plant traits may be confined to industry research and therefore will not have been found in this review.

Hull-less barley

Hull-less barley is a relatively understudied crop in comparison with the other underutilised crops in the literature studied in this study. A third of these studies were evaluating yield differences in hull-less barley cultivars and focused on how these cultivars performed under different agronomic or climatic conditions [e.g., (Sturite et al. 2019; Hosseinpour 2012)].

Beta-glucan content has been studied in relation to its nutritive benefit in hull-less barley in more recent literature e.g., Dickin et al. (2012) and Abdel-Haleem et al. (2020). These studies looked at environmental and agronomic management, and health benefits of hull-less barley genotypes, but no research has been undertaking into the improvement of breeding for beta-glucan content specifically within the confines of this study. There is scope to improve knowledge on breeding for hull-less barley with regards to its agronomic and economic traits, processing traits and its nutritional content.

Narrow-leaved lupin

Recent research has suggested that alkaloid content in narrow-leaved lupin is of key interest in use of green manures as well as an alternative protein source for animal and human food sources (Vishnyakova et al. 2020). This requires manipulation of alkaloid content, as a higher content produces better green manures, but low alkaloid content is better as a protein source. Maknickienė and Ražukas (2007), in Lithuania researched low-alkaloid hybrid lines in narrow-leaved lupin. Plewiński et al. (2019) revealed candidate genes for the expression of desirable traits, including alkaloid content, in narrow-leaved lupin adding to the core collection of molecular markers for desirable traits for the crop. Chen et al*.* (2016), developed methods to unlock rapid breeding techniques to better utilise narrow-leafed lupin as a protein source and within diversified cropping systems.

With most of the breeding research of narrow-leaved lupin focusing on disease resistance, agronomical and yield traits, this provides an opportunity to research breeding for nutritional content of this crop. This will help inform future research into this crop as breeding tools and increasing nutritional value of this crop are gaps currently in its research.

Buckwheat

Within the current research there is a focus of studying nutritional quality and protein content of buckwheat, and its use as a dietary, gluten-free alternative, there is now need to improved cultivars to maximise agronomical potential. There were two studies researching abiotic stress tolerance of buckwheat; flood tolerance (Sakata and Ohsawa 2006), and aluminum tolerance (Yokosho et al. 2014), but there is only one study which focused on agronomically important traits, including the morphological traits of buckwheat (Jerčić et al. 2020). This research provides an avenue for developing buckwheat as crops for farmers with improving yield, as well as its nutritional value.

Faba bean

The literature shows faba bean breeding studies have researched many different topics such as yield traits [e.g., (Ghaouti et al. 2016)], weed resistance [e.g., (Abd El-Fatah and Nassef 2020)], genetic diversity [e.g., (Khazaei et al. 2021)], frost and drought tolerance [e.g., (Khan et al. 2019)], disease resistance [e.g., (Rubiales et al. 1747)], and agronomic and plant traits [e.g., (Maalouf et al. 2015)]. This could lead to increased crop breeding, but also its inclusion in intercropping systems and food/feed products, utilising the current state of knowledge on faba bean breeding.

Agronomic traits

Much of the research into the more underutilised crops (narrow-leaved lupin, buckwheat, and triticale) is focused on using these as cover crops, and their effects on more traditional crops [e.g., narrow-leaved lupin (Christensen et al. 2021); buckwheat (Ghahremani et al. 2021); triticale (Rivers et al. 2020)]. In the case of hull-less barley there is only limited research into it as a companion crop (Wang et al. 2012) and its agronomic and yield traits [e.g., (Azimi et al. 2011)]. This provides proof that there is a need to study these underutilised crops further, and how they can be incorporated into a diversified cropping system.

With regards to oats and faba bean, there is a focus on intercropping and yield and agronomic traits within the current literature compared to the other underutilised crops. Many of these studies considered yield parameters of both crops in relation to different cereal-legume intercropping regimes. Other literature investigated various agronomic traits, weeds, pests, and disease suppression, as well as some literature on the nutritional content of various crops within an intercropping regime. However, when considering intercropping in relation to nutritional value, there is less research into this area with many of the studies relating to forage or silage intercropping [e.g., oats, (Tsialtas et al. 2018); faba bean, (Cannon et al. 2020)]or the nutritional value effects for other cash crops when intercropped with one of the two crops [e.g., oats, (Mut et al. 2020); faba bean, (Kamalongo and Cannon 2020)].

This shows that investing research into the agronomic traits, especially potential yield traits, of all the underutilised crops is of importance to see how these crops can fit into a diversified cropping rotation. This will also, potentially, impact future policy and on-farm usage, as any funding could consider the value of these crops within a rotation and provide a subsidy for farmers to utilise these crops. If ecosystem services and value chains can be improved by these crops, then investment in research, funding and uptake should be present throughout the food system and value chain.

Ecosystem services

The review identified 314 measured outcomes that are associated with ecosystem services. Most studies involved either breeding or agronomic traits to develop desirable traits (n = 101), their effect on soil characteristics (n = 59), and the control of disease (n = 69), pest (n = 51) and weeds (n = 89). This demonstrates that the bulk of the ecosystem service research with the six underutilised crops mostly focuses on their ability to increase their desirable traits, how to improve the soil characteristics and how best to control negative outcomes to their growth and ultimately yield. What is less commonly found in this review is research into how the six underutilised crops can have other beneficial ecosystem services related to the surround habitat and biodiversity that is not necessarily of immediate or any benefit to the crops themselves. These include arthropod diversity (n = 8), pollinator diversity (n = 9, all studies focus solely on faba bean and buckwheat), predator diversity (n = 1) and soil community diversity (n = 6). This is somewhat mitigated in the fact that a lot of the research into these wider beneficial ecosystem services occur in the last decade, showing an increasing interest in the wider effects of these six underutilised crops on biodiversity.

Nutrition and Health

The type of nutritional research tended to vary according to the crop studied. For example, for faba bean, much of the research outside of animal nutrition relates to food stuff properties, such as the impact on inclusion in wheat flour (Aprodu et al. 2019), their nutritive value [e.g., (Multari et al. 2016)], or profiling various desirable properties as an alternative food source [e.g., (Johnson et al. 2020)]. For oats, there is more research into nutritive content such as beta-glucan content [e.g., (Wang and Ellis 2014)], fibre content [e.g., (Decker et al. 2014)], and protein content [e.g., (Zarzecka et al. 2015)].

Outside of fodder and animal feed, the majority of the literature for the remaining three crops (triticale, narrow-leaved lupin and hull-less barley) concerned nutritional quality [e.g., triticale (Multari et al. 2016); narrow-leaved lupin (Chin et al. 2019); hull-less Barley (Abdel-Haleem et al. 2020)], particularly their inclusion in food produce, namely flour [e.g., triticale, (Jonnala et al. 2010); hull-less barley (Liu et al. 2020)] or their potential health risks for animals and humans [e.g., narrow-leaved lupin (Schrenk et al. 2019)].

There is a slight disparity in nutritional research of these crops, with much of the research in most of the crops concerning animal feed and fodder. Oats and faba bean aside, future research in these crops should be their potential for inclusion in human diets and foodstuffs. Future policy could help develop these crops as alternatives to gluten-based products and benefit low-income households by providing a diversity of high nutritional value food sources.

Socioeconomics

These studies addressed namely economic benefits, comparisons, and efficiencies of some (oats, faba bean, triticale, and narrow-leaved lupin) of the underutilised crops. This may indicate that most studies focus on the earlier aspects in the value chain from breeding to agronomy to food/feed production, but they do not focus on some of the associated socio-economic aspects of these crops. The searches conducted may also have missed topics related to more social aspects relating to the crops as this area was covered in the search string by "*economic" mean that any topic mentioning "socioeconomic" would have been found by those implying it by discussing social aspects may have been missed. Some of the yield studies also consider socio-economic factors but were categorised under the agronomic trait topic as that was the key focus.

Limitations of the systematic mapping approach

Due to the rapid nature of this study the breadth of detail extracted from each individual study was set at a considerably basic level to ensure meta-data could be extracted quickly and effectively. The aim of this review was to assess the research areas undertaken within each of the underutilised crop and future work could look at each crop individually, potentially providing details, within the context of a meta-analysis, of specific crop benefits within a diversified cropping system. As the meta-data was extracted from the abstracts of the primary research the full context of data collection and interpretation of results may have been missing.

A further limitation of this research is not utilising an extensive search of grey literature beyond that of searching the CORDIS database, however as one of the key purposes of this map was to assist the justification of work packages being conducted within the CROPDIVA project, academic databases took precedence over grey literature searches.

Limitations of the evidence base

Missing meta-data meant that analysis of certain features such as farming system were unable to be conducted (n = 53 studies had a clear farming system in the abstract). This meant that an analysis and visualisation could not be conducted on what type of farming practices were using the crops and what topic areas they covered. Due to the rapid nature of the evidence extraction intervention duration was not able to be noted so all meta-data in the database does not have length of study as a factor. However, due to the high variability of the topics and studies this would not have been easy to quantify effect across all topics.

Studies relating to socioeconomics may have also been unidentified during coding due to the broad nature of socioeconomics. Topics within the other key areas could be considered of socioeconomic importance but only focus on one area of the value chain. For this reason, only studies that consider the entirety of the value chain were consider pure socioeconomic studies. Social aspects relating to the six underutilised crops may also have been missed in the scoping for search terms within the search string as only studies that discussed socioeconomics outright, or economics and their associated topics in general, would have been discovered within the search results.

Implications for policy, practice, and research

This study is important for future policy making, on-farm practice and research as it highlights, even in the crops that are more well studied, that there are several avenues in which these six crops can be enhanced for inclusion in diversified cropping systems. Research on the breeding of all the crops show that there will be future prospects of improving breeding tools and breeding for desirable traits. Advancing any research into breeding tools for any of these crops can have implications for future breeding practices as they are good model crops due to the broad nature of their gene pool. Advances these technologies will help advance farming practices as it will provide further options for farmers to have crop varieties that can target different desirable traits.

With advancing breeding tools and the breeding of desirable traits of these crops this, in turn, will improve the agronomics of them. With further research into how these crops can perform in a diversified cropping system influencing policy making around sustainable farming practices. Subsidies can be provided to increase these crops inclusion in cropping systems, as well as furthering research into them as alternatives to common crops. If diversified cropping systems are to be adopted, then financial benefit to farmers should be encouraged to develop their rotations and to utilise these crops to not only benefit value chains, but also ecosystem services within agricultural landscapes.

The advancing of the nutritional and health value of underutilised crops will give a complete view of the advantages of these crops. If, via policy, practices and research, the breeding of these crops can be improved and targeted this will lead to a more efficient use of these in cropping systems and a potential for them to benefit food security, as well as improve health and nutrition in livestock and humans. Advancing breeding tools could also advance the ability to extract improved nutritional value from broad gene-pool underutilised crops. Which gives a key importance on furthering research regarding these crops breeding and nutritional value.

The complete evidence base is vital for making the best use of available evidence in national and international policy making. Proving the importance of diversifying cropping systems and how these crops can fit into those systems by future research will help to influence future policy and farming practice.

Conclusion

The systematic mapping approach has revealed that primary research varies between crops and topics. It can be concluded that that is variation in not only the number of studies per crop, but also within each topic, and how advanced that research currently is.

Breeding research primarily relates to faba beans, with a focus on yield, nutritional and agronomic traits. Oats and triticale have ample research on breeding for yield and agronomic traits but require further breeding tool development. More understudied crops like buckwheat, narrow-leaved lupin, and hull-less barley demand more research for desirable traits.

Regarding agronomic trait research, oats, faba bean and triticale dominate, with the others requiring further study, especially in diversified cropping systems. Nutritional research is mainly geared towards livestock and animal feed, leaving room for human nutrition and non-food product exploration. Socio-economic research on these crops is relatively sparse, focusing more on economic than social aspects.

Opportunities exist in breeding, genomics, cropping systems, and new food and health products when it comes to underutilised crops. Challenges span the entire value chain, from variety selection to environmental practices and product development.

This systematic map highlights the potential to fill knowledge gaps and leverage cutting-edge capabilities for these six underutilised crops.

Abbreviations

EU European Union
FAO Food and Agriculture Organisation
ROW Rest of the World
WoS Web of Science

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-023-00194-y.

Additional file 1. ROSES for Systematic Map Report. The completed ROSES form required to accompany systematic maps according to the CEE guidelines.

Additional file 2. Evidence Synthesis Search Strings. A detailed breakdown of search string development including: Crop; search terms used; number of hits; and, date searched.

Additional file 3. Simplified Coding Tool. A breakdown of the coding tool used to extract data from articles included in the database.

Additional file 4. Rapid Review Database. Database containing all articles used within the systematic map and all the metadata extracted from these articles. This file was exported from the access database used to store all relevant information gathered during the systematic map.

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Author contributions
NR, GH, KD and SL proposed the premise for the study. All authors contributed to the development and methodology of the study. TJ and SL conducted the searches and data extraction for the study, with contributions from all authors. TJ wrote the manuscript, SL was integral to the topic modelling reporting in the manuscript, with contributions to reading and editing of the manuscript conducted by all authors. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

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Competing interests
The authors declare that they have no competing interests.

Author details
[1]Harper Adams University, Edgmond, Newport TF10 8NB, Shropshire, UK.
[2]Universiteit Gent, Sint Pietersnieuwstraat 25, 9000 Ghent, Belgium.

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